TRENDS

'93

*A compendium
of data on
global change*

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WORLD DATA CENTER-A FOR ATMOSPHERIC TRACE GASES
CENTER FOR GLOBAL ENVIRONMENTAL STUDIES
OAK RIDGE NATIONAL LABORATORY

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Trends '93:

A Compendium of Data on Global Change

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Dedication

The Carbon Dioxide Information Analysis Center would like to dedicate *Trends '93* to Thomas J. Gross of the U.S. Department of Energy's Office of Health and Environmental Research. We thank Tom, who retired in 1994, for his support of the exchange of data and other information on behalf of the DOE's Global Change Research Program. He maintained responsibility within DOE for the operation of CDIAC since its inception in 1982. Tom put into practice his advocacy of the open exchange of quality data between researchers, policy makers, educators, students, and corporate officials. The quality assurance, archiving, and distribution of data is a long-term commitment, and Tom was able to provide the continuity necessary to fulfill that commitment.

Tom, this one's for you!

— Michael P. Farrell, Director
Carbon Dioxide Information Analysis Center, 1983–89

— Paul Kanciruk, Director
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— Robert M. Cushman, Director
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September 1994

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Abstract

Boden, T.A., D.P. Kaiser, R.J. Sepanski,^a and F.W. Stoss^a (eds.). 1994. *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

This document provides synopses of frequently used global-change data. This third issue of the *Trends* series presents historical and modern records of atmospheric concentrations of carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), two chlorofluorocarbons (CFC-11 and CFC-12), a hydrochlorofluorocarbon (HCFC-22), and two halons (H-1301 and H-1211) from an expanded number of globally distributed data sets. Virtually all of the modern records extend into the 1990s, some into 1994. Additional trace gas data presented in *Trends '93* include historical atmospheric CO₂, CH₄, and N₂O records derived from ice cores. *Trends '93* also includes revised and updated estimates through 1991 for global, regional, and national CO₂ emissions produced from the burning of fossil fuels, gas flaring, and the production of cement. Updated global emissions estimates through 1992 are also presented for CFC-11 and CFC-12. In addition, *Trends '93* updates and expands the presentation of long-term temperature records, whose spatial coverage ranges from an individual Antarctic (ice core) site to the entire globe and from the Earth's surface to the lower stratosphere. New subject matter appearing in *Trends '93* includes a chapter for long-term regional precipitation records, several time-series records for atmospheric aerosols, and isotopic ¹⁴C measurements for atmospheric CO₂ from several sites.

Data records are presented in multipage formats, each dealing with a specific site, region, or emissions species. The data records include tables; graphs; discussions of methods for collecting, measuring, and reporting the data; trends in the data, and references to literature providing further information.

Instructions for citing specific data in *Trends '93* are provided for each compiled data set.

All data appearing in *Trends '93* are available on digital media from the Carbon Dioxide Information Analysis Center (CDIAC). This report and all other electronic versions of the data contained in the report are available from CDIAC at no cost.

Keywords: Aerosols, atmospheric chemistry, atmospheric measurements, carbon cycle, carbon dioxide, carbon isotopes, climate, climate change, climatology, chlorofluorocarbons, Earth atmosphere, emissions, fossil fuels, gas flaring, global warming, greenhouse effect, halons, hydrochlorofluorocarbons, meteorology, methane, natural gas, nitrous oxide, radiosondes, rainfall, paleoclimatology, precipitation, regional analysis, temperature monitoring, trace gases.

^aUniversity of Tennessee, Energy, Environment, and Resources Center.

Citing Data

When using the data or figures presented in this report, **PLEASE** give proper credit to the contributing scientist(s). Do not simply refer to CDIAC, *Trends '93*, or the editors. We urge you to use the citation on the bottom of most pages.

Foreword

Trends '93: A Compendium of Data on Global Change is part of the Carbon Dioxide Information Analysis Center's (CDIAC's) continued effort to distribute, in an accessible format, scientific data critical to global-change issues. *Trends '93* is intended for researchers, policy makers, educators, and others interested in the observational data underlying the issues related to our changing global environment.

Response to the first two issues of this series (*Trends '90* and *Trends '91*) has been gratifying. Nearly 20,000 hard copies have been distributed to users in 152 countries. *Trends* has been used by researchers in the physical, life, chemical, and applied sciences, but perhaps most satisfying is its use by social and policy scientists and educators. *Trends* has been cited in many reference works, technical reports, and books including the 1990, 1991, and 1992 issues of *Environmental Quality*, the Annual Reports of the President's Council on Environmental Quality; Vice President Al Gore's best-selling book, *Earth in the Balance*; and used as a source document by the World Resources Institute for their *World Resources* reports and by World Watch in their *State of the World* and *Vital Signs* reports. Data appearing in *Trends* were also cited in *America's Climate Strategy: An Action Agenda* (distributed by the Office of the President of the United States).

Trends '93 presents historical and modern records of atmospheric concentrations of carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), two chlorofluorocarbons (CFC-11 and CFC-12), a hydrochlorofluorocarbon (HCFC-22), and two halons (H-1301 and H-1211) from an expanded number of globally distributed sites. Virtually all of the modern records extend into the 1990s, some into 1994. Additional trace gas data presented in *Trends '93* include historical atmospheric CO₂, CH₄, and N₂O records derived from ice cores. *Trends '93* also includes revised and updated estimates through 1991 for global, regional, and national CO₂ emissions produced from the burning of fossil fuels, gas flaring, and the production of cement. Updated global emissions estimates through 1992 are also presented for CFC-11 and CFC-12. In addition, *Trends '93* updates and expands the presentation of long-term temperature records, whose spatial coverage ranges from an individual Antarctic (ice core) site to the entire globe and from the Earth's surface to the lower stratosphere. New subject matter appearing in *Trends '93* includes a chapter for long-term regional precipitation records, several time-series records for atmospheric aerosols, and isotopic ¹⁴C measurements for atmospheric CO₂ from several sites.

CDIAC acknowledges the support and efforts of the international science community in contributing data appearing in *Trends '93*. Additional efforts have been made to provide readers with assistance in properly citing these data. These efforts include the general citation instructions appearing on page xxv and the specific recommended citations given at the bottom of pages presenting information on individual datasets. The following citation for atmospheric CO₂ concentrations from the Scripps Institution of Oceanography's continuous monitoring program at Mauna Loa is presented as an example:

Keeling, C.D., and T.P. Whorf. 1994. Atmospheric CO₂ records from sites in the SIO air sampling network. pp. 18–28. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

FOREWORD

Those of you familiar with *Trends '90* and *Trends '91* will note continued changes in the style and format of the document. The content and format of future issues of the series will continue to be largely determined by reader response, and we encourage you to contact us with your recommendations and comments.

Some of the data in *Trends '93* are considered preliminary. Users should pay close attention to any table footnotes to avoid misinterpretation or misrepresentation of the accuracy of some of these data. The data presented in *Trends '93* are available in machine-readable form on a variety of media at no cost to the user. More-detailed discussions on the applications and limitations of many data sets in *Trends '93* are documented in numeric data packages (NDPs) and Data Bases (DBs), which are available from CDIAC on digital media or over the Internet via file transfer protocol (FTP). (See Appendix B for descriptions of NDPs and DBs supporting *Trends '93* and instructions for accessing NDP and DB data files or the data presented in *Trends '93* through CDIAC's anonymous FTP area.) If you have any questions concerning data contained in this report or would like to discuss a particular aspect of the data's application, please contact us.

Data requests and inquiries concerning *Trends '93* or any other CDIAC information products may be sent to:

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We hope you find *Trends '93* to be a useful document.

— Robert M. Cushman, Director
Carbon Dioxide Information Analysis Center

Acknowledgments

As with any collective effort, this report has been prepared with the help of many people. Our greatest debt is to the contributing investigators whose data comprise the core of this report.

We acknowledge another group of important people, the readers for whom *Trends* is intended. We are delighted with the response received from the publication of the first two issues of *Trends*. Many of the readers' recommendations on content, format, and style have been incorporated in *Trends* '93. We will continue to consider suggestions and comments from the readers of this and future issues.

We express our gratitude to the following personnel at Oak Ridge National Laboratory (ORNL), whose collective efforts have brought this document into being. Our deepest thanks go to Cheryl Buford and Karen Dobbs from Central Publication Services of ORNL's Information Management Services (IMS) for their style designs and electronic publishing skills. We are grateful to IMS graphic artists Robert Eldridge, Jo Brooks, Dami Rich, Sonja Ring, and Jamie Payne for their assistance in the preparation of maps and other illustrations. Our gratitude is extended to the Central Printing Staff, especially to Chuck Strayer, Mike Garrett, and Ronnie Hooks. We also appreciate the efforts of editors Nathan Schulman, Philip Wolff, and J.W. Turner.

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Introduction

ATMOSPHERIC CARBON DIOXIDE

Precise records of past and present atmospheric CO₂ concentrations are critical to studies attempting to model and understand the global carbon cycle and possible CO₂-induced climate change. Researchers have attempted to determine past levels of atmospheric CO₂ concentrations by a variety of techniques, including direct measurements of trapped air in polar ice cores, indirect determinations from carbon isotopes in tree rings, analysis of spectroscopic data, and measurements of carbon and oxygen isotopic changes in carbonate sediments in deep-ocean cores. The modern period of precise atmospheric CO₂ measurements began during the International Geophysical Year (1958) with Keeling's (Scripps Institution of Oceanography) pioneering determinations at Mauna Loa, Hawaii, and at the South Pole. The Mauna Loa record remains the single most valuable CO₂ time series. Since Keeling's initial efforts, other agencies and organizations have implemented programs to monitor background levels of atmospheric CO₂ concentrations. Two of the larger programs are the World Meteorological Organization's (WMO's) Background Air Pollution Monitoring Network (BAPMoN) and the National Oceanic and Atmospheric Administration's Climate Monitoring and Diagnostics Laboratory (CMDL—formerly Geophysical Monitoring for Climate Change), which operates a flask monitoring network and an in situ monitoring network.

This chapter provides globally distributed atmospheric CO₂ records (see map below) including two historical atmospheric CO₂ records derived from ice cores; 58 modern records of monthly and annual atmospheric CO₂ concentrations from 63 sites, which include 49 land-based and 14 shipboard sites; and three atmospheric $\Delta^{14}\text{C}$ records. Collectively, these records document the atmospheric CO₂ record during the past 160,000 years (see figure on next page). Most records extend through 1992—some through 1993 and even early 1994—and show the reduced atmospheric CO₂ growth rate observed around the world

Location of the sites for which atmospheric CO₂ and $\Delta^{14}\text{C}$ records are presented in this section.

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during 1992 and 1993. For the modern records it seemed appropriate to present Keeling's Mauna Loa record first because it represents the longest continuous modern record available. Most records are indicative of background air conditions in a particular region or location. An exception is the atmospheric CO₂ record for Osnabrück, where measurements are made to determine ambient air CO₂ concentration levels for long-term field experiments investigating the effects that tropospheric CO₂ enrichment has on single plants, grassland model-ecosystems, and other vegetation types. Most sites are situated in remote locations

Annual atmospheric CO₂ concentrations during the past 160,000 years (as derived from the Vostok and Siple ice cores and Keeling's Mauna Loa record).

and are subject to large, uncontaminated air masses (see figure below showing the beautiful, remote location of the Mt. Cimone Observatory). The data presented on the following pages represent a significant portion of the modern and historical atmospheric CO₂ records and provide irrefutable evidence that atmospheric levels of CO₂ concentrations have risen during the past three decades.

Readers may note that two apparently different systems of units have been used in presenting the atmospheric CO₂ data in this chapter. For data from ice cores and for some modern atmospheric records, CO₂ levels are presented as *concentrations* in parts per million (1×10^6) by volume (ppmv). For much of the modern data, values are given as *mixing ratios*, in parts per million or in parts per million by volume. These differences in unit designations reflect the preferences of the researchers who have contributed their respective data sets for inclusion in *Trends '93*. In the context of atmospheric CO₂, *concentration* in parts per million by volume refers to the number of volumes of CO₂ per million volumes of sample. In this same context, *mixing ratio* in parts per million is derived by dividing the number of moles of CO₂ by the total number of moles in the sample and then multiplying the quotient by one million. Assuming that the volume of a gas is proportional to the number of moles contained within the volume (this assumption should be valid for CO₂ in air under the conditions that atmospheric measurements are routinely carried out), we can expect that CO₂ concentrations should be equivalent to CO₂ mixing ratios. For all practical applications, therefore, users of *Trends '93* should consider the terms *concentration* and *mixing ratio* to be interchangeable.

The data presented in this chapter were made available to the Carbon Dioxide Information Analysis Center (CDIAC) by the principal investigator(s) listed at the beginning of each data

Mt. Cimone Observatory, Italy.

INTRODUCTION

record. CDIAC acknowledges their kind cooperation. We urge readers to credit the principal investigators and their organizations when using these data. To facilitate correct referencing, each set of records provides a full citation by which contributions in the set should be referenced. Users are encouraged to contact CDIAC or the principal investigator(s) before using data for specific model exercises or research exercises. Some of the data are preliminary and subject to adjustment (values could change by several parts per million). All the data presented here are available in digitized form from CDIAC without charge.

Atmospheric Carbon Dioxide

Historical CO₂ record from the Vostok ice core

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Period of Record

160,000–1,700 years BP

Methods

The 2083-m-long ice core recovered by the Soviet Antarctic Expeditions at Vostok has been used to extend the ice record of atmospheric CO₂ to 160,000 years ago through analysis of the air bubbles trapped in the core. Because air bubbles do not close at the surface of the ice sheet but only near the firn-ice transition (that is, at ~90 m below the surface at Vostok), the air extracted from the ice is younger than the surrounding ice (Barnola et al. 1991). Using semiempirical models of densification applied to past Vostok climate conditions, Barnola et al. (1991) reported that the age difference between air and ice may be ~6000 years during the coldest periods instead of ~4000 years, as previously assumed. Ice samples were cut with a bandsaw in a cold room (at about -15°C) as close as possible to the center of the core in order to avoid surface contamination (Barnola et al. 1983). Gas extraction and measurements were performed with the "Grenoble analytical setup," which involved crushing the ice sample (~40 g) under vacuum in a stainless steel container without melting it, expanding the gas released during the crushing in a pre-evacuated sampling loop, and analyzing the CO₂ concentrations by gas chromatography (Barnola et al. 1983). The analytical system, except for the stainless steel container in which the ice was crushed, was calibrated for each ice sample measurement with a standard mixture of CO₂ in nitrogen and oxygen. For further details on the experimental procedures and the dating of the successive ice layers at Vostok, see Barnola et al. (1987, 1991) and Lorius et al. (1985).

Vostok
Antarctica
78°28' S, 106°48' E
3488 m above MSL

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VOSTOK

Trends

An atmospheric CO₂ record for the past 160,000 years was obtained from the 2083-m-long ice core recovered by the Soviet Antarctica Expeditions at Vostok (East Antarctica). This CO₂ record is probably the purest available, covering the last climatic cycle (Barnola et al. 1987). When the Vostok ice core data were compared with other ice core data (Delmas et al. 1980; Neftel et al. 1982) for the past 30,000–40,000 years, good agreement was found between the records: all show low CO₂ values [~200 parts per million by volume (ppmv)] during the Last Glacial Maximum and increased atmospheric CO₂ concentrations associated with the glacial-Holocene transition. Barnola et al. (1987) found that over the 160,000-year time scale a high correlation existed between CO₂ concentrations and Antarctic climate, with significant oscillatory behavior of CO₂ between high levels during interglacial periods and low levels during glacial periods. According to Barnola et al. (1991) these measurements and the results obtained from other ice cores indicate that, at the beginning of the deglaciations, the CO₂ increase either was in phase or lagged by less than ~1000 years with respect to the Antarctic temperature, whereas it clearly lagged behind the temperature at the onset of the last glaciation. Barnola et al. (1987) reported that long-term CO₂ changes were dominated by marked glacial-interglacial oscillations between ~190–200 and 260–280 ppmv and that a period of ~20,000 years similar to the orbital precession period appeared in the decreasing CO₂ trend during most of the last glaciation and is supported by spectral analysis.

Atmospheric CO₂ concentrations derived from the Vostok ice core.

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Atmospheric Carbon Dioxide

Historical CO₂ record from the Vostok ice core

J.M. Barnola, D. Raynaud, C. Lorius, and Y.S. Korotkevich (continued)

VOSTOK

Atmospheric Concentrations of CO₂ from Ice Cores^a

Depth (m)	Age of the ice (yr BP)	Mean age of the air (yr BP)	CO ₂ concentration (ppmv) ^b	Depth (m)	Age of the ice (yr BP)	Mean age of the air (yr BP)	CO ₂ concentration (ppmv) ^b
126.4	4,050	1,700	274.5	1274.2	87,980	84,700	218.8
173.1	5,970	3,530	270.0	1299.3	89,940	86,680	210.0
250.3	9,320	6,800	252.0	1322.5	91,760	88,520	221.5
266.0	10,040	7,500	257.0	1349.0	93,860	90,630	226.0
302.6	11,870	9,140	259.0	1374.8	95,910	92,700	234.0
375.6	16,350	12,930	245.0	1402.5	98,130	94,940	226.5
426.4	20,330	16,250	193.0	1425.5	100,000	96,810	236.0
474.2	24,280	20,090	194.5	1451.5	102,210	98,950	225.0
525.1	28,530	24,390	200.0	1476.1	104,410	101,040	229.0
576.0	32,680	29,720	198.0	1499.6	106,610	103,130	238.5
602.3	34,770	30,910	223.0	1526.3	109,240	105,620	234.5
625.6	36,600	32,800	207.0	1547.0	111,250	107,650	244.0
651.6	38,600	34,870	210.0	1575.2	113,850	110,510	233.5
700.3	42,320	38,660	207.0	1598.0	115,850	112,700	240.0
748.3	45,970	42,310	178.5	1626.5	118,220	115,290	276.0
775.2	48,000	44,350	200.0	1651.0	120,170	117,410	271.5
800.0	49,850	46,220	207.7	1676.4	122,100	119,500	280.0
852.5	53,770	50,150	201.0	1700.9	123,900	121,430	271.0
874.3	55,450	51,770	201.0	1726.8	125,730	123,380	265.3
902.2	57,660	53,860	219.5	1747.3	127,150	124,880	267.0
926.8	59,670	55,780	214.5	1774.1	129,020	126,770	275.0
951.9	61,790	57,800	206.5	1802.4	131,030	128,780	266.5
975.7	63,880	59,770	201.0	1825.7	132,700	130,460	275.0
1002.5	66,230	62,080	192.0	1850.5	134,510	132,280	266.0
1023.5	68,040	63,960	193.0	1875.9	136,450	134,170	296.5
1052.4	70,470	66,540	205.5	1902.0	138,660	136,170	266.0
1074.8	72,330	68,490	226.5	1928.0	141,170	138,410	246.5
1101.4	74,500	70,770	243.0	1948.7	143,440	140,430	231.0
1124.2	76,330	72,690	235.0	1975.3	146,860	143,370	217.0
1148.7	78,270	74,720	230.5	1998.0	150,330	146,340	191.0
1175.0	80,320	76,860	219.5	2025.7	154,980	150,700	200.5
1225.7	84,220	80,900	222.5	2050.3	159,100	154,970	191.3
1251.5	86,220	82,920	234.0	2077.5	163,670	159,690	195.5

^aThe record presented here was published in Barnola et al. (1987). Readers should also refer to Barnola et al. (1991), which presents new CO₂ measurements and age of air determinations. According to Barnola et al. (1991), the agreement between the two sets is good although the new results are slightly lower than the previous ones between 10 and 50 kyr BP.

^bThe reported CO₂ concentration for each depth level takes into account the correction of +3 ppmv for the effect of water vapor where unambiguous water-vapor peaks occurred.

CITE AS: Barnola, J.M., D. Raynaud, C. Lorius, and Y.S. Korotkevich. 1994. Historical CO₂ record from the Vostok ice core. pp. 7-10. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

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A. Neftel, H. Friedli, E. Moor, H. Lötscher, H. Oeschger, U. Siegenthaler, B. Stauffer
Physics Institute, University of Bern, CH-3012 Bern, Switzerland

Period of Record

1734–1983

Methods

Determinations of ancient atmospheric CO₂ concentrations for Siple Station, located in West Antarctica, were derived from measurements of air occluded in a 200-m core drilled at Siple Station in the Antarctic summer of 1983–84. The core was drilled by the Polar Ice Coring Office in Nebraska and the Physics Institute at the University of Bern. The ice could be dated with an accuracy of approximately ± 2 years to a depth of 144 m (which corresponds to the year 1834) by counting seasonal variations in electrical conductivity. Below that depth, the core was dated by extrapolation (Friedli et al. 1986). The gases from ice samples were extracted by a dry-extraction system, in which bubbles were crushed mechanically to release the trapped gases, and then analyzed for CO₂ by infrared laser absorption spectroscopy or by gas chromatography (Neftel et al. 1985). After the ice samples were crushed, the gas expanded over a cold trap, condensing the water vapor at -80°C in the absorption cell. The analytical system was calibrated for each ice sample measurement with a standard mixture of CO₂ in nitrogen and oxygen. For further details on the experimental and dating procedures, see Neftel et al. (1985), Friedli et al. (1986), and Schwander and Stauffer (1984).

Siple Station
Antarctica
75°55' S, 83°55' W

CITE AS: Neftel, A., H. Friedli, E. Moor, H. Lötscher, H. Oeschger, U. Siegenthaler, and B. Stauffer. 1994. Historical CO₂ record from the Siple Station ice core. pp. 11–14. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Historical CO₂ record from the Siple Station ice core

A. Neftel, H. Friedli, E. Moor, H. Lötscher, H. Oeschger, U. Siegenthaler, and B. Stauffer (continued)

SIPLE STATION

Trends

An atmospheric CO₂ record for the past 200 years was obtained from the Siple ice core. At shallow depths, atmospheric air still circulates through the open pores (Friedli et al. 1986). The enclosed air was younger than the surrounding ice because the enclosure of air in bubbles occurred only between depths of 64 and 76 m. On the basis of porosity measurements, investigators determined that the time lag between the mean age of the gas and the age of the ice was 95 years and that the duration of the close-off process was 22 years (Schwander and Stauffer 1984). Neftel et al. (1985) concluded that the atmospheric CO₂ concentration ca. 1750 was 280 ± 5 parts per million by volume (ppmv) and that it increased by 22.5% to 345 ppmv in 1984 essentially because of human factors. Graphs in Friedli et al. (1986) also reported that the preindustrial (pre-1800) CO₂ concentration was ~280 ppmv.

Atmospheric CO₂ derived from the Siple ice core.

CITE AS: Neftel, A., H. Friedli, E. Moor, H. Lötscher, H. Oeschger, U. Siegenthaler, and B. Stauffer. 1994. Historical CO₂ record from the Siple Station ice core. pp. 11–14. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric Carbon Dioxide

Historical CO₂ record from the Siple Station ice core

A. Neftel, H. Friedli, E. Moor, H. Lötscher, H. Oeschger, U. Siegenthaler, and B. Stauffer (continued)

SIPLE STATION

Atmospheric Concentrations of CO₂ from Ice Cores^a

Depth (m)	Samples measured	Date of ice (yr A.D.)	Date air enclosed (yr A.D.)	CO ₂ concentration in extracted air (ppmv) ^b	Average depth (m)	Gas (yr A.D.)	CO ₂ concentration (ppmv) ^b
187.0–187.3	10	1663	1734–1756	279 ± 3.0	187.70	1744	276.8
177.0–177.3	10	1683	1754–1776	279 ± 3.0	177.50	1764	276.7
162.0–162.3	9	1723	1794–1819	280 ± 3.0	168.30	1791	279.7
147.0–147.2	10	1743	1814–1836	284 ± 3.0	154.89	1816	283.8
128.0–129.0	47	1782	1842–1864	288 ± 3.0	142.75	1839	283.1
111.0–112.0	26	1812	1883–1905	297 ± 3.0	140.75	1843	287.4
102.0–103.0	26	1832	1903–1925	300 ± 3.0	138.20	1847	286.8
92.0–93.0	25	1850	1921–1943	306 ± 3.0	134.47	1854	288.2
82.0–83.0	28	1867	1938–1960	311 ± 3.0	126.80	1869	289.3
76.2–76.6	11	1876	1947–1969	312 ± 3.0	123.80	1874	289.5
72.4–72.7	11	1883	1954–1976	318 ± 3.0	121.80	1878	290.3
68.2–68.6	8	1891	1962–1983	328 ± 3.5	116.82	1887	292.3
					110.20	1899	295.8
					108.80	1903	294.8
					107.20	1905	296.9
					105.25	1909	299.2
					101.80	1915	300.5
					98.80	1921	301.6
					95.17	1927	305.5
					90.77	1935	306.6
					86.80	1943	307.9
					81.22	1953	312.7

^aData on the left side of the table were published in Neftel et al. (1985); data on the right were published by Friedli et al. (1986).

^bCO₂ concentrations are expressed in parts per million by volume.

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Historical CO₂ record from the Siple Station ice core

A. Nefftel, H. Friedli, E. Moor, H. Lötscher, H. Oeschger, U. Siegenthaler, and B. Stauffer (continued)

References

- Barnola, J.M., D. Raynaud, A. Nefftel, and H. Oeschger. 1983. Comparison of CO₂ measurements by two laboratories on air from bubbles in polar ice. *Nature* 303:410-13.
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- Nefftel, A., E. Moor, H. Oeschger, and B. Stauffer. 1985. Evidence from polar ice cores for the increase in atmospheric CO₂ in the past two centuries. *Nature* 315:45-47.
- Raynaud, D., and J.M. Barnola. 1985. An Antarctic ice core reveals atmospheric CO₂ variations over the past few centuries. *Nature* 315:309-11.
- Schwander, J., and B. Stauffer. 1984. Age difference between polar ice and the air trapped in its bubbles. *Nature* 311:45-47.
- Staffelbach, T., B. Stauffer, A. Sigg, and H. Oeschger. 1991. CO₂ measurements from polar ice cores: More data from different sites. *Tellus* 43(B):91-96.

C.D. Keeling, T.P. Whorf

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Mauna Loa • Barrow • Samoa • South Pole

Period of Record

1957–93 (varies by site)

Methods—Mauna Loa

Air samples at Mauna Loa are collected continuously from air intakes at the top of four 7-m towers and one 27-m tower. Four air samples are collected each hour for the purpose of determining the CO₂ concentration. Determinations of CO₂ are made by using an Applied Physics Corporation nondispersive infrared gas analyzer with a water vapor freeze trap. This analyzer registers the concentration of CO₂ in a stream of air flowing at ~0.5 L/min. Every 20 minutes, the flow is replaced by a stream of calibrating gas or “working reference gas.” In December 1983, CO₂-in-N₂ calibration gases were replaced with the currently used CO₂-in-air calibration gases. These calibration gases and other reference gases are compared periodically to determine the instrument sensitivity and to check for possible contamination in the air-handling system. These reference gases are themselves calibrated against specific standard gases whose CO₂ concentrations are determined manometrically. Greater details about the sampling methods at Mauna Loa are given in Keeling et al. (1982).

Hourly averages of atmospheric CO₂, wind speed, and direction are plotted as a basis for selecting data for further processing. Data are selected for periods of steady hourly data to within ~0.5 parts per million by volume (ppmv); at least six consecutive hours of steady data are required to form a daily average. Greater details about the data selection criteria used at Mauna Loa are given in Bacastow et al. (1985).

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Atmospheric CO₂ records from sites in the SIO air sampling network

C.D. Keeling and T.P. Whorf (continued)

Methods—Barrow

Carbon dioxide was first measured at Barrow, Alaska, by Kelley and co-workers from the University of Washington during the 1960s through the use of a continuously operating analyzer. From January 1974 through February 1982, air samples were collected biweekly in triplicate 2-L evacuated glass flasks. Since March 1982, weekly air samples have been collected in 5-L evacuated glass flask pairs. Flasks are returned to the Scripps Institution of Oceanography (SIO) for CO₂ determinations, which are made using an Applied Physics Corporation nondispersive infrared gas analyzer. In May 1983, the CO₂-in-N₂ calibration gases were replaced with the CO₂-in-air calibration gases, which are currently used.

Methods—Samoa

At Cape Matatula, Samoa, weekly air samples are collected in 5-L evacuated glass flasks exposed in triplicate. Flasks are returned to the SIO for CO₂ determinations using an Applied Physics Corporation nondispersive infrared gas analyzer. In May 1983 the CO₂-in-air calibration gases were replaced with CO₂-in-air calibration gases, which are currently used.

Methods—South Pole

Air samples are collected biweekly at the South Pole in 5-L evacuated glass flasks exposed as triplets. From 1957 until October 1963, 5-L glass flasks were exposed as singlets or pairs biweekly. Between 1960 and 1963, continuous in situ measurements of atmospheric CO₂ concentrations were made. The data presented here are derived from both the flask sampling program and the continuous sampling program. Greater details about the sampling methods used at the South Pole are described in Keeling et al. (1976) and in Bacastow and Keeling (1981). Air samples collected at the South Pole are analyzed for CO₂ concentration at SIO through the use of an Applied Physics Corporation nondispersive infrared gas analyzer with a water vapor freeze trap. In March 1983, CO₂-in-air mixtures prepared by SIO replaced CO₂-in-N₂ as the calibration gases used to ascertain instrument sensitivity, detect possible contamination, and determine CO₂ concentrations.

For air samples collected at Barrow, Samoa, and the South Pole to be considered indicative of uncontaminated background air, the replicate flask samples must agree within 0.40 parts per million by volume (ppmv).

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C.D. Keeling and T.P. Whorf (continued)

MAUNA LOA

Trends

The Mauna Loa atmospheric CO₂ measurements constitute the longest continuous record of atmospheric CO₂ concentrations available in the world. The Mauna Loa site is considered one of the most favorable locations for measuring undisturbed air because possible local influences of vegetation or human activities on atmospheric CO₂ concentrations are minimal and any influences from volcanic vents may be excluded from the records. The methods and equipment used to obtain these measurements have remained essentially unchanged during the 35-year record.

Because of the favorable site location, continuous monitoring, and careful selection and scrutiny of the data, the Mauna Loa record is considered to be a precise record and a reliable indicator of the regional trend in the concentrations of atmospheric CO₂ in the middle layers of the troposphere. The Mauna Loa record shows a 12.8% increase in the mean annual concentration, from 315.83 parts per million by volume (ppmv) of dry air in 1959 to 356.24 ppmv in 1992.

Monthly atmospheric CO₂ concentrations at Mauna Loa.

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Atmospheric CO₂ records from sites in the SIO air sampling network

C.D. Keeling and T.P. Whorf (continued)

Mauna Loa
Hawaii, U.S.A.
Barren lava field of an
active volcano
19°32' N, 155°35' W
3397 m above MSL

MAUNA LOA**Atmospheric Concentrations of CO₂**CO₂ concentrations^a at Mauna Loa (ppmv)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1958			315.56	317.29	317.34		315.69	314.78	313.05		313.19	314.50	
1959	315.42	316.31	316.50	317.56	318.13	318.00	316.39	314.66	313.68	313.18	314.66	315.43	315.83
1960	316.27	316.81	317.42	318.87	319.87	319.43	318.01	315.74	314.00	313.68	314.84	316.04	316.75
1961	316.73	317.54	318.38	319.31	320.42	319.61	318.42	316.63	314.84	315.16	315.94	316.85	317.49
1962	317.78	318.40	319.53	320.41	320.85	320.45	319.44	317.25	316.11	315.27	316.53	317.53	318.30
1963	318.58	318.92	319.70	321.22	322.08	321.31	319.58	317.61	316.05	315.83	316.91	318.20	318.83
1964	319.41				322.06	321.73	320.27	318.53	316.54	316.72	317.53	318.55	
1965	319.27	320.28	320.73	321.97	322.00	321.71	321.05	318.71	317.66	317.14	318.70	319.25	319.87
1966	320.45	321.43	322.23	323.54	323.91	323.59	322.24	320.20	318.48	317.94	319.63	320.87	321.21
1967	322.17	322.34	322.88	324.25	324.83	323.93	322.38	320.76	319.10	319.24	320.56	321.80	322.02
1968	322.40	322.99	323.73	324.86	325.41	325.20	323.97	321.95	320.18	320.09	321.16	322.74	322.89
1969	323.83	324.26	325.47	326.50	327.21	326.54	325.72	323.51	322.22	321.62	322.69	323.95	324.46
1970	324.89	325.82	326.77	327.97	327.91	327.50	326.18	324.53	322.93	322.90	323.85	324.96	325.52
1971	326.01	326.51	327.01	327.62	328.76	328.40	327.20	325.27	323.20	323.40	324.64	325.85	326.16
1972	326.60	327.47	327.58	329.56	329.90	328.92	327.88	326.16	324.68	325.04	326.34	327.39	327.29
1973	328.37	329.40	330.14	331.33	332.31	331.90	330.70	329.15	327.35	327.02	327.99	328.48	329.51
1974	329.18	330.55	331.32	332.48	332.92	332.08	331.01	329.23	327.28	327.21	328.29	329.41	330.08
1975	330.23	331.25	331.87	333.14	333.80	333.43	331.73	329.90	328.40	328.17	329.32	330.59	330.99
1976	331.58	332.39	333.33	334.41	334.71	334.17	332.89	330.77	329.14	328.77	330.14	331.52	331.98
1977	332.75	333.24	334.53	335.90	336.57	336.10	334.76	332.59	331.42	330.98	332.24	333.68	333.73
1978	334.80	335.22	336.47	337.59	337.84	337.72	336.37	334.51	332.60	332.37	333.75	334.79	335.34
1979	336.05	336.59	337.79	338.71	339.30	339.12	337.56	335.92	333.75	333.70	335.12	336.56	336.68
1980	337.84	338.19	339.91	340.59	341.29	341.00	339.38	337.43	335.72	335.84	336.93	338.05	338.52
1981	339.06	340.30	341.21	342.33	342.74	342.08	340.32	338.27	336.52	336.68	338.19	339.44	339.76
1982	340.57	341.44	342.53	343.39	343.96	343.18	341.88	339.65	337.80	337.69	339.09	340.32	340.96
1983	341.20	342.35	342.93	344.77	345.58	345.14	343.81	342.21	339.69	339.82	340.98	342.82	342.61
1984	343.52	344.33	345.11	346.87	347.25	346.62	345.22	343.11	340.90	341.17	342.80	344.04	344.25
1985	344.79	345.82	347.25	348.17	348.75	348.07	346.38	344.52	342.92	342.63	344.06	345.38	345.73
1986	346.12	346.79	347.69	349.38	350.04	349.39	347.78	345.75	344.70	344.01	345.50	346.75	346.99
1987	347.86	348.32	349.26	350.84	351.70	351.11	349.37	347.96	346.31	346.22	347.68	348.83	348.79
1988	350.29	351.58	352.08	353.45	354.08	353.66	352.25	350.30	348.57	348.74	349.93	351.20	351.34
1989	352.62	352.93	353.54	355.28	355.53	354.98	353.75	351.51	349.62	349.81	351.12	352.35	352.75
1990	353.47	354.51	355.18	356.00	356.95	356.02	354.62	352.71	350.77	350.99	352.65	354.03	353.99
1991	354.54	355.58	356.98	358.43	359.17	358.07	356.01	353.87	352.00	352.05	353.59	354.84	355.43
1992	355.83	356.57	357.66	359.02	359.53	359.12	356.89	354.87	352.88	353.18	354.04	355.28	356.24
1993	356.58	357.06	358.27	359.36	360.19	359.51							

^aAtmospheric CO₂ concentrations are expressed in parts per million by volume (ppmv). Averages of data are adjusted to the 15th day of each month. Note: Data in *Trends '91* were in the X87 mole fraction scale. The data presented here are reported in the 1993 Scripps mole fraction scale (a provisional scale).

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BARROW

Trends

Since 1975, the annual CO₂ concentration at Point Barrow has risen from 333.19 ppmv to 357.66 ppmv in 1992. This represents an annual increase of ~1.44 ppmv. The Point Barrow CO₂ record is considered indicative of maritime air masses and shows the seasonal amplitude typical of northerly latitude sites.

Monthly atmospheric CO₂ concentrations at Barrow.

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Atmospheric CO₂ records from sites in the SIO air sampling network

C.D. Keeling and T.P. Whorf (continued)

BARROW

Barrow
Alaska, U.S.A.
On the coast of the Arctic
Ocean
71°19' N, 156°36' W
11 m above MSL

Atmospheric Concentrations of CO₂CO₂ concentrations^a at Barrow (ppmv)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1974	336.01		336.89	336.25	336.80	336.25	330.81	322.90	323.79	327.61	332.39	334.94	
1975	336.95	338.54	336.41	337.23	337.24	335.40	329.82	323.95	324.74	329.09	333.43	335.46	333.19
1976	336.89	337.16	338.24	339.27	338.49	336.54	330.82	324.29	326.15	329.46	333.35	337.49	334.01
1977	337.92	337.10	337.76		340.15	337.92		325.95	326.55	330.92	334.79	339.42	
1978	339.04	340.48	342.63								339.32	339.11	
1979	340.41	341.39	343.15	342.39	343.26	342.80	335.10		328.96	333.50	337.36	341.97	
1980	341.50	343.15	344.17		343.79	342.58	336.72	331.59	332.08	337.54	341.40	344.54	
1981	344.63	344.23	344.41	345.98	346.04	343.62	335.28	330.11	333.06	338.11	341.14	343.84	340.87
1982	344.30	347.67	347.33	347.29	347.29	345.67	339.23	331.77	332.61	338.28	342.47	344.81	342.39
1983	346.59	346.63	347.55	347.77	347.97	348.02	340.10	331.79	335.53	341.02	345.64	346.16	343.73
1984	349.23	350.81	350.14	349.63	350.71	348.76	340.98	335.48	337.00	341.29	344.49	347.89	345.53
1985	349.45	349.11	350.56	351.10	352.48	349.83	343.80	337.24	338.12	343.48	347.21	348.49	346.74
1986	349.53	352.23	354.07	353.23	353.83	350.92	344.71	337.37	340.72	345.94	348.19	351.41	348.51
1987	352.99	353.26	354.50	353.93	354.83	353.47	346.51	339.43	340.71	345.52	349.37	352.55	349.76
1988	355.16	356.86	356.31	357.70	356.63	355.02	347.97	342.51	345.44	350.14	354.86	357.95	353.05
1989	359.73	359.15	359.84	359.73	359.37	360.07	352.11	341.88	344.77	350.48	355.78	358.43	355.11
1990	359.27	360.80	361.62	361.38	361.98	356.62	351.12	344.00	346.08	352.52	356.29	358.15	355.82
1991	361.25	360.82	362.28	361.75	362.00	359.98	352.79	346.67	347.59	353.48	358.76	360.18	357.29
1992	361.91	362.20	362.24	362.91	362.36	360.92	354.21	347.16	347.44	353.19	356.61	360.80	357.66
1993	362.73	362.20	363.52	363.32	363.70	360.73							

^aAtmospheric CO₂ concentrations are expressed in parts per million by volume (ppmv). Averages of data are adjusted to the 15th day of each month. Note: Data in *Trends '91* were in the X87 mole fraction scale. The data presented here are reported in the 1993 Scripps mole fraction scale (a provisional scale).

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SAMOA

Trends

NOAA established a monitoring project to observe the sea-level climate and atmospheric constituents of the tropical Southern Hemisphere at Cape Matatula, Samoa, in 1973. NOAA operates both a continuous monitoring program (Waterman et al. 1989) and a flask sampling program (Conway et al. 1988) at Cape Matatula. Independently of NOAA, Scripps Institution of Oceanography (SIO) has also collected flask samples at Samoa since 1981.

On the basis of flask samples collected by SIO, the annual average concentration of CO₂ rose from 340.43 ppmv in 1982 to 355.07 ppmv in 1992. This represents an annual growth rate of ~1.46 ppmv per year at American Samoa. For comparison, Conway et al. (1988) reported an annual growth rate of 1.35 ppmv at Samoa for 1981–84 on the basis of flask data from the NOAA/CMDL flask sampling program.

Monthly atmospheric CO₂ concentrations at Samoa.

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Atmospheric CO₂ records from sites in the SIO air sampling network

C.D. Keeling and T.P. Whorf (continued)

SAMOA

Samoa (Cape Matatula)
U.S. Territory,
Pacific Ocean
Rocky coastal promontory
14°15' S, 170°34' W
30 m above MSL

Atmospheric Concentrations of CO₂CO₂ concentrations^a at Samoa (ppmv)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1981									338.84	338.87	339.52	339.73	
1982	340.50	340.78	340.07	340.60	339.66	340.03	340.95	341.18	340.36	339.94	340.37	340.73	340.43
1983	340.43	340.84	340.85	341.66	341.85	342.22	342.20	342.23	341.98	342.46	342.76	342.38	341.82
1984	343.66	343.74	343.82	343.36	342.72	342.89	343.29	343.66	344.35	344.04	343.83	344.60	343.66
1985	344.76	345.12	345.24	345.31	344.00	344.78	344.61	345.08	346.10	345.24	345.21		
1986	346.18		346.36	346.69	344.54	346.16	345.83	345.72		347.07	346.93	346.80	
1987	346.96	347.53	348.56	347.06	347.23	347.25	347.52	347.98	348.16	348.20	348.86	349.22	347.88
1988	349.56	349.88	349.36	349.69	349.44	349.57	349.83	350.04	349.95	350.30	350.70	351.16	349.96
1989	351.57	351.91	351.01	351.80	351.67	350.99	351.14	351.20	351.22	351.29	351.76	351.72	351.44
1990	352.16	351.52	352.71	352.95	352.25	352.91	352.72	353.01	353.12	352.56	353.23	353.61	352.73
1991	354.42	354.81	354.60	353.85	353.78	354.00	354.19	354.04	353.75	353.71	354.54	354.85	354.21
1992	353.93	354.78	354.77	354.67	354.92	355.18	355.56	355.53	355.11	355.49	355.09	355.77	355.07
1993	355.28	355.74	356.25	355.60	354.89	355.95							

^aAtmospheric CO₂ concentrations are expressed in parts per million by volume (ppmv). Averages of data are adjusted to the 15th day of each month. Note: Data in *Trends '91* were in the X87 mole fraction scale. The data presented here are reported in the 1993 Scripps mole fraction scale (a provisional scale).

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SOUTH POLE

Trends

Precise measurements of atmospheric CO₂ at the South Pole have been obtained by Scripps Institution of Oceanography (SIO) since 1957. This record is based primarily on biweekly flask sampling.

The SIO CO₂ record from the South Pole shows that annual averages of atmospheric CO₂ concentrations rose from 327.44 ppmv in 1973 (the first year when data were available for the entire year) to 354.12 ppmv in 1992. This represents an annual increase of ~1.4 ppmv per year. Keeling et al. (1976) reported that the seasonally adjusted concentration of atmospheric CO₂ from the South Pole rose 3.7% between 1957 and 1971. Gillette et al. (1987) reported a mean annual CO₂ increase of 1.32 ppmv for 6 years (1975–78 and 1980–82) and Conway et al. (1988) reported a mean annual CO₂ growth rate of 1.22 ppmv for 1981–84 for the South Pole.

Monthly atmospheric CO₂ concentrations at the South Pole.

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Atmospheric CO₂ records from sites in the SIO air sampling network

C.D. Keeling and T.P. Whorf (continued)

South Pole
Antarctica
Ice- and snow-covered
plateau
89°59' S, 24°48' W
2810 m above MSL

SOUTH POLE

Atmospheric Concentrations of CO₂CO₂ concentrations^a at the South Pole (ppmv)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1957						313.21			313.71			314.31	
1958			314.12			314.37			315.16				
1959	314.93	314.97	314.92					315.81	316.06		316.16		
1960						316.21	316.51	316.58					
1961					316.63	316.70	316.78	317.19	317.52	317.57	317.71	317.51	
1962	317.30	317.10	316.90	316.95	317.02	317.09	317.11	317.48	317.91			318.47	
1963	317.97	317.71	317.31	317.74	318.10	318.06	318.10	318.21	318.24	318.85			
1964													
1965		318.53	318.40	318.52	318.73		319.22	319.51			320.01	320.11	
1966	320.19	319.84	319.89	320.15	320.52	320.28		320.91	321.19	321.30	321.40	320.90	
1967		320.85		320.70	320.84	320.79	320.89	321.67	321.92	321.64	321.66	321.61	
1968	321.37			321.45	321.31	321.28	321.34					322.49	
1969	322.20		322.11	322.13	322.42	322.63	323.08	323.43	323.97	323.78	323.80		
1970		323.37	323.27	323.51	323.62	324.02	324.30	324.55	325.26	325.03	325.07		
1971	324.64	324.44	324.15	324.32	324.51	324.74	324.99		325.61		325.57		
1972			324.88	325.00	325.14	325.66	325.96	325.95	326.38	326.62	326.78	326.65	
1973	326.58	326.02	326.19	326.66	326.95	327.26	327.57	328.24	328.53	328.46	328.42	328.42	327.44
1974	328.13	327.91	327.91	327.73	327.84	327.71	328.29	328.52	328.78	328.88	328.95	328.82	328.29
1975	328.72	328.73	328.68	328.77	328.76	328.90	329.18	329.66	330.06	330.39	330.29	330.10	329.35
1976	330.12	329.84	329.74	329.48	329.77	329.81	330.29	330.85	331.22	331.54	331.57	331.25	330.46
1977	331.09	330.83	330.68	331.16	331.23	331.45	331.88	332.29	332.70	332.92	333.14	333.01	331.87
1978	332.67	332.54	332.65	332.81		333.21	333.65	334.11	334.57	334.65	334.41	334.13	
1979	333.84	333.86	333.65	334.01	334.17	334.37	334.98	335.55	335.71	335.84	336.20	335.87	334.84
1980	335.89	335.57		335.92	336.05	336.73	337.28	337.37	337.70	337.73	337.80	337.87	
1981	337.59	337.30	337.25	337.36	337.50	337.98	338.24	338.59	338.65	338.98	338.69	338.74	338.07
1982		338.47	338.21	338.54	338.82	339.01	339.16	339.94	340.14	340.17	339.86	339.78	
1983	339.68	339.67	339.68	340.14	340.46	340.83	341.23	341.71	342.15	342.11	342.37	342.17	341.02
1984	341.87		341.54	341.66	341.70	341.85	342.62	343.02	343.28	343.32	343.14	342.97	
1985	342.83	342.64	342.56	342.61	342.96	343.29	343.77	344.36	344.71	344.78	344.62	344.47	343.63
1986	344.47	344.43	344.36	344.48	344.54	344.87	345.39	345.79	346.04	346.01	346.01	345.89	345.19
1987	345.75	345.65	345.61	345.98	346.08	346.48	347.07	347.50	347.94	347.97	348.05	348.17	346.85
1988	348.15	347.92	347.73	348.05	348.19	348.44	348.92	349.44	349.61	349.75	349.71	349.69	348.80
1989	349.66	349.59	349.47	349.55	349.75	350.00	350.41	350.94	351.19	351.12	351.14	350.79	350.30
1990	350.57	350.21	350.45	350.72	351.18	351.40	351.88	352.37	352.57	352.39	352.64	352.45	351.57
1991		352.16	352.12	352.29	352.39	352.80	353.25	353.53	353.93	353.73	353.80	353.62	
1992	353.42	353.02	352.91	353.12	353.63	353.88	354.50	354.83	355.14	355.25	354.98	354.77	354.12
1993	354.61	354.46	354.19	354.40	354.47	354.81							

^aAtmospheric CO₂ concentrations are expressed in parts per million by volume (ppmv). Averages of data are adjusted to the 15th day of each month. **Note:** Data in *Trends '91* were in the X87 mole fraction scale. The data presented here are reported in the 1993 Scripps mole fraction scale (a provisional scale).

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Atmospheric CO₂ records from sites in the NOAA/CMDL continuous monitoring network

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| Barrow • Mauna Loa • Samoa • South Pole

Period of Record

1973–92 (varies by site)

Methods

The Air Resources Laboratories of the National Oceanic and Atmospheric Administration (NOAA) established four baseline monitoring stations in the mid-1970s to conduct continuous measurements of atmospheric CO₂ mixing ratios. The stations are operated by NOAA's Climate Monitoring and Diagnostics Laboratory (CMDL). The four sites are located at Point Barrow, Alaska; Cape Matatula, Samoa; Mauna Loa Observatory, Hawaii; and South Pole Station, Antarctica.

Methodologies and instrumentation at the four sites are similar, with minor modifications made to accommodate the local environment. A detailed description of the methods used at the Mauna Loa Observatory are in Komhyr et al. (1989). This description, for the most part, also pertains to the other three sites. Additional information can be found in Peterson et al. (1986) for Barrow, Gillette et al. (1987) for the South Pole, and Waterman et al. (1989) for American Samoa. The summary of the measurement method that follows is for all four sites. Differences and important hardware information is given for each site.

Determinations of atmospheric CO₂ mixing ratios are made by using nondispersive infrared (NDIR) CO₂ gas analyzers. These NDIR CO₂ analyzers are operated as a comparator of ambient air CO₂ mixing ratios relative to known CO₂ mixing ratios in tanks of compressed

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Atmospheric CO₂ records from sites in the NOAA/CMDL
continuous monitoring network

K.W. Thoning, P.P. Tans, and L.S. Waterman (continued)

reference gases. The analyzer operates in a differential mode, with a "zero" reference gas of CO₂ mixing ratio 20–30 ppm below ambient air CO₂ levels flowing continuously through one cell of the analyzer at ~10 mL/min. When atmospheric CO₂ is measured, a diaphragm pump pulls air through a sampling line at ~5 L/min. A small fraction of this (300 mL/min) is directed to the analysis system, where it passes through a glass water vapor trap immersed in a cold alcohol bath (approximately -70°C), a particle filter, a flowmeter, and into the sample cell of the CO₂ analyzer. Both the "zero" gas and the sample gas are exhausted into the observatory building. At 1 hour intervals, two calibrated working reference gases of known CO₂ levels are passed in succession through the analyzer sample cell for 5 min each. Comparison of the response of the analyzer to ambient air with the response due to the reference gases is used to determine an hourly average ambient CO₂ mixing ratio in dry air.

In the early years of measurement, CO₂-in-nitrogen reference gases were used. These were later changed ca. 1981 to CO₂-in-synthetic air (commercial mixture of CO₂ in nitrogen, oxygen and argon), then changed again ca. 1990 to CO₂-in-natural air (reference gas tanks filled from a clean air site in the mountains west of the CMDL laboratory in Boulder, Colorado).

The gases entering the analyzer were initially controlled by an electromechanical timing device. Beginning in 1977, the device was replaced by a digital controller system (ICDAS, Herbert et al. 1980). In 1984, a new controller system was installed (CAMS, Herbert et al. 1986).

The data from all four sites undergo an identical process of editing and initial data selection. The recorded data are compared with measurement records (such as strip chart records, operator notes etc.) to determine when instrumental malfunctions have occurred, making the CO₂ mixing ratios invalid. These data are removed from the data set. The remaining data are selected based on the observation that a homogenous air mass characteristic of "background" has small within-hour changes in CO₂ levels. Hourly averaged values that show a relatively large variability in CO₂ are marked as occurring in non-background conditions. This is called the preliminary selected data. Additional steps for selecting baseline (background) data are site dependent.

Methods—Barrow

An UNOR-2 CO₂ analyzer was used from the start of the measurements until August 1978. A URAS-2T analyzer manufactured by Hartmann and Braun was used from August 1978 until September 1991. An ULTRAMAT 5F analyzer manufactured by Siemens has been used since then.

Additional data selection steps include an hour-to-hour difference criterion that rejects data that change by more than 0.25 parts per million by volume (ppmv) from one hour to the next. For data from 1983 to present, a third selection step based on residuals from a spline fit (Thoning 1989) is applied.

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Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL continuous monitoring network

K.W. Thoning, P.P. Tans, and L.S. Waterman (continued)

Methods—Mauna Loa

An URAS-2 CO₂ analyzer manufactured by Hartmann and Braun was used from the start of measurements until August 1987. Since then, an ULTRAMAT 3 CO₂ analyzer manufactured by Siemens has been used.

Additional data selection steps include an hour-to-hour difference criterion that rejects data which change by more than 0.25 parts per million by volume (ppmv) from one hour to the next. A third selection step based on residuals from a spline fit (Thoning 1989) is applied.

Methods—Samoa

An URAS-2T CO₂ analyzer manufactured by Hartmann and Braun was used from the start of measurements until October 1990. Since then, an ULTRAMAT 5F CO₂ analyzer manufactured by Siemens has been used.

Additional data selection steps for the data through 1987 include a selection based on wind direction and wind speed and an hour-to-hour difference criterion that rejects data which change by more than 0.25 parts per million by volume (ppmv) from one hour to the next. For data since 1987, the wind direction and wind speed selection has not been applied. Instead, a selection step based on residuals from a spline fit (Thoning 1989) has been applied after the hour-to-hour selection.

Methods—South Pole

An URAS-2T CO₂ analyzer manufactured by Hartmann and Braun was used from the start of measurements until December 1990. Since then, an ULTRAMAT 5F CO₂ analyzer manufactured by Siemens has been used.

Additional data selection steps for the data through 1982 include an iterative selection based on deviations from a 5-day mean. For data after 1982, an hour-to-hour difference criterion that rejects data which change by more than 0.25 parts per million by volume (ppmv) from one hour to the next and selection based on residuals from a spline fit (Thoning 1989) have been applied instead.

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Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL
continuous monitoring network

K.W. Thoning, P.P. Tans, and L.S. Waterman (continued)

BARROW

Trends

Since 1974, the annual atmospheric CO₂ concentration at Point Barrow has risen from 332.61 parts per million by volume (ppmv) to 357.70 ppmv in 1992. Peterson et al. (1982) reported that concentrations of CO₂ at Point Barrow for 1973–79 rose 4–5 ppmv and exhibited a seasonal cycle of 15.2 ppmv. Conway et al. (1988) reported a growth rate of 1.26 ppmv per year for the flask-sampling data from Point Barrow for 1981–84. Atmospheric CO₂ concentrations at Point Barrow show an annual seasonal cycle with yearly minimum values recorded in August and annual maximum values recorded in April or May.

Monthly atmospheric CO₂ mixing ratios at Barrow.

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Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL continuous monitoring network

K.W. Thoning, P.P. Tans, and L.S. Waterman (continued)

BARROW

Barrow
Alaska, U.S.A.
Coastal seashore
71°19' N, 156°36' W
11 m above MSL

Atmospheric Mixing Ratios of CO₂

CO₂ mixing ratios^a at Barrow (ppmv)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1973								321.95	323.36	327.78	332.73	333.50	
1974	336.47	336.02	336.66	337.09	336.85	335.94	328.70	323.45	324.21	328.76	331.98	335.17	332.61
1975	336.79	336.58	337.14	337.72	337.92	335.37	330.10	324.39	324.58	329.25	334.33	336.45	333.39
1976	336.98	336.70	337.73	338.04	337.80	336.77	331.04	323.47	325.09	329.78	334.07	336.57	333.67
1977	336.83	336.91	338.23	339.15	339.43	337.74	330.12	325.38	326.84	331.96	334.69	338.78	334.67
1978	339.13	340.23	341.49	340.98	340.78	339.39	332.61	327.72	327.43	332.14	338.78	339.40	336.67
1979	340.09	341.33	342.50	342.35	342.87	342.04	333.63	327.74	329.32	333.12	338.14	341.51	337.89
1980	341.92	342.44	343.36	343.30	343.26	342.61	337.29	331.77	331.35	337.87	340.52	342.59	339.86
1981	344.27	345.48	344.55	345.79	346.79	344.40	338.22	331.77	333.28	338.76	342.20	344.86	341.70
1982	345.75	347.18	348.27	348.39	347.99	345.70	339.15	333.16	333.16	337.85	342.11	344.47	342.77
1983	347.14	346.95	348.00	348.13	348.30	346.90	340.38	333.75	335.35	340.47	346.54	346.66	344.05
1984	350.97	350.74	350.04	349.77	350.66	348.30	341.34	335.92	338.30	342.18	345.00	348.52	345.98
1985	349.69	349.51	350.53	351.52	352.49	350.07	343.77	337.83	338.62	343.25	346.92	349.66	346.99
1986	350.21	351.63	353.42	353.09	353.33	351.43	344.51	339.45	342.03	345.03	348.70	351.09	348.66
1987	352.36	352.72	353.90	353.85	354.44	352.19	346.45	340.40	340.37	348.71	349.62	352.71	349.81
1988	354.87	356.23	356.56	357.40	356.83	355.27	348.43	343.10	345.87	350.59	354.28	357.86	353.11
1989	360.88	358.16	359.15	359.27	358.74	357.04	349.34	344.48	346.18	351.19	355.81	358.29	354.88
1990	359.81	359.85	361.24	361.04	360.48	356.77	349.49	345.74	346.37	353.81	356.63	359.21	355.87
1991	360.82	362.09	361.16	361.73	361.52	359.80	353.69	347.44	348.28	356.21	358.34	360.87	357.66
1992 ^b	361.62	362.21	362.48	362.55	362.77	360.42	353.58	347.09	347.69	353.66	357.24	361.05	357.70

^aAtmospheric CO₂ mixing ratios are expressed in parts per million by volume (ppmv) and reported in the Scripps Institution of Oceanography X85 manometric mole fraction scale. Monthly means are derived from hourly and daily means that represent baseline (background) conditions. Annual means are the arithmetic means of the monthly values calculated by CDIAC. Annual means are provided only for years with complete monthly records.

^bData for 1992 are preliminary and subject to change.

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Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL
continuous monitoring network

K.W. Thoning, P.P. Tans, and L.S. Waterman (continued)

MAUNA LOA

Trends

Since 1976 the annual CO₂ concentration at Mauna Loa has risen from 332.04 parts per million by volume (ppmv) to 356.20 ppmv in 1992. Thoning et al. (1989) reported that the amplitude of the seasonal cycle at Mauna Loa was 0.05 ± 0.02 ppm/year and the annual growth rate was 1.42 ± 0.02 ppm/year for 1974–85. In comparison, Conway et al. (1988) reported a growth rate of 1.21 ppmv per year for the flask-sampling data from Mauna Loa for 1981–84. Thoning et al. (1989) also compared the Mauna Loa continuous CO₂ data with the CO₂ flask sample data from the sea level site at Cape Kumukahi, Hawaii, and found that the seasonal cycle at Cape Kumukahi was 23% larger than that at Mauna Loa, with the phase of the cycle at Mauna Loa lagging the cycle at Cape Kumukahi by about 1–2 weeks.

Monthly atmospheric CO₂ mixing ratios at Mauna Loa.

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Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL continuous monitoring network

K.W. Thoning, P.P. Tans, and L.S. Waterman (continued)

MAUNA LOA

Mauna Loa
Hawaii, U.S.A.
Barren volcanic slope
19°32' N, 155°35' W
3397 m above MSL

Atmospheric Mixing Ratios of CO₂

CO₂ mixing ratios^a at Mauna Loa (ppmv)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1974					333.15	332.07	330.99	329.17	327.39	327.25	328.26	329.51	
1975	330.69	331.41	331.84	333.26	333.92	333.39	331.81	329.90	328.56	328.45	329.29		
1976	331.65	332.66	333.53	334.80	334.80	334.14	332.88	330.64	329.01	328.62	330.13	331.63	332.04
1977	332.74	333.23	334.91	336.01	336.82	336.13	334.75	332.53	331.27	331.21	332.36	333.47	333.79
1978	334.74	335.22	336.52	337.77	338.00	338.04	336.39	334.33	332.35	332.33	333.77	334.80	335.36
1979	336.20	336.65	337.79	338.95	339.03	339.22	337.58	335.51	333.83	334.05	335.26	336.70	336.73
1980	337.81	338.26	340.07	340.87	341.48	341.30	339.36	337.84	335.98	336.07	337.22	338.33	338.72
1981	339.35	340.47	341.73	342.47	343.02	342.46	340.78	338.61	337.04	337.13	338.49	339.85	340.12
1982	340.93	341.67	342.78	343.71	344.31	343.41	341.96	339.79	337.91	338.10	339.27	340.67	341.21
1983	341.45	342.69	343.42	345.17	345.79	345.40	343.99	342.00	340.02	340.16	341.39	343.01	342.87
1984	343.92	344.64	345.18	347.10	347.45	346.80	345.44	343.24	341.25	341.49	342.84	344.37	344.48
1985	345.03	345.89	347.47	348.02	348.73	348.11	346.59	344.59	343.01	342.88	344.19	345.64	345.85
1986	346.48	346.98	347.94	349.60	350.40	349.74	347.80	345.89	344.80	344.31	345.67	346.87	347.21
1987	348.23	348.50	349.58	351.10	351.87	351.46	349.80	347.73	346.38	346.49	347.71	348.93	348.98
1988	350.19	351.50	352.11	353.51	354.16	353.60	352.61	350.32	348.81	348.96	350.09	351.32	351.43
1989	352.72	353.16	353.71	355.42	355.67	355.14	353.81	351.40	349.80	350.04	351.28	352.63	352.90
1990	353.65	354.81	355.56	356.10	357.04	356.06	354.45	352.67	350.97	351.28	352.73	354.16	354.12
1991	354.64	355.53	357.05	358.42	358.98	357.99	356.07	353.77	352.20	352.20	353.64	354.93	355.45
1992 ^b	356.02	356.79	357.60	358.75	359.33	359.15	356.68	354.74	352.76	353.16	354.09	355.34	356.20

^aAtmospheric CO₂ mixing ratios are expressed in parts per million by volume (ppmv) and reported in the Scripps Institution of Oceanography X85 manometric mole fraction scale. Monthly means are derived from hourly and daily means that represent baseline (background) conditions. Annual means are the arithmetic means of the monthly values calculated by CDIAC. Annual means are provided only for years with complete monthly records.

^bData for 1992 are preliminary and subject to change.

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Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL
continuous monitoring network

K.W. Thoning, P.P. Tans, and L.S. Waterman (continued)

SAMOA

Trends

Since 1976 the annual atmospheric CO₂ concentration at Cape Matatula has risen from 331.45 parts per million by volume (ppmv) to 354.86 ppmv in 1992. Waterman et al. (1989) found that the average growth rate of CO₂ at Cape Matatula for 1976–87 was 1.44 ppmv per year and stated that the interannual variability of the CO₂ growth rate correlates very well with that observed at other CMDL sites. In comparison, Conway et al. (1988) reported a growth rate of 1.35 ppmv per year for the flask-sampling data from American Samoa for 1981–84. Waterman et al. (1989) indicated that the Cape Matatula record is characterized by the lack of a prominent seasonal cycle, with CO₂ concentrations for the first half of each year being more variable than those for the latter half of each year, when the wind flow is dominated by strong southeasterly trades. This record is considered indicative of maritime air for the central pacific region of the Southern Hemisphere.

Monthly atmospheric CO₂ mixing ratios at Samoa.

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Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL continuous monitoring network

K.W. Thoning, P.P. Tans, and L.S. Waterman (continued)

SAMOA

Samoa (Cape Matatula)
U.S. Territory
Pacific Ocean
An ancient barren lava flow atop
an island rocky promontory
14°15' S, 170°34' W
30 m above MSL

Atmospheric Mixing Ratios of CO₂

CO₂ mixing ratios^a at Samoa (ppmv)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1976	332.24	331.90	331.32	331.09	330.67	331.17	331.14	331.15	331.29	331.45	332.03	331.93	331.45
1977	331.82	331.95	332.05	332.09	332.60	332.67	332.23	333.03	332.82	333.16			
1978		334.76	335.15	335.33	335.00	335.15	335.00	335.76	335.75				
1979		336.13	335.86	336.57	335.81	336.03	336.28	336.33	336.32	336.62	336.73	336.87	
1980	337.44	337.60	337.89	337.34	337.77	337.99	338.39	338.30	338.19	338.11	338.54	338.83	338.03
1981	339.04	339.25	338.98	339.51	338.72	339.27	338.99	339.09	339.11	338.90	339.42	339.83	339.18
1982	340.39	340.38	340.33	340.20	339.99	339.87	340.55	340.71	340.36	339.90	340.31	340.23	340.27
1983	340.41	340.61	340.82	340.67	341.20	341.70	341.94	342.05	342.05	342.18	342.53	342.75	341.58
1984	343.08	343.39	343.45	343.37	342.47	342.85	343.20	343.33	343.39	343.37	343.46	344.07	343.29
1985	344.05	344.50	344.56	344.41	344.74	344.41	344.77	344.69	344.41	344.39	344.76	345.23	344.58
1986	345.56	345.71	345.76	345.85	345.55	346.29	346.23	345.89	345.98	346.06	346.05	346.21	345.93
1987	346.58	346.94	346.80	346.44	347.89	347.83	348.24	347.76	347.93	348.06	348.23	348.79	347.62
1988	349.30	349.75	349.67	350.63	349.62	349.65	349.93	349.97	349.59	349.92	350.40	351.03	349.96
1989	351.38	351.70	351.47	351.48	351.75	350.82	351.13	351.23	351.12	351.23	351.61	351.59	351.38
1990	352.20	353.10			352.08	352.78	352.64	352.71	352.77	352.59	352.74	353.26	
1991	353.84	354.52	354.17	353.55	353.48	353.95	353.91	353.58	353.54	353.65	354.26	354.69	353.93
1992 ^b	354.20	354.56	354.78	354.58	354.63	354.87	355.35	355.31	354.96	355.05	354.78	355.25	354.86

^aAtmospheric CO₂ mixing ratios are expressed in parts per million by volume (ppmv) and reported in the Scripps Institution of Oceanography X85 manometric mole fraction scale. Monthly means are derived from hourly and daily means that represent baseline (background) conditions. Annual means are the arithmetic means of the monthly values calculated by CDIAC. Annual means are provided only for years with complete monthly records.

^bData for 1992 are preliminary and subject to change.

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Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL
continuous monitoring network

K.W. Thoning, P.P. Tans, and L.S. Waterman (continued)

SOUTH POLE

Trends

Since 1975, annual atmospheric CO₂ mixing ratios at the South Pole Observatory (SPO) have risen from 329.33 parts per million by volume (ppmv) to 353.74 ppmv in 1992.

Gillette et al. (1987) reported that, except for 1976, the continuous data from SPO for 1975–82 showed good agreement with the SIO and CMDL flask data collected at the South Pole and with the results of the Australian Commonwealth Scientific and Industrial Research Organisation aircraft monitoring program.

Gillette et al. (1987) found that the average growth rate of CO₂ at the South Pole for 1975–82 was 1.32 ± 0.66 ppm per year and that the amplitude of the seasonal cycle ranged from 1.59 ± 0.36 before 1979 to 1.02 ± 0.18 ppm after 1979. For comparison, Conway et al. (1988) reported a growth rate of 1.22 ppm per year for the CMDL flask sampling data from the South Pole for 1981–84.

Monthly atmospheric CO₂ mixing ratios at the South Pole.

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Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL continuous monitoring network

K.W. Thoning, P.P. Tans, and L.S. Waterman (continued)

SOUTH POLE

South Pole
Antarctica
Ice and snow-
covered plateau
89°59' S, 24°48' W
2810 m above MSL

Atmospheric Mixing Ratios of CO₂

CO₂ mixing ratios^a at South Pole (ppmv)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1975	329.10	328.80	328.47	328.32	328.60	328.64	329.37	329.80	330.10	330.30	330.20	330.25	329.33
1976	330.05	329.76	329.64	329.64	329.70	329.91	330.29	330.70	331.01	331.12	331.09	331.14	330.34
1977	330.89	330.32	330.27	330.64	331.00	331.39	331.81	332.24	332.70	332.98	332.98	332.74	331.66
1978	332.56	332.38	332.29	332.51	332.95	333.31	333.84	334.44	334.93	335.02	334.87	334.70	333.65
1979													
1980	336.13	335.96	336.00	336.22	336.60	336.93	337.38	337.65	337.90	338.09	338.04	338.03	337.08
1981	337.84	337.77	337.88	337.91	338.07	338.29	338.72	338.95	339.17	339.13	338.93	338.50	338.43
1982	338.45	338.60	338.37	338.56	338.88	338.93	339.24	339.61	339.86	339.77	339.52	339.24	339.09
1983	339.67	339.61	339.71	340.05		340.88	341.15	341.85	342.08	342.16	342.23	342.04	
1984	341.90	341.86	341.65	341.73	341.88	342.08	342.52	343.05	343.35	343.44	343.24	343.02	342.48
1985	343.13	342.94	342.81	342.96	343.27	343.58	344.06	344.53	344.76	344.78	344.84	344.58	343.85
1986	344.53	344.41	344.39	344.47	344.60	344.89	345.37	345.77	346.03	346.23	345.98	345.76	345.20
1987	345.72	345.55	345.54	345.72	345.95	346.41	346.92	347.47	347.94	348.02	348.17	348.10	346.79
1988	348.06	347.92	347.98	348.18	348.28	348.50	348.89	349.33	349.63	349.70	349.70	349.69	348.82
1989	349.62	349.68	349.60	349.68	349.92	350.22	350.58	351.00	351.08	351.24	351.29	350.87	350.40
1990	350.76	350.57	350.64	350.91	351.25	351.58	352.06	352.40	352.70	352.74	352.74	352.30	351.72
1991	351.97	351.66	351.50	351.77	352.03	352.38	352.81	353.22	353.37	353.32	353.46	353.33	352.57
1992 ^b	353.05	352.80	352.68	352.90	353.25	353.65	354.09	354.47	354.66	354.67	354.49	354.22	353.74

^aAtmospheric CO₂ mixing ratios are expressed in parts per million by volume (ppmv) and reported in the Scripps Institution of Oceanography X85 manometric mole fraction scale. Monthly means are derived from hourly and daily means that represent baseline (background) conditions. Annual means are the arithmetic means of the monthly values calculated by CDIAC. Annual means are provided only for years with complete monthly records.

^bData for 1992 are preliminary and subject to change.

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Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL
continuous monitoring network

K.W. Thoning, P.P. Tans, and L.S. Waterman (continued)

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Atmospheric CO₂ records from sites in the NOAA/CMDL
continuous monitoring network

K.W. Thoning, P.P. Tans, and L.S. Waterman (continued)

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Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL
air sampling network

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Alert • Amsterdam Island • Ascension Island • Azores • Barbados • Barrow •
Bermuda (East) • Bermuda (West) • Cape Grim • Cape Kumukahi • Cape
Meares • Christmas Island • Cold Bay • Guam • Halley Bay • Izaña • Key
Biscayne • Mace Head • Mauna Loa • Midway Islands • Mould Bay •
Niwt Ridge • Pacific Ocean • Palmer Station • Qinghai Province • Samoa •
Seychelles • Shemya Island • South Pole • Station "C" • Station "M" • Syowa
Station • Tae-ahn Peninsula • Ulaan Uul • Virgin Islands

Period of Record

1968–92 (varies by site)

Methods

Starting in 1968, air samples were collected in cylindrical glass flasks tapered at both ends to ground glass stopcocks lubricated with hydrocarbon grease. At several sites from 1980 to 1985 samples were also collected in spherical 5-L flasks equipped with a single ground glass stopcock. These flasks were filled by the evacuation method described below. In 1983, measurements of CH₄ in the flask samples were begun. Experiments at this time revealed

Sites in the NOAA/CMDL air sampling network.

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Atmospheric CO₂ records from sites in the NOAA/CMDL
air sampling network

T.J. Conway, P.P. Tans, and L.S. Waterman (continued)

that CO mixing ratios increased with time in the greased flasks. In 1989, 0.5-L glass flasks equipped with glass piston Teflon O-ring stopcocks were introduced into the network so CO could be measured in addition to CO₂ and CH₄. In 1990, measurements of ¹³C/¹²C and ¹⁸O/¹⁶O of CO₂ in the flask samples were begun. The precision of the isotopic measurements was better with larger volume flasks, so in 1991 2.5-L glass flasks with two Teflon O-ring stopcocks began to replace the 0.5-L flasks. In 1994, the conversion of the network to 2.5-L flasks will be completed.

Flasks samples are always collected in pairs, once or twice per week, on a schedule determined largely by the sample collector. The sample collectors have been given guidelines concerning preferred wind speeds, directions, and time of day for sample collection. Whole air samples are collected with no attempt to remove water vapor. Samples are dried during analysis using a cryogenic trap at -70°C.

From 1968 to 1980, collectors used a hand-held aspirator bulb to pull air through the flasks. In 1980, a portable battery powered pumping unit was introduced. This method allowed the sample collector to move downwind while the flasks, connected in series, were being flushed, enabled pressurization of the flasks, and incorporated an intake line that could be extended to 2 m above the ground. This device resulted in improved agreement between members of flask pairs and decreased scatter in the measurements. To avoid artifacts due to this inhomogeneity in the data quality, most CMDL analyses of the flask data begin with the 1981 data.

The sampling method changed again in mid-1990 when an improved portable sampler was introduced. While the sampling principles were unchanged, the new sampler employed a single, larger battery; a more rugged, higher capacity pump; a 5-m intake line; and a back pressure regulator to control the pressure in the flasks.

The effect of the flask and sampler improvements has been an increase in the percentage of sample pairs meeting a CO₂ agreement criterion of 0.5 ppm, from ~75% in the mid-1980s to ~90% in 1992. However, overlapped sampling was conducted at several sites and no offsets due to the new flasks or sampling equipment were observed.

At Barrow, Niwot Ridge, Mauna Loa, Cape Kumukahi, Christmas Island, and Samoa, flask samples have also been collected in evacuated 3-L flasks. This type of flask is also used on the container ships making regular voyages in the Pacific Ocean between Los Angeles and New Zealand. In this method two flasks are filled in rapid succession by holding the flask into the wind, purging the dead volume in the inlet to the flask, opening the stopcock, and allowing the flask to fill with air to ambient atmospheric pressure. In overlapped sampling at Mauna Loa and Niwot Ridge, no significant difference was found between the 3-L flasks and the pressurized flasks. At Barrow and Cape Kumukahi, there is an indication of an offset of ~0.3 ppm, with the evacuated flasks generally being higher.

From 1968 until 1980, flask samples were measured by transferring the air from the flasks to a nondispersive infrared analyzer (NDIR) manually by means of a mercury displacement pump (Komhyr et al. 1983). In 1980, this apparatus was replaced by a semiautomatic

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Atmospheric CO₂ records from sites in the NOAA/CMDL
air sampling network

T.J. Conway, P.P. Tans, and L.S. Waterman (continued)

analysis apparatus described by Komhyr et al. (1983). In 1988, this system was replaced by a more highly automated system that was capable of higher precision CO₂ measurements and able to handle up to three times as many flasks per analysis day.

All the CMDL CO₂ measurements are reported in the WMO X85 mole fraction scale. The CMDL measurements are made using standard gases traceable to the WMO Central CO₂ Laboratory operated by C.D. Keeling at Scripps Institution of Oceanography (Thoning et al. 1987). From 1968 to 1980, the working standard gases consisted of CO₂ in N₂. From 1980 to 1990, the secondary standards were CO₂ in natural air and the tertiary and working gases were CO₂ in synthetic air (N₂, O₂, and Ar) (Komhyr et al. 1985a). Since 1990, only CO₂ in natural air standards have been used.

The data selection methods used to obtain the values from which monthly and annual means are calculated have been discussed in detail by Komhyr et al. (1985a), Conway et al. (1988), and Conway et al. (1994), so only a brief description will be given here. First, both members of sample pairs are flagged when the CO₂ difference between them is greater than 0.5 ppm. Prior to 1989, one value of a bad pair was sometimes retained, based on the results of the curve-fitting procedure described below. Since 1989, both members of bad pairs are automatically rejected. Samples that are affected by improper sampling techniques, or analytical problems are also flagged as rejected data. At this point a curve is fit to the remaining data, and values lying more than ± 3 residual standard deviations from the curve are flagged as not representing well mixed, regionally representative air masses. The curve-fitting procedure is repeated until no more samples are flagged. The fitted curves are then used to calculate monthly and annual means. Most analyses of the NOAA/CMDL flask CO₂ data use only the retained data, but the samples flagged as not representative of background conditions may still contain useful information.

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Atmospheric CO₂ records from sites in the NOAA/CMDL air sampling network

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ALERT

Trends

The NOAA/CMDL sampling site at Alert is operated in cooperation with the Atmospheric Environment Service (AES) of Environment Canada. The NOAA/CMDL flask data from Alert show an increase in the annual mixing ratio from 348.4 parts per million (ppm) in 1986 to 357.6 ppm in 1992. Conway et al. (1994) reported a mean global growth rate of 1.4 ppm per year based on the NOAA/CMDL flask network data from 1981 to 1992. Trivett and Higuchi (1989) reported an annual growth rate of 1.49 ppm based on the AES flask sampling program at Alert. Alert is the northernmost site in the NOAA/CMDL network. The Alert data are consistent with previous results (Komhyr et al. 1985a; Conway et al. 1988) showing that annual mean CO₂ mixing ratios are highest at high northern latitudes and decrease toward the equator.

Monthly atmospheric CO₂ mixing ratios at Alert.

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Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL
air sampling network

T.J. Conway, P.P. Tans, and L.S. Waterman (continued)

Alert
Northwest Territories, Canada
Tundra
82°27' N, 62°31' W
210 m above MSL

ALERT

Atmospheric Mixing Ratios of CO₂

CO₂ mixing ratios^a at Alert (ppm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1985						350.0	343.8	337.7	339.0	342.8	345.5	348.8	
1986	351.2	352.0	352.6	353.0	353.1	351.3	345.6	340.2	339.8	344.3	347.8	349.6	348.4
1987	350.9	352.2	353.3	353.9	354.1	352.7	347.8	341.6	341.7	346.3	350.2	352.5	349.8
1988	354.3	355.4	356.5	357.3	357.2	355.2	349.9	344.6	345.4	350.3	353.9	355.8	353.0
1989	357.7	359.3	360.1	359.6	359.0	357.6	351.9	345.7	346.4	350.6	355.5	358.9	355.2
1990	359.5	359.6	360.5	360.7	360.2	357.2	350.9	346.2	346.6	351.3	355.7	358.2	355.6
1991	360.4	361.3	361.4	361.7	361.4	359.8	353.8	347.5	348.0	352.5	357.1	361.1	357.2
1992	362.6	362.6	363.2	362.9	362.7	361.3	353.9	346.8	347.4	352.0	356.2	359.8	357.6

^aAtmospheric CO₂ mixing ratios are expressed in parts per million (ppm) and reported in the Scripps Institution of Oceanography X85 manometric mole fraction scale. These monthly values were calculated by using a method combining a fit of a four-harmonic function and a quadratic trend with digital filtering of the residuals to obtain a smooth curve. The monthly means were then actually calculated by using weekly values from the curve.

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AMSTERDAM ISLAND

Trends

The sampling site on Amsterdam Island is operated in cooperation with the French Centre des Faibles Radioactivités. Except during the summer (December–February), when this island is within the wind regime of the westerlies, the monthly mean mixing ratios from Amsterdam Island can be considered representative of the background subantarctic atmosphere (Gaudry et al. 1983).

The NOAA flask data from Amsterdam Island show an increase in the annual value from 341.1 parts per million (ppm) in 1983 to 350.5 ppm in 1989 or 1.6 ppm per year. Conway et al. (1994) reported a global growth rate of 1.43 ppm per year for 1981–92 for all NOAA/CMDL flask-sampling sites. Ascencio-Parvy et al. (1983) found a 0.11 ppm-per-month increase in atmospheric CO₂ concentrations at Amsterdam Island from October 1980 to November 1983. Both Conway et al. (1988) and Ascencio-Parvy et al. (1984) found considerable variability within each year and suggested that the growth rate minimum in 1982 and the growth rate maximum in 1983 may result partly from the 1982–83 El Niño event.

Monthly atmospheric CO₂ mixing ratios at Amsterdam Island.

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Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL
air sampling network

T.J. Conway, P.P. Tans, and L.S. Waterman (continued)

AMSTERDAM ISLAND

Amsterdam Island
Indian Ocean
Island seashore
37°52' S, 77°32' E
150 m above MSL

Atmospheric Mixing Ratios of CO₂

CO₂ mixing ratios^a at Amsterdam Island (ppm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1982			338.8	338.9	338.9	339.2	339.6	339.8	339.8	339.8	339.8	340.0	
1983	340.1	340.3	340.4	340.6	340.6	340.9	341.4	341.7	341.8	341.8	341.9	341.9	341.1
1984	342.0	342.4	342.1	341.5	341.4	341.9	342.8	343.0	342.7	342.6	342.8	343.2	342.4
1985	343.4	343.3	343.7	343.8	343.6	343.8	344.1	344.6	344.7	344.8	344.9	344.9	344.1
1986	345.0	345.2	345.2	344.8	344.7	345.2	345.6	345.9	346.0	346.2	346.5	346.5	345.6
1987	346.7	346.7	346.7	347.0	347.1	347.4	347.8	348.5	349.0	349.2	349.2	349.3	347.9
1988	349.2	349.0	348.8	348.8	349.0	349.5	350.0	350.1	350.0	350.0	349.9	349.9	349.5
1989	350.0	350.2	350.2	350.0	349.9	350.2	350.7	351.0	351.1	350.9	350.9	351.2	350.5
1990	351.8	352.3	351.8	351.4	352.0	352.7	353.1	353.2	353.3	353.4	353.5		

^aAtmospheric CO₂ mixing ratios are expressed in parts per million (ppm) and reported in the Scripps Institution of Oceanography X85 manometric mole fraction scale. These monthly values were calculated by using a method combining a fit of a four-harmonic function and a quadratic trend with digital filtering of the residuals to obtain a smooth curve. The monthly means were then actually calculated by using weekly values from the curve.

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ASCENSION ISLAND

Trends

The sampling site on Ascension Island is operated in cooperation with the U.S. Air Force and Pan American World Airways. The NOAA/CMDL flask data from Ascension Island show an increase in the annual value from 338.8 parts per million (ppm) in 1980 to 355.2 ppm in 1992, or 1.37 ppm per year. Conway et al. (1994) reported a 1.43-ppm per year mean annual growth rate during 1981–92 for all NOAA/CMDL flask sampling sites.

Atmospheric CO₂ mixing ratios at Ascension Island show a seasonal pattern. Conway et al. (1994) found that the seasonality at Ascension Island does not appear to be affected by transport of northern air and reported the peak-to-trough seasonal amplitude for Ascension Island was 2.0 ppm for 1981–92.

Monthly atmospheric CO₂ mixing ratios at Ascension Island.

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Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL
air sampling network

T.J. Conway, P.P. Tans, and L.S. Waterman (continued)

ASCENSION ISLAND

*Ascension Island
U.K. Territory
South Atlantic Ocean
Island seashore
7°55' S, 14°25' W
54 m above MSL*

Atmospheric Mixing Ratios of CO₂

CO₂ mixing ratios^a at Ascension Island (ppm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1979								337.6	337.4	337.2	337.9	338.4	
1980	338.2	337.9	337.9	338.4	338.8	339.4	339.7	339.7	339.4	339.0	338.8	338.8	338.8
1981	339.1	338.9	339.3	339.6	339.1	339.1	340.3	340.9	340.7	340.4	340.3	339.8	339.8
1982	339.7	339.9	340.0	340.7	341.1	340.8	340.9	341.4	341.4	341.2	340.9	340.6	340.7
1983	341.4	341.9	341.6	341.7	342.5	343.4	343.5	343.2	343.2	343.3	343.2	343.3	342.7
1984	343.3	342.6	342.4	342.7	343.4	344.2	345.1	345.2	344.3	344.5	345.0	344.2	343.9
1985	343.7	343.8	344.2	344.1	344.2	345.5	346.1	345.8	345.8	346.3	346.2	346.1	345.2
1986	345.9	345.1	344.4	344.8	345.6	346.2	347.1	347.4	347.0	346.8	347.0	346.7	346.2
1987	346.5	346.7	346.8	347.1	348.1	349.1	349.4	349.6	349.4	349.2	349.6	349.5	348.4
1988	349.2	349.4	349.3	349.1	349.6	350.8	351.5	351.3	351.2	351.2	351.2	351.3	350.4
1989	351.4	351.3	350.6	350.7	351.2	351.6	352.3	352.5	352.3	352.1	351.9	351.8	351.6
1990	351.8	351.7	351.2	351.8	352.7	353.0	353.7	354.2	354.0	353.9	353.9	353.4	352.9
1991	353.4	353.5	352.9	352.5	353.2	354.0	354.4	354.7	354.4	354.7	354.8	354.4	353.9
1992	354.2	354.0	354.0	354.5	355.1	355.5	356.1	356.1	355.8	355.8	355.6	355.1	355.2

^aAtmospheric CO₂ mixing ratios are expressed in parts per million (ppm) and reported in the Scripps Institution of Oceanography X85 manometric mole fraction scale. These monthly values were calculated by using a method combining a fit of a four-harmonic function and a quadratic trend with digital filtering of the residuals to obtain a smooth curve. The monthly means were then actually calculated by using weekly values from the curve.

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AZORES

Trends

The NOAA/CMDL sampling site in the Azores is located on Terceira Islands and is operated in cooperation with the 7th Weather Wing of the U.S. Air Force. The NOAA/CMDL flask data from the Azores show an increase in the annual mixing ratio from 339.0 parts per million (ppm) in 1980 to 355.9 ppm in 1991, or 1.54 ppm per year. Conway et al. (1994) reported a global growth rate of 1.43 ppm per year during 1981–92 for all NOAA/CMDL flask-sampling sites.

Conway et al. (1988) found that the average peak-to-peak amplitude at the Terceira Islands sampling site during 1981–84 was 10.15 ppm. Unlike the majority of stations in the NOAA/CMDL flask-sampling network during 1981–84, the data from the Azores did not show a growth rate minimum in 1982 and a growth rate maximum in 1983. Instead, the data from the Terceira Islands sampling site exhibited large oscillations in growth rate throughout the data record.

Monthly atmospheric CO₂ mixing ratios at the Azores.

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Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL
air sampling network

T.J. Conway, P.P. Tans, and L.S. Waterman (continued)

AZORES

*Azores (Terceira Island)
North Atlantic Ocean
Island seashore
38°45' N, 27°05' W
30 m above MSL*

Atmospheric Mixing Ratios of CO₂

CO₂ mixing ratios^a at Terceira Islands, Azores (ppm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1979												339.2	
1980	340.2	341.7	342.3	342.1	341.8	340.4	337.2	334.3	333.6	335.9	338.7	340.0	339.0
1981	340.4	342.0	343.7	344.2	343.5	340.3	336.8	334.5	333.9	336.2	338.6	340.6	339.6
1982	342.0	343.4	345.3	346.2	345.1	342.2	336.3	332.5	335.0	339.2	343.2	344.5	341.2
1983	345.0	345.7	345.3	345.5	345.3	343.7	341.5	338.4	337.3	339.9	343.3	344.8	343.0
1984	346.5	348.1	347.5	346.8	347.8	345.3	340.9	339.0	339.2	341.5	344.7	346.4	344.5
1985	346.6	347.9	350.3	350.7	348.7	345.9	341.8	338.5	340.5	345.2	347.9	349.0	346.1
1986	349.6	349.3	349.5	350.7	350.6	350.1	348.2	345.7	345.3	347.3	349.3	349.0	348.7
1987	348.4	349.7	352.0	353.1	351.0	348.7	347.5	344.4	342.5	346.0	349.3	350.7	348.6
1988	352.2	353.1	353.2	354.0	353.3	351.6	350.2	347.9	346.6	349.3	353.1	354.6	351.6
1989	354.3	354.9	357.4	357.6	355.8	353.3							
1990										352.7	356.5	358.0	
1991	357.9	358.0	359.9	361.1	359.3	358.5	355.3	350.3	350.2	352.3	353.7	354.4	355.9
1992	355.4												

^aAtmospheric CO₂ mixing ratios are expressed in parts per million (ppm) and reported in the Scripps Institution of Oceanography X85 manometric mole fraction scale. These monthly values were calculated by using a method combining a fit of a four-harmonic function and a quadratic trend with digital filtering of the residuals to obtain a smooth curve. The monthly means were then actually calculated by using weekly values from the curve.

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BARBADOS

Trends

The monitoring site at Ragged Point, Barbados is operated with the help of P.G. Simmons of International Science Consultants. Annual atmospheric CO₂ mixing ratios at Ragged Point have risen from 351.6 parts per million (ppm) in 1988 to 356.0 ppm in 1992. The record from Ragged Point exhibits a seasonal cycle with the yearly minimum occurring in September or October and yearly maximum measured during April or May.

Monthly atmospheric CO₂ mixing ratios at Ragged Point, Barbados.

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Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL
air sampling network

T.J. Conway, P.P. Tans, and L.S. Waterman (continued)

Barbados (Ragged Point)
Atlantic Ocean
Island seashore
13°10' N, 59°26' W
3 m above MSL

BARBADOS

Atmospheric Mixing Ratios of CO₂

CO₂ mixing ratios^a at Barbados (ppm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1987											348.2	349.7	
1988	351.4	352.0	352.6	353.7	354.3	353.4	351.5	349.8	348.9	348.5	350.1	352.4	351.6
1989	353.6	353.7	354.4	355.2	355.6	355.2	353.2	350.5	349.4	349.6	351.1	352.9	352.9
1990	354.6	355.8	356.0	357.0	357.7	356.6	354.6	352.0	351.3	352.4	353.4	355.1	354.7
1991	356.1	356.5	357.7	358.9	358.7	358.1	356.1	353.1	352.2	352.8	354.0	356.1	355.9
1992	357.2	357.9	358.3	358.7	359.2	358.2	355.4	352.7	351.8	352.4	353.9	355.8	356.0

^aAtmospheric CO₂ mixing ratios are expressed in parts per million (ppm) and reported in the Scripps Institution of Oceanography X85 manometric mole fraction scale. These monthly values were calculated by using a method combining a fit of a four-harmonic function and a quadratic trend with digital filtering of the residuals to obtain a smooth curve. The monthly means were then actually calculated by using weekly values from the curve.

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BARROW

Trends

The NOAA/CMDL flask data from Point Barrow show an increase in the annual atmospheric CO₂ mixing ratio from 330.3 parts per million (ppm) in 1972 to 357.6 ppm in 1992, or 1.37 ppm per year. Conway et al. (1994) reported a global growth rate of 1.43 ppm per year during 1981–92 for all NOAA/CMDL flask-sampling sites.

Atmospheric CO₂ mixing ratios at Point Barrow show a seasonal pattern with the annual drawdown occurring in August and the annual maximum occurring in March–May. Conway et al. (1994) found that the average peak-to-peak amplitude for Point Barrow was 16.7 ppm for 1981–92.

Monthly atmospheric CO₂ mixing ratios at Barrow.

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Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL
air sampling network

T.J. Conway, P.P. Tans, and L.S. Waterman (continued)

Barrow
Alaska, U.S.A.
Arctic coastal seashore
71°19' N, 156°36' W
11 m above MSL

BARROW

Atmospheric Mixing Ratios of CO₂

CO₂ mixing ratios^a at Barrow (ppm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1971					332.2	330.2	323.7	317.7	318.7	322.9	327.3	331.1	
1972	333.4	334.2	334.1	334.5	335.3	333.3	325.7	319.1	322.0	327.3	330.7	333.5	330.3
1973	334.7	335.4	336.5	337.0	336.5	334.0	327.6	322.2	323.6	328.6	332.1	334.7	331.9
1974	337.0	337.8	337.8	337.6	338.7	338.1	330.6	323.1	323.7	329.0	333.3	335.7	333.5
1975	336.6	336.5	336.4	336.6	336.2	334.6	329.7	324.5	325.0	329.6	333.5	336.3	333.0
1976	337.5	337.8	338.5	338.9	338.1	335.7	330.0	324.8	325.1	329.6	333.1	336.0	333.8
1977	337.7	337.7	338.3	339.4	339.7	337.7	331.6	326.3	327.3	331.0	334.6	337.4	334.9
1978	339.9	341.0	341.0	341.1	340.9	338.9	333.4	327.4	327.7	332.4	337.1	339.0	336.7
1979	340.1	341.3	342.1	342.3	343.2	341.3	333.8	327.4	328.9	334.4	337.6	338.6	337.6
1980	341.0	342.7	343.3	344.3	345.1	342.9	337.3	332.2	332.5	337.0	340.6	343.0	340.2
1981	344.8	345.4	345.4	346.0	346.4	343.9	336.5	330.8	332.6	338.3	342.1	344.5	341.4
1982	346.2	347.3	347.8	347.6	347.6	345.6	339.6	333.3	333.2	338.4	342.3	344.9	342.8
1983	346.6	347.1	347.6	347.9	348.2	346.5	339.9	333.8	333.9	340.4	345.2	347.0	343.7
1984	349.0	350.4	349.9	349.7	350.3	348.4	341.4	335.9	337.5	341.4	344.9	348.1	345.6
1985	349.5	349.3	350.3	351.8	352.1	349.5	343.5	337.2	338.3	343.5	347.3	348.9	346.8
1986	350.7	352.9	353.4	353.1	353.0	350.3	344.0	338.8	341.9	347.5	350.3	352.0	349.0
1987	353.1	353.7	354.1	354.4	355.0	352.9	346.0	340.2	340.9	345.7	349.8	352.6	349.9
1988	355.6	357.0	357.2	357.8	357.6	354.9	348.1	343.1	345.0	350.5	355.0	358.1	353.3
1989	359.0	358.6	359.7	360.1	359.4	358.4	350.9	342.7	345.1	351.6	355.9	359.3	355.1
1990	360.6	361.0	361.6	361.6	361.4	356.7	348.5	344.5	346.8	352.7	356.5	359.8	356.0
1991	361.7	361.7	362.1	362.1	361.8	360.0	353.6	346.7	348.3	354.6	358.5	360.5	357.6
1992	361.8	362.0	362.3	362.7	362.5	360.1	353.9	347.2	348.1	352.6	356.7	360.7	357.6

^aAtmospheric CO₂ mixing ratios are expressed in parts per million (ppm) and reported in the Scripps Institution of Oceanography X85 manometric mole fraction scale. These monthly values were calculated by using a method combining a fit of a four-harmonic function and a quadratic trend with digital filtering of the residuals to obtain a smooth curve. The monthly means were then actually calculated by using weekly values from the curve.

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BERMUDA (EAST)

Trends

The sampling site on the eastern end of the island of Bermuda at St. David's Head is operated as part of the Atmosphere/Ocean Chemistry Experiment (AEROCE). The first NOAA/CMDL flask air samples from St. David's Head were collected in early 1989. Since 1990, annual mixing ratios have risen from 355.2 parts per million (ppm) to 357.1 ppm in 1992. This 1992 annual mixing ratio is comparable to other North Atlantic measurements (e.g., 356.5 ppm at Station "M"). The atmospheric CO₂ mixing ratio records from Bermuda show a seasonal pattern: minimum mixing ratios are measured during the late northern summer, and maximum values, during the late winter and early spring.

Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL
air sampling network

T.J. Conway, P.P. Tans, and L.S. Waterman (continued)

BERMUDA (EAST)

Bermuda (East, St. David's Head)
U.K.

Rocky seashore
32°22' N, 64°39' W
30 m above MSL

Atmospheric Mixing Ratios of CO₂

CO₂ mixing ratios^a at Bermuda (East) (ppm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1989		356.6	357.4	358.0	355.9	352.8	351.5	349.5	349.3	352.3	355.2	356.7	
1990	356.9	357.5	358.4	359.0	357.1	354.4	352.2	349.7	350.0	353.9	356.1	356.7	355.2
1991	357.9	358.9	359.7	360.8	359.9	356.9	355.0	351.5	349.1	353.0	355.5	356.1	356.2
1992	359.0	360.6	360.5	360.7	359.3	356.6	355.7	353.5	350.8	353.6	356.8	357.9	357.1

^aAtmospheric CO₂ mixing ratios are expressed in parts per million (ppm) and reported in the Scripps Institution of Oceanography X85 manometric mole fraction scale. These monthly values were calculated by using a method combining a fit of a four-harmonic function and a quadratic trend with digital filtering of the residuals to obtain a smooth curve. The monthly means were then actually calculated by using weekly values from the curve.

CITE AS: Conway, T.J., P.P. Tans, and L.S. Waterman. 1994. Atmospheric CO₂ records from sites in the NOAA/CMDL air sampling network. pp. 41-119. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

BERMUDA (WEST)

Trends

The sampling site on the western end of the island of Bermuda at Southampton is operated in cooperation with AEROCE and the Bermuda Biological Station. The first NOAA/CMDL flask air samples from Southampton were collected in mid 1989. Since 1990, annual mixing ratios have risen from 355.1 parts per million (ppm) to 356.2 ppm in 1992. This 1992 annual mixing ratio is comparable to other North Atlantic measurements (e.g., 356.5 ppm at Station "M"). The atmospheric CO₂ mixing ratio records from Bermuda show a seasonal pattern: minimum mixing ratios are measured during the late northern summer, and maximum values are observed during the late winter and early spring.

Monthly atmospheric CO₂ mixing ratios at Bermuda (West).

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Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL
air sampling network

T.J. Conway, P.P. Tans, and L.S. Waterman (continued)

BERMUDA (West)

Bermuda (West, Southampton)
U.K.
Promontory seashore
32°16' N, 64°53' W
30 m above MSL

Atmospheric Mixing Ratios of CO₂

CO₂ mixing ratios^a at Bermuda (West) (ppm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1989					357.2	354.2	350.8	349.6	351.1	351.9	352.8	354.8	
1990	355.6	356.5	357.9	359.1	358.6	354.5	352.3	351.4	349.9	352.9	356.2	356.0	355.1
1991	357.4	358.2	359.8	361.6	360.0	358.1	356.4	350.7	349.4	354.9	356.3	357.1	356.7
1992	359.3	359.9	360.7	360.2	358.8	358.6	356.1	348.6	347.2	353.0	355.7	356.7	356.2

^aAtmospheric CO₂ mixing ratios are expressed in parts per million (ppm) and reported in the Scripps Institution of Oceanography X85 manometric mole fraction scale. These monthly values were calculated by using a method combining a fit of a four-harmonic function and a quadratic trend with digital filtering of the residuals to obtain a smooth curve. The monthly means were then actually calculated by using weekly values from the curve.

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Atmospheric CO₂ records from sites in the NOAA/CMDL air sampling network

T.J. Conway, P.P. Tans, and L.S. Waterman (continued)

CAPE GRIM

Trends

The sampling site at Cape Grim, Tasmania, is operated in cooperation with Graeme Pearman and Paul Fraser of the Commonwealth Scientific and Industrial Research Organisation's (CSIRO's) Division of Atmospheric Research. Cape Grim replaced Kaitorete Spit, New Zealand, in the NOAA/CMDL network after it was established that Cape Grim was a more suitable site for representative measurements at that latitude (Conway et al. 1988). From the outset of this cooperative program, samples have been taken in 0.5-L flasks. However, two sampling procedures have been used. One of the procedures is followed at all of the NOAA/CMDL flask sampling sites, as detailed in Komhyr et al. (1985a) and Conway et al. (1988). In the second procedure, the air samples are dried by passage through a glass column packed with anhydrous, granular magnesium perchlorate, as detailed in CSIRO (1989).

From 1985 to 1992, annual average mixing ratios of CO₂ at Cape Grim, calculated on the basis of undried air samples, rose from 343.5 parts per million (ppm) to 353.5 ppm. This represents an annual increase of 1.43 ppm at Cape Grim in comparison with the increase of 1.43 ppm per year reported by Conway et al. (1994) for all NOAA/CMDL flask sampling sites from 1981–92.

Monthly atmospheric CO₂ mixing ratios at Cape Grim.

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Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL
air sampling network

T.J. Conway, P.P. Tans, and L.S. Waterman (continued)

Cape Grim
Tasmania, Australia
Promontory seashore
40°41' S, 144°41' E
94 m above MSL

CAPE GRIM

Atmospheric Mixing Ratios of CO₂

CO₂ mixing ratios^a at Cape Grim (ppm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1984				341.4	341.6	341.8	342.7	343.4	343.2	342.9	342.9	342.7	
1985	342.5	342.5	342.6	342.7	342.9	343.3	343.9	344.4	344.5	344.4	344.2	344.1	343.5
1986	344.0	344.1	344.2	344.1	344.3	344.7	345.1	345.2	345.4	345.8	345.9	345.6	344.9
1987	345.2	345.2	345.4	345.7	346.2	346.5	346.6	347.1	347.5	347.7	347.6	347.3	346.5
1988	347.5	348.0	348.1	348.0	348.3	348.7	349.2	349.9	349.8	349.5	349.6	349.5	348.8
1989	349.6	349.8	349.8	349.8	350.1	350.4	350.2	350.5	350.9	350.8	350.7	350.6	350.3
1990	350.6	350.5	350.4	350.9	351.2	351.3	351.8	352.2	352.4	352.5	352.4	352.2	351.5
1991	352.5	352.5	352.2	352.5	352.7	352.8	353.0	353.4	353.2	352.8	352.8	352.7	352.8
1992	352.4	352.3	352.4	352.8	353.3	353.6	353.9	354.3	354.5	354.4	354.2	354.0	353.5

^aAtmospheric CO₂ mixing ratios are expressed in parts per million (ppm) and reported in the Scripps Institution of Oceanography X85 manometric mole fraction scale. These monthly values were calculated by using a method combining a fit of a four-harmonic function and a quadratic trend with digital filtering of the residuals to obtain a smooth curve. The monthly means were then actually calculated by using weekly values from the curve.

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CAPE KUMUKAHI

Trends

The NOAA/CMDL flask data from Cape Kumukahi show an increase in the annual value from 334.3 parts per million (ppm) in 1977 to 356.3 ppm in 1992 or 1.47 ppm per year. Conway et al. (1994) reported a global growth rate of 1.43 ppm per year during 1981–92 for all NOAA/CMDL flask sampling sites.

Atmospheric CO₂ concentrations at Cape Kumukahi show a seasonal pattern: the annual minimum mixing ratios are recorded in September, and the annual buildup occurs in the spring. Conway et al. (1994) reported that the peak-to-trough seasonal amplitude for Cape Kumukahi was 8.5 ppm during 1981–92.

Monthly atmospheric CO₂ mixing ratios at Cape Kumukahi.

CITE AS: Conway, T.J., P.P. Tans, and L.S. Waterman. 1994. Atmospheric CO₂ records from sites in the NOAA/CMDL air sampling network. pp. 41–119. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL
air sampling network

T.J. Conway, P.P. Tans, and L.S. Waterman (continued)

CAPE KUMUKAHI

*Cape Kumukahi
Hawaii, U.S.A.
Island seashore
19°31' N, 154°49' W
3 m above MSL*

Atmospheric Mixing Ratios of CO₂

CO₂ mixing ratios^a at Cape Kumukahi (ppm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1976			334.0	335.7	336.4	334.6	331.4	328.9	328.6	330.1	331.9	332.6	
1977	333.7	334.4	334.9	336.8	337.9	336.5	334.8	332.8	331.1	331.5	333.0	334.3	334.3
1978	335.6	336.7	337.6	338.3	339.4	338.9	335.8	332.7	331.4	332.6	334.4	335.6	335.8
1979	337.1	338.6	339.3	339.9	341.2	340.1	336.6	334.3	333.2	334.3	336.9	337.3	337.4
1980							339.9	337.0	335.5	336.5	338.0	339.1	
1981	341.0	341.8	342.2	343.4	343.9	342.5	339.6	337.3	336.6	337.7	339.1	340.1	340.4
1982	341.5	342.8	343.7	344.5	344.9	343.5	340.8	338.5	336.8	337.5	339.5	340.9	341.2
1983	341.9	343.4	344.7	345.6	346.0	345.1	342.7	339.2	338.2	339.9	341.6	342.9	342.6
1984	344.1	345.2	346.2	347.5	347.9	346.7	343.8	340.5	340.2	341.4	342.9	344.6	344.3
1985	345.7	346.5	347.3	348.4	349.6	348.6	345.8	342.6	341.2	342.7	344.7	346.2	345.8
1986	347.2	347.6	348.4	349.4	350.0	349.2	346.7	344.4	343.3	343.8	345.9	347.5	347.0
1987	348.9	349.4	349.9	351.2	352.3	351.3	348.2	345.9	344.9	345.8	347.9	349.5	348.8
1988	350.8	351.9	352.7	354.0	354.8	353.8	351.5	348.4	347.5	349.4	350.6	351.8	351.4
1989	352.8	353.1	354.3	356.2	356.5	355.0	352.4	349.9	349.2	350.0	351.9	353.7	352.9
1990	354.6	355.7	356.4	357.1	357.3	355.6	353.4	351.6	350.2	351.0	353.2	354.9	354.3
1991	355.7	356.6	357.7	359.3	359.8	357.9	355.5	352.6	351.4	352.6	354.3	355.7	355.8
1992	357.4	358.3	358.6	359.4	359.8	358.1	355.6	353.3	351.7	352.8	354.9	356.2	356.3

^aAtmospheric CO₂ mixing ratios are expressed in parts per million (ppm) and reported in the Scripps Institution of Oceanography X85 manometric mole fraction scale. These monthly values were calculated by using a method combining a fit of a four-harmonic function and a quadratic trend with digital filtering of the residuals to obtain a smooth curve. The monthly means were then actually calculated by using weekly values from the curve.

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CAPE MEARES

Trends

The sampling site at Cape Meares is operated in cooperation with the Oregon Graduate Institute of Science and Technology. The NOAA/CMDL flask data from Cape Meares show an increase in the annual value from 343.0 parts per million (ppm) in 1983 to 356.5 ppm in 1992. This represents an increase of ~1.5 ppm per year in comparison with a global growth rate of 1.43 ppm per year reported by Conway et al. (1994) for all NOAA/CMDL flask sampling sites during 1981–92.

Atmospheric CO₂ mixing ratios at Cape Meares show a seasonal pattern: the annual minimum is recorded during August, and the annual maximum, during January–April.

Monthly atmospheric CO₂ mixing ratios at Cape Meares.

CITE AS: Conway, T.J., P.P. Tans, and L.S. Waterman. 1994. Atmospheric CO₂ records from sites in the NOAA/CMDL air sampling network. pp. 41–119. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL
air sampling network

T.J. Conway, P.P. Tans, and L.S. Waterman (continued)

CAPE MEARES

Cape Meares
Oregon, U.S.A.
Promontory seashore
45°29' N, 120°00' W
30 m above MSL

Atmospheric Mixing Ratios of CO₂

CO₂ mixing ratios^a at Cape Meares (ppm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1982			344.6	345.1	344.8	342.1	337.7	334.8	335.8	338.8	340.6	342.1	
1983	343.3	343.9	345.6	347.1	345.2	342.6	340.3	335.9	337.1	341.8	345.1	347.8	343.0
1984	347.5	347.0	348.1	348.7	347.7	343.3	339.8	339.9	341.0	341.9	344.8	349.4	344.9
1985	351.2	349.4	348.8	349.9	350.0	347.8	343.8	340.8	343.0	345.7	347.5	350.2	347.3
1986	351.9	351.6	350.9	350.7	350.9	349.5	342.7	340.4	345.1	346.5	347.9	350.3	348.2
1987	351.9	352.1	352.4	354.4	354.1	351.1	346.3	344.1	348.6	353.2	352.4	352.7	351.1
1988	354.6	355.5	355.8	356.3	355.7	353.3	349.5	346.8	348.2	349.9	351.6	354.8	352.7
1989	357.4	357.9	356.8	356.5	357.0	354.8	349.1	347.4	351.4	354.2	354.5	355.8	354.4
1990	357.0	357.1	358.3	358.8	357.7	355.1	351.5	349.6	351.2	353.8	356.4	358.3	355.4
1991	358.7	359.5	360.0	359.6	359.0	357.0	352.0	349.1	353.6	357.4	357.4	357.3	356.7
1992	359.6	361.2	360.5	359.6	359.8	357.6	352.1	347.4	348.9	353.8	356.9	360.0	356.5

^aAtmospheric CO₂ mixing ratios are expressed in parts per million (ppm) and reported in the Scripps Institution of Oceanography X85 manometric mole fraction scale. These monthly values were calculated by using a method combining a fit of a four-harmonic function and a quadratic trend with digital filtering of the residuals to obtain a smooth curve. The monthly means were then actually calculated by using weekly values from the curve.

CITE AS: Conway, T.J., P.P. Tans, and L.S. Waterman. 1994. Atmospheric CO₂ records from sites in the NOAA/CMDL air sampling network. pp. 41-119. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

CHRISTMAS ISLAND

Trends

The NOAA/CMDL sampling site on Christmas Island, located in the Kiribati island group in the western Pacific Ocean, is operated in cooperation with the Scripps Institution of Oceanography. The NOAA/CMDL flask data from Christmas Island show an increase in the annual atmospheric CO₂ mixing ratio from 346.0 parts per million (ppm) in 1985 to 356.5 ppm in 1992, or 1.5 ppm per year.

Monthly atmospheric CO₂ mixing ratios at Christmas Island.

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Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL
air sampling network

T.J. Conway, P.P. Tans, and L.S. Waterman (continued)

CHRISTMAS ISLAND

Christmas Island
Kiribati
Pacific Ocean
Island seashore
2°00' N, 157°18' W
3 m above MSL

Atmospheric Mixing Ratios of CO₂

CO₂ mixing ratios^a at Christmas Island (ppm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1984			345.7	346.7	346.5	345.5	345.2	344.6	343.8	343.5	344.0	345.0	
1985	345.4	345.9	346.8	347.1	347.1	347.0	346.4	345.7	345.1	344.5	345.0	346.1	346.0
1986	346.8	347.1	347.9	348.7	348.3	347.9	347.5	346.3	345.8	345.9	345.9	345.8	347.0
1987	346.6	348.0	348.9	349.9	350.4	349.8	349.1	348.7	348.5	348.1	348.2	349.5	348.8
1988	350.5	351.1	351.6	352.0	352.3	352.0	351.3	350.5	350.5	350.8	350.9	351.8	351.3
1989	353.0	353.8	354.7	354.6	353.7	353.6	353.7	353.1	352.3	352.0	352.2	352.7	353.3
1990	353.9	355.0	355.2	354.5	354.5	354.9	354.5	354.1	353.7	353.4	353.4	354.2	354.3
1991	355.0	355.5	356.3	356.5	356.2	356.3	355.8	354.7	353.9	354.1	354.8	355.2	355.4
1992	356.0	356.5	356.8	357.9	358.6	357.7	356.8	355.8	355.3	355.1	355.1	355.8	356.5

^aAtmospheric CO₂ mixing ratios are expressed in parts per million (ppm) and reported in the Scripps Institution of Oceanography X85 manometric mole fraction scale. These monthly values were calculated by using a method combining a fit of a four-harmonic function and a quadratic trend with digital filtering of the residuals to obtain a smooth curve. The monthly means were then actually calculated by using weekly values from the curve.

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COLD BAY

Trends

The sampling site at Cold Bay, Alaska, is operated in cooperation with the National Weather Service. The NOAA/CMDL flask data from Cold Bay show an increase in the annual atmospheric CO₂ mixing ratio from 337.8 parts per million (ppm) in 1979 to 357.3 ppm in 1992, or 1.5 ppm per year. Conway et al. (1994) reported a global growth rate of 1.43 ppm per year during 1981–92 for all NOAA/CMDL flask sampling sites.

Atmospheric CO₂ mixing ratios at Cold Bay show a seasonal pattern: the annual minimum typically occurs in August; the annual maximum in April or May. Conway et al. (1994) found that the average peak-to-trough amplitude for Cold Bay was 16.5 ppm during 1981–92.

Monthly atmospheric CO₂ mixing ratios at Cold Bay.

CITE AS: Conway, T.J., P.P. Tans, and L.S. Waterman. 1994. Atmospheric CO₂ records from sites in the NOAA/CMDL air sampling network. pp. 41–119. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL
air sampling network

T.J. Conway, P.P. Tans, and L.S. Waterman (continued)

COLD BAY

Cold Bay
Alaska, U.S.A.
Treeless peninsula
55°12' N, 162°43' W
11 m above MSL

Atmospheric Mixing Ratios of CO₂

CO₂ mixing ratios^a at Cold Bay (ppm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1978										334.0	336.6	338.3	
1979	340.1	340.8	341.7	342.9	342.6	338.6	332.4	328.0	331.2	336.8	339.1	339.8	337.8
1980	341.0	342.7	343.7	344.2	344.6	341.6	334.3	330.5	332.5	337.3	340.6	342.0	339.6
1981	343.8	344.9	345.6	346.3	345.2	341.9	335.5	331.0	333.6	339.5	342.5	343.9	341.1
1982	345.6	346.5	347.3	348.1	347.2	343.7	336.3	330.7	333.1	338.8	342.2	345.0	342.0
1983	346.6	346.3	346.3	347.2	347.1	343.7	336.7	332.8	337.1	343.5	345.7	346.1	343.3
1984	347.7	349.4	349.1	349.4	349.6	345.1	339.3	337.7	339.9	344.0	347.5	348.8	345.6
1985	348.9	349.6	351.4	352.3	351.9	349.1	344.0	338.0	338.9	344.5	347.6	349.1	347.1
1986	351.4	352.0	352.2	353.1	353.2	350.4	343.8	338.5	341.3	346.3	349.2	351.2	348.6
1987	352.2	352.6	353.6	354.9	354.9	351.9	345.2	339.5	341.5	348.7	352.6	353.6	350.1
1988	354.9	355.6	356.2	357.2	357.2	353.2	344.8	340.9	345.1	351.4	354.7	356.3	352.3
1989	357.6	358.1	359.3	360.7	359.6	355.7	347.9	342.7	346.3	352.1	355.4	358.2	354.5
1990	359.6	359.8	360.2	360.5	359.1	353.9	347.4	344.4	346.8	353.8	358.9	359.5	355.3
1991	359.4	360.5	361.7	363.0	362.4	357.2	351.0	348.7	349.6	354.1	359.3	360.8	357.3
1992	361.4	361.9	362.2	363.1	362.2	357.0	350.5	346.5	349.1	354.4	358.2	360.5	357.3

^aAtmospheric CO₂ mixing ratios are expressed in parts per million (ppm) and reported in the Scripps Institution of Oceanography X85 manometric mole fraction scale. These monthly values were calculated by using a method combining a fit of a four-harmonic function and a quadratic trend with digital filtering of the residuals to obtain a smooth curve. The monthly means were then actually calculated by using weekly values from the curve.

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Atmospheric CO₂ records from sites in the NOAA/CMDL
air sampling network

T.J. Conway, P.P. Tans, and L.S. Waterman (continued)

GUAM

Trends

The NOAA/CMDL sampling site at Guam, in the Mariana Islands, is operated in cooperation with the University of Guam. The NOAA/CMDL flask data from Guam show an increase in the annual mixing ratio from 340.0 parts per million (ppm) in 1980 to 356.3 ppm in 1992, or 1.36 ppm per year. Conway et al. (1994) reported a global growth rate of 1.43 ppm per year during 1981–92 for all NOAA/CMDL flask sampling sites.

Atmospheric CO₂ mixing ratios at Guam show a seasonal pattern: the annual drawdown typically occurs in September–October, and the annual maximum, in May. Conway et al. (1994) found that the average peak-to-peak amplitude for Guam from 1981–92 was 6.9 ppm.

Monthly atmospheric CO₂ mixing ratios at Guam.

CITE AS: Conway, T.J., P.P. Tans, and L.S. Waterman. 1994. Atmospheric CO₂ records from sites in the NOAA/CMDL air sampling network. pp. 41–119. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL
air sampling network

T.J. Conway, P.P. Tans, and L.S. Waterman (continued)

GUAM

*Guam, Mariana Islands
U.S. Territory,
Pacific Ocean
Island seashore
13°26' N, 144°47' E
2 m above MSL*

Atmospheric Mixing Ratios of CO₂

CO₂ mixing ratios^a at Guam (ppm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1979			339.2	339.8	340.1	339.7	338.5	337.0	335.4	334.6	335.9	337.9	
1980	339.1	340.2	340.9	341.6	342.6	342.4	341.2	339.8	338.0	337.1	338.4	339.2	340.0
1981	340.4	342.5	343.5	343.5	343.6	343.2	341.8	339.7	338.1	338.6	339.9	340.3	341.3
1982	341.5	343.2	343.5	343.7	344.2	343.3	341.5	338.7	336.6	336.8	338.6	340.4	341.0
1983	341.3	342.4	343.5	344.7	345.9	345.8	344.4	342.1	339.7	340.0	341.3	342.2	342.8
1984	343.4	344.5	345.1	346.3	347.2	346.8	345.9	344.3	341.9	341.8	343.1	343.9	344.5
1985	344.6	345.9	347.4	347.9	348.0	347.7	346.9	345.8	343.8	343.7	345.1	346.3	346.1
1986	347.6	348.1	348.6	349.8	350.7	349.9	347.8	345.7	344.5	344.8	346.2	347.2	347.6
1987	348.4	349.6	350.3	351.5	352.6	352.4	350.8	348.4	347.2	347.2	348.2	349.6	349.7
1988	350.8	352.1	353.1	353.8	354.5	354.1	352.9	352.2	351.1	349.8	350.0	351.0	352.1
1989	352.9	355.0	355.4	355.9	356.8	356.2	354.5	351.3	349.3	350.5	352.1	352.9	353.6
1990	354.2	355.6	356.2	356.6	357.2	357.1	354.2	350.3	350.1	351.7	352.9	354.4	354.2
1991	356.2	357.3	357.5	358.2	358.9	358.6	357.0	355.0	353.1	352.7	353.5	354.8	356.1
1992	355.9	357.1	358.2	358.7	359.7	359.1	357.0	354.8	352.7	352.6	354.1	355.8	356.3

^aAtmospheric CO₂ mixing ratios are expressed in parts per million (ppm) and reported in the Scripps Institution of Oceanography X85 manometric mole fraction scale. These monthly values were calculated by using a method combining a fit of a four-harmonic function and a quadratic trend with digital filtering of the residuals to obtain a smooth curve. The monthly means were then actually calculated by using weekly values from the curve.

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HALLEY BAY

Trends

The sampling site at Halley Bay, Antarctica, is operated in cooperation with the British Antarctic Survey. The NOAA/CMDL flask data from Halley Bay show an increase in the annual value from 341.4 parts per million (ppm) in 1983 to 347.5 ppm in 1987, or 1.53 ppm per year.

Like the South Pole atmospheric CO₂ mixing ratio record and other Southern Hemisphere sites, the Halley Bay record shows a small seasonal oscillation. Conway et al. (1994) reported that the average peak-to-trough amplitude for Halley Bay was only 1.5 ppm.

Monthly atmospheric CO₂ mixing ratios at Halley Bay.

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Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL
air sampling network

T.J. Conway, P.P. Tans, and L.S. Waterman (continued)

HALLEY BAY

Halley Bay
Antarctica
Barren seashore
75°40' S, 27°00' W
3 m above MSL

Atmospheric Mixing Ratios of CO₂

CO₂ mixing ratios^a at Halley Bay (ppm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1983	340.1	339.9	340.1	340.5	341.0	341.7	341.8	342.0	342.5	342.3	342.2	342.3	341.4
1984	342.0	341.8	341.7	341.7	342.2	342.8	342.9	343.0	343.5	343.9	343.8	343.6	342.7
1985	343.2	343.1	343.8	344.1	344.1	344.2	344.1	344.4	345.1	345.1	345.2	345.2	344.3
1986	345.0	345.0	344.6	344.4	344.7	345.1	345.5	345.7	346.0	346.1	346.1	346.0	345.4
1987	346.0	346.6	346.7	346.3	346.5	347.2	347.6	348.0	348.5	348.7	348.8	348.8	347.5
1988	348.6	348.9	349.1	348.9	349.1	349.7	349.7	350.0	350.5	350.3			
1989													
1990													
1991	352.1	352.0	352.5	352.9	353.0	353.1	353.2	353.7	354.0	354.1			

^aAtmospheric CO₂ mixing ratios are expressed in parts per million (ppm) and reported in the Scripps Institution of Oceanography X85 manometric mole fraction scale. These monthly values were calculated by using a method combining a fit of a four-harmonic function and a quadratic trend with digital filtering of the residuals to obtain a smooth curve. The monthly means were then actually calculated by using weekly values from the curve.

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IZAÑA

Trends

The sampling site at the Izaña Observatory is operated in cooperation with the Spanish National Meteorological Institute. The first NOAA/CMDL flask air samples from Izaña were collected in late 1991. The 1992 annual mixing ratio of 356.3 ppm is comparable to other European measurements.

Monthly atmospheric CO₂ mixing ratios at Izaña.

CITE AS: Conway, T.J., P.P. Tans, and L.S. Waterman. 1994. Atmospheric CO₂ records from sites in the NOAA/CMDL air sampling network. pp. 41–119. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL
air sampling network

T.J. Conway, P.P. Tans, and L.S. Waterman (continued)

IZAÑA

Izaña
Canary Islands, Spain
28°18' N 16°29' W
2300 m above MSL

Atmospheric Mixing Ratios of CO₂

CO₂ mixing ratios^a at Izaña (ppm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1991											354.5	356.1	
1992	356.5	356.4	357.5	358.8	359.3	358.6	356.6	353.4	353.0	353.9	354.7	356.6	356.3

^aAtmospheric CO₂ mixing ratios are expressed in parts per million (ppm) and reported in the Scripps Institution of Oceanography X85 manometric mole fraction scale. These monthly values were calculated by using a method combining a fit of a four-harmonic function and a quadratic trend with digital filtering of the residuals to obtain a smooth curve. The monthly means were then actually calculated by using weekly values from the curve.

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KEY BISCAIYNE

Trends

The sampling site at Key Biscayne, Florida, is operated in cooperation with the NOAA Atlantic Oceanographic and Meteorological Laboratory. The NOAA/CMDL flask data from Key Biscayne show an increase in the annual mixing ratio from 330.8 parts per million (ppm) in 1973 to 357.4 ppm in 1992 or 1.4 ppm per year. Conway et al. (1994) reported a global growth rate of 1.43 ppm per year during 1981–92 for all NOAA/CMDL flask sampling sites.

Atmospheric CO₂ concentrations at Key Biscayne show a seasonal pattern: the annual minimum occurs in the late northern summer or early fall; the annual maximum, in April–May. Conway et al. (1994) found that the peak-to-trough amplitude for the seasonal cycle at Key Biscayne was 8.0 ppm during 1981–92.

Monthly atmospheric CO₂ mixing ratios at Key Biscayne.

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Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL
air sampling network

T.J. Conway, P.P. Tans, and L.S. Waterman (continued)

*Key Biscayne
Florida, U.S.A.
Coastal island seashore
24°40' N, 80°12' W
3 m above MSL*

KEY BISCAYNE

Atmospheric Mixing Ratios of CO₂

CO₂ mixing ratios^a at Key Biscayne (ppm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1972												330.5	
1973	330.8	331.5	332.7	334.0	334.3	332.7	330.6	328.1	326.9	327.9	329.2	330.6	330.8
1974	332.2	333.2	333.8										
1975													
1976				335.3	335.5	334.2	332.2	330.6	329.4	329.8	331.4	333.4	
1977	335.0	335.9	336.4	336.8	336.8	336.1	334.8	333.2	332.1	333.1	335.0	336.6	335.2
1978	337.8	338.6	339.3	339.8	339.7	338.0	335.2	332.7	332.2	333.8	335.9	337.6	336.7
1979	339.0	340.0	341.1	342.0	341.4	339.6	337.7	335.6	334.6	335.7	337.7	339.3	338.6
1980	341.0	342.1	342.8	343.3	342.7	341.1	339.7	337.7	336.3	337.3	339.5	341.0	340.4
1981	342.2	343.3	344.1	344.9	345.4	344.8	343.2	340.4	337.8	338.3	341.0	342.1	342.3
1982	342.6	343.7	344.5	345.2	344.6	343.2	340.9	337.3	336.1	338.2	340.2	341.8	341.5
1983	343.6	344.7	345.1	345.9	346.7	346.3	343.9	340.9	339.7	340.3	341.5	343.6	343.5
1984	345.8	346.2	346.9	348.0	348.1	347.0	344.8	342.5	341.1	342.2	344.5	346.1	345.3
1985	346.7	347.6	349.0	349.8	349.3	348.3	346.6	343.4	342.0	343.8	346.3	347.9	346.7
1986	348.9	349.5	350.1	350.8	350.7	349.5	348.0	345.2	343.3	344.5	347.0	349.0	348.0
1987	349.6	351.3	352.7	352.6	352.2	351.5	350.3	348.5	347.2	347.8	350.0	351.5	350.4
1988	352.4	352.9	354.1	355.3	355.0	353.9	352.3	350.1	349.3	350.5	352.5	353.7	352.7
1989	353.9	354.2	355.3	356.3	356.8	356.0	354.0	352.4	351.9	352.5	354.2	355.5	354.4
1990	355.8	356.5	357.5	358.8	359.2	357.6	355.0	352.0	351.7	354.9	356.3	355.9	355.9
1991	356.1	357.8	359.5	359.6	359.1	358.2	356.0	353.5	352.1	352.7	355.0	357.9	356.5
1992	359.0	358.7	359.2	361.0	360.7	357.8	355.5	353.6	353.7	355.6	356.5	356.9	357.4

^aAtmospheric CO₂ mixing ratios are expressed in parts per million (ppm) and reported in the Scripps Institution of Oceanography X85 manometric mole fraction scale. These monthly values were calculated by using a method combining a fit of a four-harmonic function and a quadratic trend with digital filtering of the residuals to obtain a smooth curve. The monthly means were then actually calculated by using weekly values from the curve.

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MACE HEAD

Trends

The sampling site at Mace Head is operated in cooperation with the University College, Galway. The first NOAA/CMDL flask air samples from Mace Head were collected in late 1991. The 1992 annual atmospheric CO₂ mixing ratio of 356.2 ppm is comparable to other North Atlantic measurements.

Monthly atmospheric CO₂ mixing ratios at Mace Head.

CITE AS: Conway, T.J., P.P. Tans, and L.S. Waterman. 1994. Atmospheric CO₂ records from sites in the NOAA/CMDL air sampling network. pp. 41-119. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL
air sampling network

T.J. Conway, P.P. Tans, and L.S. Waterman (continued)

MACE HEAD

Mace Head
County Galway, Ireland
Island promontory
53°20' N, 09°54' W
25 m above MSL

Atmospheric Mixing Ratios of CO₂

CO₂ mixing ratios^a at Mace Head (ppm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1991						356.5	351.4	348.0	349.4	353.2	356.3	358.7	
1992	360.7	360.1	359.9	361.3	360.2	357.9	352.7	346.5	346.6	353.0	357.0	358.1	356.2

^aAtmospheric CO₂ mixing ratios are expressed in parts per million (ppm) and reported in the Scripps Institution of Oceanography X85 manometric mole fraction scale. These monthly values were calculated by using a method combining a fit of a four-harmonic function and a quadratic trend with digital filtering of the residuals to obtain a smooth curve. The monthly means were then actually calculated by using weekly values from the curve.

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MAUNA LOA

Trends

The NOAA/CMDL flask data from Mauna Loa show an increase in the annual value from 325.3 parts per million (ppm) in 1970 to 356.4 ppm in 1992, or 1.41 ppm per year.

Conway et al. (1994) reported a global growth rate of 1.43 ppm per year during 1981–92 for all NOAA/CMDL flask sampling sites.

Atmospheric CO₂ concentrations at Mauna Loa show a seasonal pattern: the annual drawdown occurs in September–October, and the annual buildup occurs in May.

Conway et al. (1994) reported that the peak-to-peak seasonal amplitude for Mauna Loa was 6.9 ppm during 1981–92.

Monthly atmospheric CO₂ mixing ratios at Mauna Loa.

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Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL air sampling network

T.J. Conway, P.P. Tans, and L.S. Waterman (continued)

MAUNA LOA

Mauna Loa
Hawaii, U.S.A.
Barren volcanic slope
19°32' N, 155°35' W
3397 m above MSL

Atmospheric Mixing Ratios of CO₂

CO₂ mixing ratios^a at Mauna Loa (ppm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1969								322.9	321.4	320.7	322.0	323.8	
1970	325.1	325.5	325.7	326.6	327.7	327.3	326.1	324.9	323.0	322.5	323.8	325.2	325.3
1971													
1972													
1973													
1974													
1975													
1976							332.4	331.0	329.7	329.3	330.6	332.1	
1977	332.8	333.1	334.0	335.7	336.5	336.0	334.7	332.3	331.0	331.4	332.0	333.6	333.6
1978	335.3	335.8	336.8	337.8	338.0	337.5	336.0	333.9	332.3	332.3	333.2	334.5	335.3
1979	336.0	337.0	338.4	339.0	338.9	339.0	337.6	335.4	333.9	334.0	335.1	336.4	336.7
1980	338.1	339.7	341.3	342.4	342.2	341.0	339.0	337.0	336.2	336.1	337.1	338.7	339.1
1981	340.0	341.4	342.3	343.2	343.4	342.0	340.3	338.6	337.2	337.4	338.9	340.0	340.4
1982	340.9	342.0	343.1	343.8	343.8	342.9	341.5	339.0	337.3	337.5	339.0	340.4	340.9
1983	341.7	342.2	342.9	344.9	345.8	345.1	343.3	341.0	339.6	339.7	340.9	342.5	342.5
1984	343.8	344.4	345.4	346.8	347.3	346.6	344.9	342.7	341.2	341.6	342.7	343.8	344.3
1985	344.5	345.4	346.7	347.8	348.4	348.0	346.0	343.9	342.7	342.7	343.8	345.2	345.4
1986	346.0	346.4	347.6	349.2	349.8	348.9	346.8	345.1	343.8	343.6	345.2	346.7	346.6
1987	347.3	348.0	349.1	350.6	351.6	351.1	349.4	347.3	346.3	346.5	347.9	349.3	348.7
1988	350.1	351.3	352.3	353.4	354.1	353.6	352.2	350.1	348.6	349.0	350.0	351.3	351.3
1989	352.5	353.0	353.8	355.2	355.9	355.3	353.6	351.0	349.3	349.7	351.3	352.5	352.8
1990	353.7	354.8	355.6	356.5	356.9	356.2	354.1	352.0	351.0	351.2	352.7	354.5	354.1
1991	355.0	355.8	357.3	358.5	359.2	358.2	355.8	353.7	352.1	352.3	353.6	355.2	355.6
1992	356.4	357.0	357.9	359.0	359.7	359.1	356.7	354.8	353.4	353.2	354.3	355.7	356.4

^aAtmospheric CO₂ mixing ratios are expressed in parts per million (ppm) and reported in the Scripps Institution of Oceanography X85 manometric mole fraction scale. These monthly values were calculated by using a method combining a fit of a four-harmonic function and a quadratic trend with digital filtering of the residuals to obtain a smooth curve. The monthly means were then actually calculated by using weekly values from the curve.

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MIDWAY ISLANDS

Trends

Annual averages derived from individual flask samples collected at the NOAA/CMDL sampling site on Sand Island, in the Midway Islands, have shown an increase in atmospheric CO₂ mixing ratios from 348.0 parts per million (ppm) in 1986 to 356.8 ppm in 1992, or 1.47 ppm per year. Monthly atmospheric CO₂ mixing ratios from Sand Island exhibit a seasonal pattern: annual minima occur in September; annual maxima, in April or May.

Monthly atmospheric CO₂ mixing ratios at Midway Islands.

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Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL
air sampling network

T.J. Conway, P.P. Tans, and L.S. Waterman (continued)

MIDWAY ISLANDS

*Midway Islands, (Sand Island)
Pacific Ocean
Island seashore
28°13' N, 177°22' W
4 m above MSL*

Atmospheric Mixing Ratios of CO₂

CO₂ mixing ratios^a at Midway Islands (ppm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1985					350.0	348.8	347.0	344.5	342.2	343.2	345.6	346.6	
1986	348.2	349.5	349.7	350.3	351.2	350.3	348.2	344.7	342.6	344.8	347.6	349.0	348.0
1987	350.3	350.9	351.6	353.2	353.5	352.0	349.3	345.6	345.0	347.3	349.3	350.9	349.9
1988	352.8	353.9	353.9	355.0	355.7	355.1	353.2	350.5	349.6	350.9	352.0	353.0	353.0
1989	354.5	355.2	356.0	357.8	357.7	356.3	353.2	348.5	348.9	352.2	353.8	355.7	354.2
1990	356.4	356.9	357.9	358.7	358.4	356.6	353.8	350.8	350.4	352.3	354.1	355.6	355.2
1991	357.2	358.6	358.9	360.3	361.0	358.6	355.8	353.6	352.5	354.4	356.2	357.2	357.0
1992	358.2	359.1	359.7	360.5	360.6	358.1	355.5	353.1	351.8	353.2	355.1	356.7	356.8

^aAtmospheric CO₂ mixing ratios are expressed in parts per million (ppm) and reported in the Scripps Institution of Oceanography X85 manometric mole fraction scale. These monthly values were calculated by using a method combining a fit of a four-harmonic function and a quadratic trend with digital filtering of the residuals to obtain a smooth curve. The monthly means were then actually calculated by using weekly values from the curve.

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MOULD BAY

Trends

The sampling site at Mould Bay is operated in cooperation with the Atmospheric Environment Service of Environment Canada. The NOAA/CMDL flask data from Mould Bay show an increase in the annual value from 341.9 parts per million (ppm) in 1981 to 357.4 ppm in 1992, or 1.41 ppm per year. A notable feature of the Mould Bay record is the slight decline in the annual atmospheric CO₂ mixing ratio from 1991 to 1992. Conway et al. (1994) reported a growth rate of 1.43 ppm per year for all the NOAA/CMDL flask sampling sites during 1981–92. The Mould Bay record supports Conway et al. (1988, 1994) finding that global measurements of CO₂ at remote locations have shown that during the winter in the Northern Hemisphere, mixing ratios of CO₂ are highest at high latitudes, and they decrease toward the equator.

Atmospheric CO₂ concentrations at Mould Bay show a seasonal pattern, with the annual minimum occurring in August and the annual maximum occurring in March–May. Conway et al. (1994) reported that the peak-to-peak seasonal amplitude for Mould Bay was 15.9 ppm during 1981–92.

Monthly atmospheric CO₂ mixing ratios at Mould Bay.

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Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL
air sampling network

T.J. Conway, P.P. Tans, and L.S. Waterman (continued)

MOULD BAY

*Mould Bay
Northwest Territories
Canada
Island tundra
76°14' N, 119°20' W
57.6 m above MSL*

Atmospheric Mixing Ratios of CO₂

CO₂ mixing ratios^a at Mould Bay (ppm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1980				344.0	343.9	343.1	338.6	333.5	333.6	337.0	340.0	342.7	
1981	344.1	344.9	345.5	345.9	346.7	346.1	339.4	332.6	333.9	338.4	341.3	344.1	341.9
1982	346.1	346.8	347.0	347.3	347.6	345.8	339.9	334.2	333.4	337.2	340.8	344.2	342.5
1983	346.6	347.0	347.5	347.8	347.9	346.4	340.5	334.4	335.0	339.6	344.4	347.5	343.7
1984	349.4	350.1	349.8	349.8	350.2	348.0	342.3	336.7	337.1	341.3	345.0	347.9	345.6
1985	349.3	349.4	350.4	351.5	351.9	349.7	344.0	338.3	338.5	343.1	347.0	349.4	346.9
1986	351.4	352.6	353.0	353.2	353.4	352.1	346.5	340.3	339.8	344.4	348.6	351.4	348.9
1987	353.2	353.1	353.8	354.6	354.6	353.1	347.6	341.4	340.8	345.6	349.9	352.9	350.1
1988	355.6	356.2	356.7	357.5	357.2	355.1	348.9	343.7	345.1	350.3	354.8	359.8	353.4
1989	361.0	359.9	359.5	359.6	359.3	357.6	351.7	345.6	346.0	351.3	355.4	358.8	355.5
1990	359.9	360.5	361.8	361.1	360.5	358.0	351.5	346.4	347.5	351.8	355.3	358.9	356.1
1991	362.5	362.5	361.8	362.2	361.7	359.7	354.0	347.5	348.1	353.1	357.7	360.8	357.6
1992	362.0	361.8	361.9	362.3	362.7	360.5	353.1	346.9	347.6	352.2	356.9	361.0	357.4

^aAtmospheric CO₂ mixing ratios are expressed in parts per million (ppm) and reported in the Scripps Institution of Oceanography X85 manometric mole fraction scale. These monthly values were calculated by using a method combining a fit of a four-harmonic function and a quadratic trend with digital filtering of the residuals to obtain a smooth curve. The monthly means were then actually calculated by using weekly values from the curve.

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NIWOT RIDGE

Trends

The sampling site at Niwot Ridge is operated in cooperation with the University of Colorado's Institute of Arctic and Alpine Research (INSTAAR). The NOAA/CMDL flask data from Niwot Ridge show an increase in the annual atmospheric CO₂ mixing ratio from 323.1 parts per million (ppm) in 1968 to 356.8 ppm in 1992, or 1.40 ppm per year. Conway et al. (1994) reported a global growth rate of 1.43 ppm per year during 1981–92 for all NOAA/CMDL flask sampling sites.

Atmospheric CO₂ concentrations at Niwot Ridge show a seasonal pattern: the annual minimum occurs in August or September, and the annual buildup occurs in March–May. Conway et al. (1994) reported that the peak-to-peak seasonal amplitude for Niwot Ridge was 8.9 ppm during 1981–92.

Monthly atmospheric CO₂ mixing ratios at Niwot Ridge.

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Atmospheric CO₂ records from sites in the NOAA/CMDL
air sampling network

T.J. Conway, P.P. Tans, and L.S. Waterman (continued)

NIWOT RIDGE

Niwot Ridge
Colorado, U.S.A.
Alpine mountain
40°03' N, 105°38' W
3749 m above MSL

Atmospheric Mixing Ratios of CO₂CO₂ mixing ratios^a at Niwot Ridge (ppm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1968	323.7	325.1	326.1	326.5	326.5	324.0	320.1	318.2	318.9	321.1	323.2	324.1	323.1
1969	324.5	325.6	327.1	327.9	327.1	325.1	321.3	318.6	319.4	322.2	323.9	325.4	324.0
1970	326.6	327.4	329.0	330.5	329.2	326.1	322.3	319.5	320.6	324.2	326.1	326.4	325.7
1971	327.4	328.9	329.7	330.2	329.1	324.6	320.7	319.7	320.2	323.0	325.6	326.3	325.5
1972	327.4	328.8	329.3	330.4	329.3	324.3	320.6	320.4	322.1	325.4	328.6	329.9	326.4
1973	330.7	331.7	332.5	333.3	333.5	331.2	327.4	325.5	326.6	328.4	330.6	331.9	330.3
1974	332.6	333.8	335.2	336.0	334.9	332.0							
1975													
1976	332.8	334.3	334.6	335.0	334.5	332.3	330.2	328.1	327.6	330.0	332.1	333.6	332.1
1977	334.8	335.8	336.6	337.3	337.3	335.3	332.7	331.4	331.5	333.4	335.2	336.4	334.8
1978	337.4	338.0	338.4	338.5	338.7	337.4	333.8	331.0	330.9	333.4	335.0	336.5	335.8
1979	338.0	338.7	339.9	340.5	340.5	338.1	334.4	332.6	332.5	334.1	336.7	338.0	337.0
1980	339.3	340.7	341.6	341.8	339.5	335.9	334.1	334.1	335.0	336.4	338.6	339.8	338.1
1981	341.2	343.1	343.6	343.2	341.9	339.6	337.2	335.4	335.4	338.0	341.0	341.8	340.1
1982	342.3	343.9	345.1	345.4	344.0	340.5	336.7	334.9	336.6	339.6	340.7	341.4	340.9
1983	343.3	344.7	345.3	346.1	345.1	342.4	339.4	336.5	336.7	340.3	343.6	345.8	342.4
1984	345.7	346.2	348.0	349.1	348.4	345.1	340.1	338.6	340.7	343.2	344.9	345.9	344.7
1985	347.1	347.8	348.1	348.6	347.8	345.7	344.7	343.8	342.1	343.5	346.6	347.6	346.1
1986	347.9	349.1	349.6	349.8	348.7	345.6	344.2	344.2	344.3	345.1	346.2	347.7	346.9
1987	349.0	350.4	351.8	351.8	350.8	349.6	347.4	344.9	345.2	347.1	349.4	351.3	349.1
1988	352.5	353.7	354.4	355.3	354.4	351.4	349.7	348.3	348.0	349.6	352.5	354.1	352.0
1989	354.3	355.0	355.5	355.8	355.7	354.7	352.6	349.7	349.1	351.1	353.6	354.5	353.5
1990	355.3	357.0	357.5	357.8	358.0	355.9	352.0	350.2	351.2	352.2	353.7	355.7	354.7
1991	357.2	358.4	359.4	360.0	358.6	356.7	353.7	351.3	351.3	353.3	356.0	357.7	356.1
1992	358.8	359.3	360.1	359.7	357.5	356.6	356.1	354.0	352.8	354.1	355.9	357.1	356.8

^aAtmospheric CO₂ mixing ratios are expressed in parts per million (ppm) and reported in the Scripps Institution of Oceanography X85 manometric mole fraction scale. These monthly values were calculated by using a method combining a fit of a four-harmonic function and a quadratic trend with digital filtering of the residuals to obtain a smooth curve. The monthly means were then actually calculated by using weekly values from the curve.

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PACIFIC OCEAN

Trends

Air sampling for the shipboard NOAA/CMDL program has been carried out since December 1986 by the merchant vessel *Southland Star*, operated by Blue Star Line, Ltd. Beginning in May 1990, air sampling has also been carried out by the merchant vessel *Wellington Star* (also operated by Blue Star Line, Ltd.). Each ship usually sails southward from Los Angeles, passing near Christmas Island, American Samoa, and Fiji en route to its destination in Auckland, New Zealand. Air samples are collected at a latitude of 30° N, and then at every 5° latitude southward to 35° S. The northward return voyage follows a different track, passing Hawaii en route to Seattle. Air samples are collected at 35° S and then at every 5° latitude northward to 30° N (samples are sometimes also collected at 35° N, 40° N, and 45° N, but data at these latitudes were too sparse to calculate averages). Thus, samples are collected at a minimum of two longitudes for a given latitude. Because the longitudinal variations in CO₂ mixing ratios are small compared with the latitudinal variations, all samples collected within a given latitudinal band, defined as the center latitude (e.g., 30° N, 0°, 35° S) $\pm 2.5^\circ$, are considered representative of a single latitude "site." The frequency of sampling on average is ~3 weeks per latitude per ship. Since May 1990, when the Pacific Ocean air sampling program was augmented by the contribution of the *Wellington Star*, the overall frequency of sampling has increased because of the somewhat staggered cruise schedules of the two ships.

The CO₂ mixing ratios at Pacific Ocean shipboard sites exhibit both a temporal trend and a latitudinal gradient. The annual mean mixing ratios for 1987 ranged from 347.4 parts per million (ppm) at 30° S to 349.6 ppm at 30° N. For 1992, the annual mean values ranged from 354.4 ppm at 30° S to 357.1 ppm at 30° N. At all latitudes, the mixing ratios increased with time during the period of record (January 1987–December 1992). For any given year, the annual mean mixing ratios generally decreased along a gradient from north to south. Accordingly, CO₂ levels were consistently highest at the northernmost latitude, 30° N, and they decreased to their minimum values at 30° S. Overall, the shipboard CO₂ mixing ratios were consistent with those obtained at land-based sites at similar latitudes. The shipboard data also exhibited seasonal cycles that were most evident at higher latitudes, particularly in the Northern Hemisphere. This observed seasonality was also in general agreement with results from land-based monitoring sites.

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Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL
air sampling network

T.J. Conway, P.P. Tans, and L.S. Waterman (continued)

PACIFIC OCEAN

Monthly mixing ratios of atmospheric CO₂ at Pacific Ocean shipboard sites.

Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL air sampling network

T.J. Conway, P.P. Tans, and L.S. Waterman (continued)

PACIFIC OCEAN

Monthly mixing ratios of atmospheric CO₂ at Pacific Ocean shipboard sites.

Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL
air sampling network

T.J. Conway, P.P. Tans, and L.S. Waterman (continued)

PACIFIC OCEAN

*Southland Star and Wellington
Star cruise tracks
Pacific Ocean
Sample collection at 5°-latitude
increments from 30° N to 35° S.*

Atmospheric Mixing Ratios of CO₂

CO₂ mixing ratios^a at the Pacific Ocean (ppm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
30°N													
1986												347.6	
1987	348.7	349.6	351.3	353.3	354.1	352.5	349.1	345.8	344.6	346.0	348.9	351.3	349.6
1988	352.6	353.2	354.1	355.1	355.5	354.2	351.6	349.2	348.6	350.1	352.4	354.0	352.6
1989	354.4	354.4	355.1	356.6	357.4	356.3	353.2	349.1	349.3	352.0	354.4	355.6	354.0
1990	355.8	356.3	357.4	358.3	357.5	354.7	351.3	349.4	350.0	352.5	355.2	356.8	354.6
1991	357.5	358.3	359.7	360.7	360.0	357.1	353.3	350.9	351.1	353.6	356.6	358.4	356.4
1992	358.9	359.2	360.1	361.1	360.8	358.4	354.7	351.9	351.6	353.7	356.6	358.6	357.1
25°N													
1986												346.7	
1987	347.6	348.8	350.8	352.9	353.6	352.2	349.2	346.7	346.0	347.2	349.3	350.8	349.6
1988	351.6	352.5	354.1	355.8	356.3	354.5	351.1	347.8	346.7	348.0	350.5	352.5	351.8
1989	353.4	353.8	354.7	356.1	356.9	355.9	353.2	350.3	349.0	350.8	353.5	354.3	353.5
1990	354.7	355.6	357.1	358.0	357.1	354.4	351.3	349.8	350.7	353.0	355.1	356.1	354.4
1991	356.6	357.4	358.9	360.2	359.7	357.1	353.6	351.3	351.3	353.3	355.8	357.5	356.1
1992	358.4	359.3	360.5	361.4	360.8	358.3	354.8	352.3	352.0	353.6	355.7	357.2	357.0
20°N													
1986												348.0	
1987	348.7	349.2	350.2	351.7	352.7	352.4	350.5	348.4	347.1	347.4	348.8	350.1	349.8
1988	351.1	351.8	352.9	354.2	354.8	353.9	351.5	348.9	347.4	347.7	349.3	351.0	351.2
1989	352.2	353.1	354.2	355.5	356.3	355.7	353.6	351.2	349.9	350.3	352.0	354.7	353.2
1990	356.2		357.1	357.8	357.0	355.0	352.7	351.3	351.5	353.0	354.7	355.9	
1991	356.6	357.5	358.8	359.9	359.6	357.7	354.8	352.4	351.7	352.7	354.5	356.1	356.0
1992	357.3	358.4	359.7	360.8	360.6	358.7	355.7	353.2	352.3	353.2	355.1	356.8	356.8
15°N													
1986												346.5	
1987	347.6	348.6	350.1	351.9	352.9	352.1	349.7	347.1	345.9	346.5	348.3	350.0	349.2
1988	351.1	351.7	352.8	354.2	355.3	354.9	352.8	350.1	348.4	348.4	349.7	351.3	351.7
1989	352.2	352.8	353.7	355.2	356.5	356.6	355.1	352.6	350.6	350.3	351.4	352.9	353.3
1990	354.5	-10.0	355.7	356.9	357.7	355.9	353.4	351.6	351.3	352.5	354.2	355.4	324.1
1991	356.2	357.0	358.3	359.6	359.7	358.0	355.1	352.6	351.7	352.7	354.6	356.3	356.0
1992	357.3	358.1	359.0	360.1	360.3	359.0	356.5	354.1	353.1	353.8	355.4	356.8	357.0
10°N													
1987	347.3	348.5	350.1	351.6	352.4	351.7	350.0	348.1	347.1	347.5	348.8	350.3	349.5
1988	351.5	352.5	353.6	354.5	354.7	353.8	351.9	350.0	349.1	349.5	350.7	352.1	352.0
1989	353.1	353.9	354.8	355.7	356.1	355.4	353.8	351.9	350.9	351.1	352.2	353.5	353.5
1990	354.5	355.3	356.0	356.9	357.3	356.9	355.6	354.0	352.9	352.8	353.5	354.6	355.0
1991	355.5	356.3	357.3	358.4	359.2	359.0	357.6	355.5	353.8	353.3	353.9	355.1	356.2
1992	356.2	357.2	358.0	359.0	359.7	359.7	358.7	357.0	355.4	354.7	355.6	356.4	357.3

Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL
air sampling network

T.J. Conway, P.P. Tans, and L.S. Waterman (continued)

PACIFIC OCEAN

Atmospheric Mixing Ratios of CO₂ (continued)

CO ₂ mixing ratios ^a at the Pacific Ocean (ppm)													
Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
5° N													
1987	346.7	348.3	350.1	351.6	352.3	351.8	350.6	349.4	348.8	349.0	349.6	350.4	349.9
1988	351.1	351.7	352.3	352.8	353.0	352.8	352.4	351.9	351.7	351.9	352.4	353.0	352.3
1989	353.5	354.1	354.7	355.1	355.1	354.7	354.0	353.2	352.6	352.6	353.2	354.0	353.9
1990	354.8	355.6	356.1	356.2	355.8	355.0	354.3	353.8	353.8	354.2	354.6	355.0	354.9
1991	355.3	355.8	356.6	357.2	357.5	357.1	356.2	355.1	354.4	354.4	354.9	355.8	355.9
1992	356.7	357.6	358.3	358.9	358.8	358.2	357.1	356.0	355.3	355.1	355.4	355.9	356.9
Equator													
1987						350.8	350.3	349.8	349.5	349.3	349.6	350.1	
1988	351.0	352.0	352.8	353.3	353.2	352.9	352.4	352.1	351.9	352.0	352.4	353.0	352.4
1989	353.8	354.6	355.2	355.3	354.9	354.3	353.7	353.2	353.0	352.9	353.2	353.6	354.0
1990	354.2	354.9	355.5	355.9	355.9	355.7	355.2	354.4	353.9	353.9	354.3	355.0	354.9
1991	355.8	356.4	356.8	356.8	356.5	356.1	355.5	354.9	354.6	354.5	354.8	355.4	355.7
1992	356.1	356.7	357.0	357.1	357.0	356.7	356.4	356.0	355.8	355.7	355.8	356.2	356.4
5° S													
1987		347.8	348.8	349.7	350.4	350.6	350.2	349.5	348.9	348.7	349.0	349.7	
1988	350.7	351.6	352.3	352.7	352.7	352.3	351.8	351.5	351.4	351.7	352.3	353.0	352.0
1989	353.5	353.9	354.1	354.1	354.0	353.8	353.4	353.0	352.8	352.7	353.0	353.6	353.5
1990	354.3	354.9	355.3	355.6	355.7	355.7	355.4	354.9	354.4	354.1	354.2	354.6	354.9
1991	355.0	355.4	355.7	356.0	356.2	356.2	355.9	355.4	354.9	354.6	354.7	354.9	355.4
1992	355.3	355.6	355.9	356.3	356.8	357.1	356.8	355.9	355.4	355.3	355.6	356.2	356.0
10° S													
1987			348.2	348.1	348.1	348.4	348.7	348.9	348.9	348.9	349.2	349.6	
1988	350.2	350.5	350.6	350.6	350.7	351.0	351.3	351.4	351.3	351.3	351.7	352.3	351.1
1989	353.0	353.3	353.3	353.1	352.9	352.8	352.8	352.6	352.4	352.3	352.5	353.1	352.8
1990	353.7	354.2	354.4	354.5	354.5	354.5	354.5	353.9	353.3	353.4	353.9	354.7	354.1
1991	355.3	355.5	355.4	355.3	355.1	355.1	354.9	354.6	354.3	354.3	354.7	355.1	355.0
1992	355.4	355.3	355.2	355.2	355.5	355.9	356.2	356.0	355.6	355.3	355.4	355.7	355.6
15° S													
1986												344.6	
1987	345.4	346.0	346.4	346.7	347.2	347.9	348.5	348.7	348.5	348.1	348.1	348.5	347.5
1988	349.2	349.8	350.1	350.1	350.1	350.3	350.6	350.8	350.7	350.7	351.0	351.7	350.4
1989	352.6	353.2	353.3	352.9	352.5	352.2	352.2	352.2	352.1	352.0	352.1	352.4	352.5
1990	352.9	353.3	353.2	352.9	352.6	352.5	352.6	352.8	352.9	353.0	353.3	353.8	353.0
1991	354.4	354.8	354.8	354.5	354.1	353.9	354.1	354.4	354.5	354.3	354.3	354.6	354.4
1992	354.9	355.1	355.1	355.1	355.3	355.7	355.9	355.9	355.6	355.3	355.3	355.6	355.4
20° S													
1987		346.2	346.2	346.3	346.7	347.3	347.8	348.2	348.4	348.7	349.1	349.4	
1988	349.4	349.0	348.6	348.5	348.9	349.5	350.1	350.3	350.3	350.4	350.8	351.4	349.8
1989	351.9	351.9	351.6	351.1	350.8	350.9	351.1	351.4	351.5	351.7	351.8	352.1	351.5
1990	352.2	352.2	352.0	351.8	351.9	352.3	352.6	352.8	352.8	352.8	352.9	353.2	352.5
1991	353.5	353.6	353.5	353.4	353.5	353.8	354.1	354.2	354.1	353.9	353.8	354.1	353.8
1992	354.4	354.4	354.4	354.5	354.8	355.1	355.4	355.3	355.2	355.0	355.1	355.2	354.9

Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL
air sampling network

T.J. Conway, P.P. Tans, and L.S. Waterman (continued)

PACIFIC OCEAN

Atmospheric Mixing Ratios of CO₂ (continued)

CO₂ mixing ratios^a at the Pacific Ocean (ppm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
25° S													
1986												345.5	
1987	345.9	346.1	346.3	346.5	346.9	347.4	347.9	348.3	348.5	348.6	348.8	349.1	347.5
1988	349.4	349.4	349.2	348.9	348.8	349.1	349.5	349.9	350.1	350.2	350.4	350.7	349.6
1989	351.0	351.0	350.8	350.5	350.3	350.6	351.0	351.4	351.5	351.6	351.7	351.9	351.1
1990	352.2	352.3	352.2	352.0	351.9	352.2	352.6	352.9	353.0	352.9	352.8	352.9	352.5
1991	353.2	353.5	353.6	353.5	353.5	353.7	354.0	354.1	354.0	353.8	353.7	353.7	353.7
1992	354.0	354.3	354.4	354.3	354.2	354.3	354.7	355.0	354.9	354.7	354.5	354.6	354.5
30° S													
1986												345.3	
1987	345.6	345.8	346.0	346.3	346.8	347.3	347.7	348.1	348.3	348.6	349.0	349.2	347.4
1988	349.2	348.9	348.5	348.4	348.6	349.2	349.8	350.2	350.3	350.4	350.5	350.7	349.6
1989	350.8	350.7	350.6	350.5	350.6	350.8	351.1	351.3	351.4	351.4	351.5	351.6	351.0
1990	351.8	351.8	351.7	351.7	351.9	352.2	352.5	352.7	352.7	352.6	352.7	352.9	352.3
1991	353.1	353.2	353.0	352.9	352.8	353.1	353.5	353.8	353.9	353.8	353.7	353.8	353.4
1992	353.9	353.9	353.8	353.7	353.8	354.2	354.8	355.1	354.9	354.7	354.7	354.8	354.4
35° S													
1987	345.7	346.0	346.3	346.7	347.1	347.4	347.8	348.3	348.9	349.3	349.4	349.3	347.7
1988	349.2	349.1	349.0	348.9	348.8	348.8	349.3	350.1	350.5	350.7	350.7	350.7	349.7
1989	350.8	351.0	351.1	351.1	350.9	350.8	350.9	351.2	351.5	351.5	351.5	351.4	351.1
1990	351.4	351.5	351.7	351.8	351.8	351.9	352.2	352.6	352.8	352.8	352.6	352.5	352.1
1991	352.6	353.0	353.5	353.8	353.9	353.9	354.0	354.2	354.3	354.2	353.8	353.5	353.7
1992	353.3	353.3	353.6	354.0	354.2	354.4	354.7	354.9	355.2	355.4	355.4	355.3	354.5

^aAtmospheric CO₂ mixing ratios are expressed in parts per million (ppm) and reported in the Scripps Institution of Oceanography X85 manometric mole fraction scale. These monthly values were calculated by using a method combining a fit of a two-harmonic function and a quadratic trend with digital filtering of the residuals to obtain a smooth curve. The monthly means were then actually calculated by using weekly values from the curve.

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PALMER STATION

Trends

The NOAA/CMDL sampling site at Palmer Station on Anvers Island, Antarctica is operated in cooperation with the National Science Foundation. The NOAA/CMDL flask data from Palmer Station show an increase in the annual atmospheric CO₂ mixing ratio from 333.9 parts per million (ppm) in 1978 to 354.2 ppm in 1992, or 1.45 ppm per year. Conway et al. (1994) reported a global growth rate of 1.43 ppm per year during 1981–92 for all NOAA/CMDL flask-sampling sites.

Atmospheric CO₂ concentrations at Palmer Station show a seasonal pattern typical of Southern Hemisphere sites, with the annual drawdown usually occurring in January or February and the annual maximum observed from August to November. Conway et al. (1994) reported that the peak-to-peak seasonal amplitude for Palmer Station was 1.7 ppm for 1981–92.

Monthly atmospheric CO₂ mixing ratios at Palmer Station.

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Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL
air sampling network

T.J. Conway, P.P. Tans, and L.S. Waterman (continued)

PALMER STATION

Palmer Station
Anvers Island, Antarctica
Barren island seashore
64°55' S, 64°00' W
33 m above MSL

Atmospheric Mixing Ratios of CO₂

CO₂ mixing ratios^a at Palmer Station (ppm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1978	332.1	332.4	333.0	333.1	333.3	334.1	334.8	335.1	335.1	334.9	334.8	334.5	333.9
1979	334.2	334.1	333.9	333.9	334.3	334.6	335.0	335.9	336.8	337.0	336.6	336.3	335.2
1980													
1981	338.8	338.9	339.0	339.1	339.8	340.4	340.7	340.9	340.9	340.9	341.0	340.7	340.1
1982	340.1	339.7	339.1	339.2	339.5	339.4	339.6	340.1	340.4	340.5	340.4	340.1	339.8
1983	339.7	339.4	339.5	340.1	340.6	340.9	341.4	342.0	342.2	342.2	342.2	342.1	341.0
1984	341.9	341.5	341.6	341.8	341.9	342.2	342.6	343.4	344.0	343.9	344.0	343.7	342.7
1985	343.0	342.8	343.1	343.4	343.3	343.5	344.1	344.8	345.1	345.1	345.2	344.9	344.0
1986	344.6	344.3	344.3	344.5	344.6	344.8							
1987	345.1	345.4	345.7	346.1	346.7	347.1	347.2	347.7	348.0	348.0	347.9	347.8	346.9
1988	347.9	348.0	348.8	349.4	349.4	349.5	349.7	350.0	350.7	350.7	350.4	350.0	349.5
1989	349.6	349.5	349.8	349.9	350.1	351.0	352.0	352.2	352.0	351.9	351.7	351.4	350.9
1990	350.5	350.1	350.6	351.1	351.4	351.8	352.3	353.0	353.3	353.1	352.9	352.6	351.9
1991	352.2	352.1	352.3	352.5	352.8	353.1	353.5	353.8	354.0	354.1	354.1	353.7	353.2
1992	353.1	352.9	353.1	353.4	353.8	354.1	354.6	355.0	355.2	355.4	355.0	354.7	354.2

^aAtmospheric CO₂ mixing ratios are expressed in parts per million (ppm) and reported in the Scripps Institution of Oceanography X85 manometric mole fraction scale. These monthly values were calculated by using a method combining a fit of a four-harmonic function and a quadratic trend with digital filtering of the residuals to obtain a smooth curve. The monthly means were then actually calculated by using weekly values from the curve.

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QINGHAI PROVINCE

Trends

The NOAA/CMDL sampling site in the Qinghai Province of the Peoples Republic of China is operated in cooperation with the Chinese Academy of Meteorological Sciences. The first NOAA/CMDL flask air samples from the Qinghai Province were collected in late 1991. The 1992 annual mixing ratio at Qinghai was 356.6 parts per million (ppm).

Monthly atmospheric CO₂ mixing ratios at Qinghai Province.

CITE AS: Conway, T.J., P.P. Tans, and L.S. Waterman. 1994. Atmospheric CO₂ records from sites in the NOAA/CMDL air sampling network. pp. 41-119. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric Carbon Dioxide
Atmospheric CO₂ records from sites in the NOAA/CMDL
air sampling network

T.J. Conway, P.P. Tans, and L.S. Waterman (continued)

QINGHAI PROVINCE

Qinghai Province
Peoples Republic of China
Semidesert
36°16' N, 100°55' E
3810 m above MSL

Atmospheric Mixing Ratios of CO₂

CO₂ mixing ratios^a at Qinghai Province (ppm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1991									352.6	354.6	355.1	355.4	
1992	356.8	358.8	359.7	361.9	361.7	355.7	352.2	352.1	353.1	354.8	355.3	356.7	356.6

^aAtmospheric CO₂ mixing ratios are expressed in parts per million (ppm) and reported in the Scripps Institution of Oceanography X85 manometric mole fraction scale. These monthly values were calculated by using a method combining a fit of a four-harmonic function and a quadratic trend with digital filtering of the residuals to obtain a smooth curve. The monthly means were then actually calculated by using weekly values from the curve.

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SAMOA

Trends

The NOAA/CMDL flask data from Samoa show an increase in the annual atmospheric CO₂ mixing ratio from 330.9 parts per million (ppm) in 1974 to 354.9 ppm in 1992, or 1.33 ppm per year. Conway et al. (1994) reported a global growth rate of 1.43 ppm per year during 1981–92 for all NOAA/CMDL flask sampling sites. Conway et al. (1994) reported that the peak-to-trough seasonal amplitude for Samoa was 1.3 ppm for 1981–92.

Monthly atmospheric CO₂ mixing ratios at Samoa.

CITE AS: Conway, T.J., P.P. Tans, and L.S. Waterman. 1994. Atmospheric CO₂ records from sites in the NOAA/CMDL air sampling network. pp. 41–119. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL
air sampling network

T.J. Conway, P.P. Tans, and L.S. Waterman (continued)

Samoa (Cape Matatula)
U.S. Territory,
Pacific Ocean
Island rocky promontory
14°15' S, 170°34' W
42 m above MSL

SAMOA

Atmospheric Mixing Ratios of CO₂

CO₂ mixing ratios^a at Samoa (ppm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1973								330.3	330.3	330.1	330.1	330.3	
1974	330.6	331.2	331.3	331.1	331.4	331.1	330.5	330.6	330.8	331.1	330.5	330.0	330.9
1975	330.6	330.6	330.2	329.7	329.7	330.6	330.9	330.7	331.5	331.6	330.9	330.5	330.6
1976	330.5	330.5	330.8	331.2	331.4	331.1	331.0	331.5	331.9	332.2	332.6	333.0	331.5
1977	333.0	332.6	332.2	332.7	332.8	332.6	332.8	332.9	332.7	333.0	333.1	333.7	332.8
1978	334.0	333.8	334.4	334.5	334.3	334.8	334.5	334.2	334.4	334.5	334.4	334.1	334.3
1979	334.8	335.5	335.8	335.9	335.6	335.8	335.8	335.8	336.2	336.7	336.8	336.7	336.0
1980	337.4	338.0	337.7	337.7	338.3	338.6	338.4	338.5	338.4	338.3	338.6	338.9	338.2
1981	339.2	339.1	339.4	339.3	338.6	338.8	339.1	339.1	339.0	339.1	339.5	339.8	339.2
1982	340.5	340.9	340.7	340.2	339.7	339.8	340.5	340.9	340.5	340.1	340.3	340.8	340.4
1983	340.8	340.5	340.6	340.8	341.2	341.6	341.8	341.7	341.6	341.8	342.0	342.4	341.4
1984	343.0	343.1	342.9	342.4	342.0	342.3	342.8	343.1	343.2	343.1	343.4	344.0	342.9
1985	344.3	344.6	344.8	344.3	343.9	344.2	344.5	344.5	344.3	344.5	344.9	345.1	344.5
1986	345.5	345.7	345.5	345.2	345.4	346.1	345.8	345.3	345.6	345.9	346.0	346.1	345.7
1987	346.5	347.0	347.0	346.6	346.7	347.0	347.2	347.6	348.0	348.2	348.6	349.1	347.5
1988	349.4	349.5	349.8	350.5	350.3	349.9	350.0	350.1	349.9	350.3	350.9	351.4	350.2
1989	351.8	351.9	351.8	352.1	352.0	351.3	351.3	351.4	351.3	351.5	351.8	352.0	351.7
1990	352.2	352.3	352.9	352.9	352.3	352.5	352.8	352.9	352.9	352.8	353.1	353.6	352.8
1991	354.2	354.7	354.4	353.9	354.0	354.1	354.3	354.0	353.6	353.7	354.4	354.7	354.2
1992	354.4	354.6	354.8	354.5	354.6	354.9	355.3	355.3	355.0	355.0	355.0	355.2	354.9

^aAtmospheric CO₂ mixing ratios are expressed in parts per million (ppm) and reported in the Scripps Institution of Oceanography X85 manometric mole fraction scale. These monthly values were calculated by using a method combining a fit of a four-harmonic function and a quadratic trend with digital filtering of the residuals to obtain a smooth curve. The monthly means were then actually calculated by using weekly values from the curve.

CITE AS: Conway, T.J., P.P. Tans, and L.S. Waterman. 1994. Atmospheric CO₂ records from sites in the NOAA/CMDL air sampling network. pp. 41-119. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

SEYCHELLES

Trends

The Seychelles sampling site on Mahé Island is operated in cooperation with the Physical Science Laboratory at New Mexico State University. The NOAA/CMDL flask data from the Seychelles show an increase in the annual atmospheric CO₂ mixing ratio from 339.4 parts per million (ppm) in 1980 to 354.8 ppm in 1992, or 1.28 ppm per year. Conway et al. (1994) reported a global growth rate of 1.43 ppm per year during 1981–92 for all NOAA/CMDL flask sampling sites.

Atmospheric CO₂ concentrations at the Seychelles show a seasonal pattern: the annual minimum typically occurs in May or June, and the annual maximum occurs in February–March. Conway et al. (1994) reported that the peak-to-peak seasonal amplitude for the Seychelles site was 3.5 ppm for 1981–92.

Monthly atmospheric CO₂ mixing ratios at the Seychelles.

CITE AS: Conway, T.J., P.P. Tans, and L.S. Waterman. 1994. Atmospheric CO₂ records from sites in the NOAA/CMDL air sampling network. pp. 41–119. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL
air sampling network

T.J. Conway, P.P. Tans, and L.S. Waterman (continued)

SEYCHELLES

Seychelles (Mahé Island)
Indian Ocean
Island seashore
4°40' S, 55°10' E
3 m above MSL

Atmospheric Mixing Ratios of CO₂

CO₂ mixing ratios^a at Seychelles (ppm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1980	340.4	341.3	341.2	339.6	338.3	338.3	338.5	338.5	338.6	338.9	339.2	339.8	339.4
1981	341.0	342.0	342.2	340.9	339.1	339.0	338.9	338.5	338.7	339.4	339.9	340.4	340.0
1982	341.2	342.4	342.6	341.1	339.9	339.8	339.6	339.8	339.7	339.5	339.9	340.4	340.5
1983	340.4	341.6	343.3	342.2	340.2	339.6	339.3	339.7	340.0				253.0
1984													
1985													
1986	345.3	346.6	346.8	345.7	345.5	346.3	346.4	346.3	346.6	347.2	347.0	347.0	346.4
1987	348.0	348.7	349.3	349.6	348.9	348.2	348.4	349.2	348.3	347.1	348.8	350.3	348.7
1988	350.5	351.2	351.2	349.9	349.0	349.6	350.6	350.9	351.3	350.7	349.1	349.3	350.3
1989	352.0	353.9	353.4	352.1	350.8	350.9	351.9	352.1	352.1	352.0	352.2	353.3	352.2
1990	354.5	355.2	355.2	354.0	352.6	352.7	353.2	352.7	352.1	352.4	352.7	353.1	353.4
1991	354.0	354.5	354.2	353.0	352.8	353.4	353.6	353.5	353.6	354.3	355.0	354.9	353.9
1992	354.8	355.5	356.4	356.0	354.1	352.8	353.8	354.7	354.4	354.9	355.0	355.0	354.8

^aAtmospheric CO₂ mixing ratios are expressed in parts per million (ppm) and reported in the Scripps Institution of Oceanography X85 manometric mole fraction scale. These monthly values were calculated by using a method combining a fit of a four-harmonic function and a quadratic trend with digital filtering of the residuals to obtain a smooth curve. The monthly means were then actually calculated by using weekly values from the curve.

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SHEMYA ISLAND

Trends

The monitoring site at Shemya Island, Alaska, is operated in cooperation with the U.S. Air Force. Annual atmospheric CO₂ mixing ratios at Shemya Island have risen from 349.3 parts per million (ppm) in 1986 to 357.2 ppm in 1992, or 1.32 ppm per year. The record from Shemya Island exhibits a seasonal cycle: the yearly minimum occurs in August; the yearly maximum, between the late winter and spring.

Monthly atmospheric CO₂ mixing ratios at Shemya Island.

CITE AS: Conway, T.J., P.P. Tans, and L.S. Waterman. 1994. Atmospheric CO₂ records from sites in the NOAA/CMDL air sampling network. pp. 41–119. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL
air sampling network

T.J. Conway, P.P. Tans, and L.S. Waterman (continued)

SHEMYA ISLAND

Shemya Island
Alaska, U.S.A.
Island seashore
52°43' N, 174°06' E
40 m above MSL

Atmospheric Mixing Ratios of CO₂

CO₂ mixing ratios^a at Shemya Island (ppm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1985									340.4	345.8	348.5	350.3	
1986	350.9	351.4	353.3	354.6	353.7	348.7	339.9	338.1	344.3	350.9	353.1	352.7	349.3
1987	353.5	354.5	355.3	356.5	356.6	352.8	342.5	337.0	343.0	348.7	351.1	354.1	350.5
1988	355.8	356.2	357.2	358.4	358.2	354.6	346.6	341.5	345.0	351.4	354.5	357.1	353.0
1989	358.9	358.6	359.0	360.3	360.1	355.2	346.5	342.5	346.9	353.0	356.1	357.6	354.6
1990	359.9	360.7	360.4	360.7	359.1	353.5	346.1	342.2	347.2	353.4	357.1	360.2	355.0
1991	360.9	360.8	362.0	363.3	362.8	357.1	348.5	344.2	349.0	355.1	358.0	359.7	356.8
1992	361.2	361.6	362.2	363.0	362.1	357.6	349.9	346.0	349.0	354.8	358.3	360.1	357.2

^aAtmospheric CO₂ mixing ratios are expressed in parts per million (ppm) and reported in the Scripps Institution of Oceanography X85 manometric mole fraction scale. These monthly values were calculated by using a method combining a fit of a four-harmonic function and a quadratic trend with digital filtering of the residuals to obtain a smooth curve. The monthly means were then actually calculated by using weekly values from the curve.

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SOUTH POLE

Trends

The CMDL sampling site at Amundsen Scott is operated in cooperation with the National Science Foundation. The annual atmospheric CO₂ mixing ratio calculated from NOAA/CMDL flask data obtained at Amundsen Scott show an increase in the annual value from 329.4 parts per million (ppm) in 1975 to 354.1 ppm in 1992, or 1.45 ppm per year. Conway et al. (1994) reported a 1.43-ppm mean annual growth rate for all the NOAA/CMDL flask-sampling sites during 1981–92.

Atmospheric CO₂ mixing ratios at this South Pole site show a seasonal pattern: the annual drawdown typically occurs in December–January, and the annual buildup occurs in June–July. Conway et al. (1994) reported that the peak-to-peak seasonal amplitude for Amundsen Scott was 1.2 ppm for 1981–92.

Monthly atmospheric CO₂ mixing ratios at the South Pole.

CITE AS: Conway, T.J., P.P. Tans, and L.S. Waterman. 1994. Atmospheric CO₂ records from sites in the NOAA/CMDL air sampling network. pp. 41–119. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL
air sampling network

T.J. Conway, P.P. Tans, and L.S. Waterman (continued)

*South Pole
Antarctica
Ice and snow-
covered plateau
89°59' S, 24°48' W
210 m above MSL*

SOUTH POLE

Atmospheric Mixing Ratios of CO₂

CO₂ mixing ratios^a at the South Pole (ppm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1975	328.7	328.7	328.6	328.7	328.9	329.1	329.4	329.9	330.1	330.3	330.5	330.1	329.4
1976	329.4	329.2	329.2	329.4	329.6	329.8	330.2	330.7	331.1	331.5	331.5	331.1	330.2
1977	330.8	330.7	330.5	330.5	330.7	331.0	331.6	332.5	333.0	332.8	332.5	332.4	331.6
1978	332.4	332.4	332.3	332.6	333.2	333.5	333.9	334.4	334.9	335.3	335.3	334.8	333.8
1979	334.6	334.6	334.5	334.6	335.0	335.3	335.7	336.3	336.4	336.4	336.4	336.3	335.5
1980	336.0	335.6	335.5	335.7	336.3	336.9	337.0	337.1	337.3	337.5	337.6	337.5	336.7
1981	337.6	337.7	337.6	337.8	338.0	338.1	338.7	339.3	339.3	339.2	339.3	339.1	338.5
1982	338.9	338.6	338.5	338.7	339.0	339.1	339.4	339.8	340.1	340.2	340.0	339.8	339.3
1983	339.7	339.5	339.5	340.0	340.4	340.7	341.0	341.5	341.8	341.8	341.8	341.7	340.8
1984	341.6	341.5	341.5	341.4	341.6	341.8	342.2	342.7	343.0	343.1	343.0	342.9	342.2
1985	342.8	342.9	342.8	342.8	343.1	343.4	343.9	344.4	344.6	344.6	344.6	344.5	343.7
1986	344.4	344.2	344.1	344.2	344.4	344.7	345.0	345.6	345.9	345.9	345.8	345.7	345.0
1987	345.7	345.7	345.8	346.0	346.2	346.6	347.1	347.6	348.0	348.2	348.3	348.3	347.0
1988	348.1	347.9	348.0	348.2	348.4	348.7	349.1	349.5	349.8	349.9	349.9	349.8	348.9
1989	349.9	349.8	349.8	349.8	350.0	350.2	350.7	351.2	351.3	351.5	351.8	351.6	350.6
1990	351.0	350.8	350.7	351.0	351.4	351.6	351.9	352.3	352.5	352.7	352.7	352.6	351.8
1991	352.5	352.2	352.2	352.5	352.6	352.8	353.4	353.7	353.8	353.7	353.7	353.7	353.1
1992	353.5	353.0	352.9	353.1	353.5	353.9	354.4	354.8	355.0	355.0	354.9	354.8	354.1

^aAtmospheric CO₂ mixing ratios are expressed in parts per million (ppm) and reported in the Scripps Institution of Oceanography X85 manometric mole fraction scale. These monthly values were calculated by using a method combining a fit of a four-harmonic function and a quadratic trend with digital filtering of the residuals to obtain a smooth curve. The monthly means were then actually calculated by using weekly values from the curve.

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STATION "C"

Trends

The ocean sampling site on Ocean Station "Charlie", in the North Atlantic, was operated in cooperation with NOAA's National Weather Service from November 1968 to May 1973. The annual atmospheric CO₂ mixing ratio at Ocean Station "C" rose from 324.0 parts per million (ppm) in 1969 to 327.5 ppm in 1972.

Atmospheric CO₂ mixing ratios from this North Atlantic site show a seasonal pattern: the annual minimum typically occurs in August; the annual maximum, in April–May.

Monthly atmospheric CO₂ mixing ratios at Station "C".

CITE AS: Conway, T.J., P.P. Tans, and L.S. Waterman. 1994. Atmospheric CO₂ records from sites in the NOAA/CMDL air sampling network. pp. 41–119. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL
air sampling network

T.J. Conway, P.P. Tans, and L.S. Waterman (continued)

STATION "C"

Station "C"
North Atlantic Ocean
Open ocean
54°00' N, 35°00' W
6 m above MSL

Atmospheric Mixing Ratios of CO₂

CO₂ mixing ratios^a at Station "C" (ppm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1968											324.1	324.8	
1969	325.7	326.5	326.9	327.9	328.4	325.2	320.8	318.0	318.4	321.1	323.7	325.8	324.0
1970	327.9	329.2	330.4	330.8	329.0	326.1	322.5	319.8	321.1	324.8	327.2	327.7	326.4
1971	329.0	331.2	331.5	331.1	330.0	326.9	322.6	319.0	319.6	324.2	327.3	329.4	326.8
1972	331.1	331.0	331.4	333.1	332.2	326.7	321.0	319.5	320.7	325.2	328.5	330.0	327.5
1973	331.8	332.8	333.7	334.7	334.2								

^aAtmospheric CO₂ mixing ratios are expressed in parts per million (ppm) and reported in the Scripps Institution of Oceanography X85 manometric mole fraction scale. These monthly values were calculated by using a method combining a fit of a four-harmonic function and a quadratic trend with digital filtering of the residuals to obtain a smooth curve. The monthly means were then actually calculated by using weekly values from the curve.

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STATION "M"

Trends

The Ocean Station "M" sampling site, in the North Atlantic, is operated in cooperation with the Norway Meteorological Institute. The NOAA/CMDL flask data from Ocean Station "M" show an increase in the annual value from 341.8 parts per million (ppm) in 1982 to 356.5 ppm in 1992, or 1.47 ppm per year. Conway et al. (1994) reported a global growth rate of 1.43 ppm per year during 1981–92 for all NOAA/CMDL flask sampling sites. Conway et al. (1993) found the CO₂ and CH₄ flask data from Station "M" were highly correlated during winter, and suggested the CO₂ variations observed in the Arctic atmosphere during winter are due primarily to variations in emissions and transport of CO₂ from Europe and Asia.

Atmospheric CO₂ concentrations at Ocean Station "M" show a seasonal pattern, with the annual minimum occurring in August or September and the annual maximum occurring in March or April. Conway et al. (1994) reported that the peak-to-trough seasonal amplitude for Ocean Station "M" was 15.0 ppm for 1981–92.

Monthly atmospheric CO₂ mixing ratios at Station "M."

CITE AS: Conway, T.J., P.P. Tans, and L.S. Waterman. 1994. Atmospheric CO₂ records from sites in the NOAA/CMDL air sampling network. pp. 41–119. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL
air sampling network

T.J. Conway, P.P. Tans, and L.S. Waterman (continued)

STATION "M"

Station "M"
North Atlantic Ocean
Open ocean
66°00' N, 2°00' E
6 m above MSL

Atmospheric Mixing Ratios of CO₂

CO₂ mixing ratios^a at Station "M" (ppm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1981			345.5	345.6	346.4	344.8	337.4	332.9	335.1	339.3	342.7	344.1	
1982	344.7	345.4	345.9	346.0	345.8	344.7	338.8	332.4	333.2	338.1	342.0	344.3	341.8
1983	345.1	345.4	346.9	347.4	346.3	344.2	338.6	333.9	335.5	340.5	343.6	345.9	342.8
1984	347.5	348.1	349.1	349.5	347.9	345.3	340.2	336.0	339.0	342.8	345.0	347.1	344.8
1985	348.4	349.3	350.6	351.5	351.0	347.6	341.4	336.8	338.1	342.5	346.6	349.4	346.1
1986	350.9	351.2	352.4	353.2	351.7	348.6	343.9	338.9	339.1	344.0	348.5	350.6	347.8
1987	351.5	352.7	353.5	353.5	352.7	350.3	345.4	341.0	341.0	345.4	350.2	352.2	349.1
1988	354.3	355.8	355.9	356.5	356.0	353.9	348.3	343.2	345.0	350.0	353.6	355.5	352.3
1989	356.6	357.5	358.1	358.4	358.1	355.9	350.1	345.1	346.2	351.0	354.8	356.9	354.1
1990	358.2	359.3	359.8	359.7	358.9	355.2	348.9	345.4	347.3	352.0	355.1	357.4	354.8
1991	359.3	360.7	361.3	361.0	360.6	357.7	352.0	347.9	349.1	352.9	356.8	359.0	356.5
1992	359.6	360.3	361.8	362.4	361.2	358.1	352.5	346.8	347.7	352.3	356.7	359.0	356.5

^aAtmospheric CO₂ mixing ratios are expressed in parts per million (ppm) and reported in the Scripps Institution of Oceanography X85 manometric mole fraction scale. These monthly values were calculated by using a method combining a fit of a four-harmonic function and a quadratic trend with digital filtering of the residuals to obtain a smooth curve. The monthly means were then actually calculated by using weekly values from the curve.

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SYOWA STATION

Trends

The sampling site at Syowa is operated in cooperation with the Japanese Antarctic Research Expedition and the National Institute for Polar Research. The first NOAA/CMDL flask air samples from Syowa were collected in 1986. The annual atmospheric CO₂ mixing ratio at Syowa rose from 349.3 parts per million (ppm) in 1988 to 354.2 ppm in 1992, or 1.23 ppm per year.

Atmospheric CO₂ mixing ratios at this Antarctic site show a seasonal pattern: the annual drawdown typically occurs in January–April, and the annual buildup occurs in September–December. As in the CO₂ records from other Antarctic sites, the seasonal amplitude is quite small, no more than a few parts per million.

Monthly atmospheric CO₂ mixing ratios at Syowa Station.

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Atmospheric CO₂ records from sites in the NOAA/CMDL
air sampling network

T.J. Conway, P.P. Tans, and L.S. Waterman (continued)

SYOWA STATION

Syowa Station
Antarctica
69°00' S, 39°35' E
11 m above MSL

Atmospheric Mixing Ratios of CO₂CO₂ mixing ratios^a at Syowa Station (ppm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1986		344.9	344.7	344.6	344.7	345.0	345.5	346.2	346.3	346.3	346.3	346.0	
1987													
1988	348.0	348.5	348.6	348.5	348.8	348.9	349.5	350.3	350.2	350.0	350.3	350.1	349.3
1989													
1990	351.6	352.0	351.9	351.4	351.6	351.9	352.1	352.5	352.7	353.1	353.6	353.0	352.3
1991	352.3	352.3	352.6	352.7	352.8	353.1	353.6	354.0	353.9	353.8	353.9	353.8	353.2
1992	353.4	353.1	353.0	353.1	353.5	354.1	354.5	354.9	355.1	355.2	355.2	354.8	354.2

^aAtmospheric CO₂ mixing ratios are expressed in parts per million (ppm) and reported in the Scripps Institution of Oceanography X85 manometric mole fraction scale. These monthly values were calculated by using a method combining a fit of a four-harmonic function and a quadratic trend with digital filtering of the residuals to obtain a smooth curve. The monthly means were then actually calculated by using weekly values from the curve.

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TAE-AHN PENINSULA

Trends

The sampling site at Tae-ahn Peninsula, South Korea, is operated in cooperation with the Korean National University of Education. The first NOAA/CMDL flask air samples from Tae-ahn were collected in late 1990. The annual atmospheric CO₂ mixing ratio at Tae-ahn Peninsula rose from 359.8 parts per million (ppm) in 1991 to 360.6 ppm in 1992; the growth rate is comparable to those seen at other monitoring sites around the world for the same period.

Monthly atmospheric CO₂ mixing ratios at Tae-ahn Peninsula.

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Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL
air sampling network

T.J. Conway, P.P. Tans, and L.S. Waterman (continued)

TAE-AHN PENINSULA

Tae-ahn Peninsula
South Korea
Vegetation-covered peninsula
36°44' N, 126°08' E
20 m above MSL

Atmospheric Mixing Ratios of CO₂

CO₂ mixing ratios^a at Tae-ahn Peninsula (ppm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1990											360.9	361.3	
1991	362.5	364.2	364.5	364.0	362.6	358.0	354.8	353.8	354.4	357.0	359.6	362.4	359.8
1992	364.0	365.2	367.4	369.1	367.0	357.9	350.8	347.5	351.8	359.2	362.9	364.8	360.6

^aAtmospheric CO₂ mixing ratios are expressed in parts per million (ppm) and reported in the Scripps Institution of Oceanography X85 manometric mole fraction scale. These monthly values were calculated by using a method combining a fit of a four-harmonic function and a quadratic trend with digital filtering of the residuals to obtain a smooth curve. The monthly means were then actually calculated by using weekly values from the curve.

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ULAAN UUL

Trends

The NOAA/CMDL sampling site at Ulaan Uul, Mongolia, is operated in cooperation with the Mongolian Hydrometeorological Research Institute. The first NOAA/CMDL flask air samples from Ulaan Uul were collected in 1992. The 1992 annual atmospheric CO₂ mixing ratio of 356.3 parts per million is comparable to other Asian measurements (e.g., Qinghai Province). During the first year of measurements, the minimum mixing ratios were measured during July, and the maximum mixing ratios, during April.

Monthly atmospheric CO₂ mixing ratios at Ulaan Uul.

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Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL
air sampling network

T.J. Conway, P.P. Tans, and L.S. Waterman (continued)

ULAAN UUL

Ulaan Uul
Mongolia
44°27' N, 111°06' E
914 m above MSL

Atmospheric Mixing Ratios of CO₂

CO₂ mixing ratios^a at Ulaan Uul (ppm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1992	359.1	361.1	362.2	364.1	361.7	353.6	346.8	347.8	351.5	354.4	355.7	357.2	356.3

^aAtmospheric CO₂ mixing ratios are expressed in parts per million (ppm) and reported in the Scripps Institution of Oceanography X85 manometric mole fraction scale. These monthly values were calculated by using a method combining a fit of a four-harmonic function and a quadratic trend with digital filtering of the residuals to obtain a smooth curve. The monthly means were then actually calculated by using weekly values from the curve.

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Atmospheric CO₂ records from sites in the NOAA/CMDL air sampling network

T.J. Conway, P.P. Tans, and L.S. Waterman (continued)

VIRGIN ISLANDS

Trends

The NOAA/CMDL sampling site at St. Croix, Virgin Islands, was operated in cooperation with Fairleigh Dickinson University. The NOAA/CMDL flask data from the Virgin Islands show an increase in the annual atmospheric CO₂ mixing ratio from 340.4 parts per million (ppm) in 1981 to 353.5 ppm in 1989, or 1.64 ppm per year. Conway et al. (1994) reported a global growth rate of 1.43 ppm per year during 1981–92 for all NOAA/CMDL flask-sampling sites.

Atmospheric CO₂ mixing ratios at the Virgin Islands show a seasonal pattern: the annual minimum is observed in September or October; the annual maximum in April–May. Conway et al. (1994) found that the average peak-to-peak amplitude at the Virgin Islands during 1981–92 was 7.7 ppm. Unlike the data from a majority of stations in the NOAA/CMDL flask sampling network during 1981–84, the data from the Virgin Islands did not show a growth rate minimum in 1982 and a growth rate maximum in 1983. Instead, the Virgin Islands data exhibited large oscillations in their growth rate throughout the data record.

Monthly atmospheric CO₂ mixing ratios at the Virgin Islands.

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Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL
air sampling network

T.J. Conway, P.P. Tans, and L.S. Waterman (continued)

VIRGIN ISLANDS

Virgin Islands, U.S. (St. Croix)
Atlantic Ocean
Island seashore
17°45' N, 64°45' W
3 m above MSL

Atmospheric Mixing Ratios of CO₂

CO₂ mixing ratios^a at the Virgin Islands (ppm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1979			339.7	340.6	340.6	338.8	334.7	332.5	333.4	334.8	336.2	337.7	
1980									335.4	335.8	338.1	340.0	
1981	341.0	341.8	342.8	343.8	343.2	342.0	340.7	337.9	336.3	336.8	338.2	340.0	340.4
1982	342.0	343.0	343.4	343.9	344.0	343.2	341.0	337.4	336.2	337.6	339.4	341.1	341.0
1983	342.0	343.0	344.6	344.9	344.2	344.6	342.3	339.1	339.7	339.8	338.9	340.4	342.0
1984	343.2	344.6	345.5	347.0	347.9	347.0	343.7	339.9	338.5	339.5	341.1	343.5	343.5
1985	345.6	345.9	346.3	347.6	348.6	348.3	345.9	343.3	342.3	342.5	344.1	345.8	345.5
1986	346.4	347.5	348.9	349.3	349.4	349.1	346.7	344.2	343.1	343.9	345.6	347.1	346.8
1987	347.9	349.0	350.7	351.6	351.0	349.6	348.2	346.7	345.5	345.5	347.2	349.2	348.5
1988	350.4	351.7	353.0	354.0	354.6	353.6	351.0	348.8	348.4	349.1	350.6	352.1	351.4
1989	353.3	354.1	354.8	355.9	356.7	355.5	353.4	351.3	350.3	350.7	352.2	353.8	353.5
1990	354.6	355.6	356.6	357.3	357.6	357.0	354.4	351.6					

^aAtmospheric CO₂ mixing ratios are expressed in parts per million (ppm) and reported in the Scripps Institution of Oceanography X85 manometric mole fraction scale. These monthly values were calculated by using a method combining a fit of a four-harmonic function and a quadratic trend with digital filtering of the residuals to obtain a smooth curve. The monthly means were then actually calculated by using weekly values from the curve.

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Atmospheric CO₂ records from sites in the NOAA/CMDL
air sampling network

T.J. Conway, P.P. Tans, and L.S. Waterman (continued)

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Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the NOAA/CMDL
air sampling network

T.J. Conway, P.P. Tans, and L.S. Waterman (continued)

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| Alert • Cape St. James • Estevan Point • Sable Island

Period of Record

1975–94 (varies by site)

Methods

Air samples are collected approximately once per week, between 12:00 and 16:00 local time, in a pair of evacuated 2-L thick-wall borosilicate glass flasks. Samples are collected under preferred conditions of wind speed and direction (i.e., upwind of the main station and when winds are strong and steady). The flasks are evacuated to pressures of $\sim 1 \times 10^{-4}$ mbar or 0.01 Pa prior to being sent to the stations. The air is not dried during sample collection.

The Atmospheric Environment Service (AES) designed a new grab type flask in 1989. The new flasks are 2 L in volume and have single glass-barreled, high-vacuum stopcocks with double Buna-N o-ring seals. The flasks are made of borosilicate glass and have a UV protective plastic coating. Field tests are currently being carried out at Alert to assess the suitability of the new flasks. The new flask is being used during the same sampling period as the greased stopcock flask, and the results are being compared. It is hoped that the new flasks will soon replace the greased stopcock type flasks in the sampling network.

An alternate method of flask sampling, currently ongoing at Alert and Estevan Point, involves pressurizing a flask by using a pumping unit connected to a sample line. The flask has both an inlet valve and an outlet valve so that the flask can be completely flushed with sample air and any contamination can be removed from the flask before it is pressurized

*Sites in the
Atmospheric
Environment
Service air
sampling network.*

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Atmospheric CO₂ records from sites in the AES air sampling network

N.B.A. Trivett, V.C. Hudec, and C.S. Wong (continued)

with sample air. Because of the possible advantages of this method, a new double-valved sampling flask was designed for use in a pressurized flask sampling program. The new 2-L flasks are composed of borosilicate glass and have two glass-barrelled, high-vacuum stopcocks with double Buna-N o-rings. The flasks are also plastic coated and have a specially designed internally anchored glass delivery inlet tube with outlet ports, to ensure complete flushing of the flask during sampling. A pressurized flask sampling program was implemented at Estevan Point in January 1993 and at Alert in June 1993. The pressurized samples will be directly compared with the evacuated grab samples taken during the same time period at the site.

From 1975 to 1988, flask samples were analyzed for CO₂ concentrations at the Institute of Ocean Sciences (IOS) by using a URAS 2T nondispersive infrared analyzer (NDIR). From 1988 through 1991, AES analyzed samples on URAS 3E and UNOR 6N NDIR analyzers. Currently, a Siemens ULTRAMAT III NDIR is used for CO₂ flask determinations. All samples are dried before entering the analyzer. Since March 1989, the calibration gases used have been CO₂ in natural air mixtures. Before that time, CO₂-in-nitrogen and CO₂-in-synthetic air mixtures were used for calibration. All of the calibration gases are traceable to the Scripps Institution of Oceanography scales. More details about the sampling methods used in the Canadian flask-sampling program are provided in Trivett and Higuchi (1989).

To be considered indicative of background conditions, flask pairs must agree within 0.6 parts per million by volume (ppmv), and aliquots from the same flask must agree within 0.3 ppmv. Flasks that meet these criteria are retained for time series analysis to determine trends and seasonal cycles. For further details on data selection criteria, see Trivett and Higuchi (1989).

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ALERT

Trends

Alert is located ~800 km from the North Pole on the northern tip of Ellesmere Island. Currently, both continuous and grab flask sampling programs are conducted at Alert. The flask data from Alert show an increase in the annual atmospheric CO₂ concentration from 341.35 parts per million by volume (ppmv) in 1981 to 357.21 ppmv in 1991. Trivett and Higuchi (1989) reported that the mean annual rate of increase, obtained from the slope of a least squares regression line through the annual averages, for Alert was 1.49 ppmv per year.

Atmospheric CO₂ concentrations at Alert show a seasonal pattern: the annual minimum occurs during the late summer (August–September); the annual maximum, during the early spring (April–May).

Atmospheric CO₂ concentrations from Alert.

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Atmospheric CO₂ records from sites in the AES air sampling network

N.B.A. Trivett, V.C. Hudec, and C.S. Wong (continued)

ALERT

Alert
Northwest Territories, Canada
Tundra (snow covered for almost
three quarters of the year)
82°28' N, 62°30' W
210 m above MSL

Atmospheric Concentrations of CO₂CO₂ concentrations^a at Alert (ppmv)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1975							329.98				333.49		
1976	335.64	336.72	338.05		338.48		329.60	323.61		331.92	332.61	338.65	
1977	336.32		339.00		340.03	338.56	331.55	327.17	325.98	330.81	334.25	338.84	
1978		339.74	341.57	341.16	340.67	340.22	332.81	327.19	327.57	333.54			
1979		339.94	342.42	341.64	343.52	340.59	334.35	329.50		334.15	336.09		
1980	341.28	343.25		343.56	344.49	343.57		331.40		336.65	340.51		
1981	344.31	345.82	344.38	345.78	346.36	343.04	336.57	333.03	334.64	335.80	341.79	344.70	341.35
1982	345.64	348.28	348.34	348.63	347.49	346.10	342.77	334.84		338.51	342.95	345.11	
1983	347.34	347.50	348.09	348.66	349.20	346.02	346.20	336.58	336.46	341.53	345.24		344.80
1984	347.57	350.48	350.03	350.09	350.85				337.78	341.74	345.34		
1985		349.14	350.27	351.68	352.40	350.09	343.56	338.03	339.85	343.73		346.77	
1986	351.12	351.46	352.95	353.09	353.54	349.43	345.92	340.89	340.09	342.57	348.09	350.29	348.29
1987		352.37	353.89	354.48	354.84	352.44	346.17	339.90	341.15	346.57	349.57	352.95	
1988	352.03	355.05	356.60	357.87	357.70				346.56		354.36	358.01	
1989	357.25	363.11		359.73	359.26	357.42	349.96	344.86	347.39	350.92	354.10	359.67	
1990	359.69	360.19	360.57	360.75	360.31	356.75	350.53	345.84	347.87	352.19	356.20	358.02	355.74
1991	360.88	361.04	360.85	361.83	361.48	358.96	353.56	347.63	349.11	353.77	358.35	359.08	357.21
1992	359.52	362.80	363.85	363.04	363.15	362.58	353.03	347.62	348.25	352.72	357.67	362.57	358.07
1993	361.92	362.86	363.03	364.73	364.31	361.40	354.50	349.76	349.76	356.89	356.95	361.03	358.93
1994	363.02												

^aAtmospheric CO₂ concentrations are expressed in parts per million by volume (ppmv) and reported in the Scripps Institution of Oceanography X85 manometric mole fraction scale. Monthly values represent the arithmetic mean of the paired flask values for a given month as calculated by CDIAC. Annual means are the arithmetic means of the monthly values and are calculated by CDIAC. Annual means are provided only for years with complete monthly records.

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CAPE ST. JAMES

Trends

For Cape St. James, Trivett and Higuchi (1989) reported that the mean annual rate of increase, obtained from the slope of a least-squares regression line through the annual averages, was 1.43 ppmv per year.

In August 1992, the weather station at Cape St. James was automated; as a result, the flask sampling program was discontinued at this site. Estevan Point, on the West Coast of Vancouver Island, was chosen as a replacement station. The record for Estevan Point is presented on the following pages and will be included in future issues of *Trends*.

Atmospheric CO₂ concentrations from Cape St. James.

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Atmospheric CO₂ records from sites in the AES air sampling network

N.B.A. Trivett, V.C. Hudec, and C.S. Wong (continued)

Cape St. James

CAPE ST. JAMES

*Cape St. James
British Columbia, Canada
Island seashore
51°56' N, 131°01' W
89 m above MSL*

Atmospheric Concentrations of CO₂CO₂ concentrations^a at Cape St. James (ppmv)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1979					341.75		336.12	327.81	330.63	334.75		340.18	
1980		340.00	342.55		343.14	341.66	334.04	328.51	331.85	337.79	341.18		
1981	342.75								334.00	338.34	341.59	343.23	
1982	343.46	345.00		345.70	347.96			337.33	334.29	339.13	342.61	342.68	
1983	344.62	346.86	345.76					334.42	336.31	341.16	345.24		
1984												346.46	
1985			350.41	351.60	351.49	348.72			340.08	344.90			
1986	349.26	349.81	350.83	352.30	352.32	346.95			341.00	345.71			
1987								341.77	344.47	346.61	348.54		
1988	354.03	353.64	354.38	356.58	355.75	353.01	349.73	341.47		350.97	353.37	354.18	
1989	356.76	356.56	357.29	357.84		355.88	348.46		348.00	351.86	353.05	355.99	
1990	360.12	359.05	358.64	360.22	358.82	355.36		346.99	347.99	352.77	358.15	359.12	
1991	359.15		361.53	361.48	361.97	357.94	355.52	347.33	348.86	351.40	357.69	358.50	
1992	359.57	360.88	360.80	360.74		360.43	354.64						

^aAtmospheric CO₂ concentrations are expressed in parts per million by volume (ppmv) and reported in the Scripps Institution of Oceanography X85 manometric mole fraction scale. Monthly values represent the arithmetic mean of the paired flask values for a given month as calculated by CDIAC. Annual means are the arithmetic means of the monthly values and are calculated by CDIAC. Annual means are provided only for years with complete monthly records.

CITE AS: Trivett, N.B.A., V.C. Hudec, and C.S. Wong. 1994. Atmospheric CO₂ records from sites in the AES air sampling network. pp. 120–130. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

ESTEVAN POINT

Trends

Sampling at Estevan Point started in 1992; thus, the monthly and annual CO₂ record from Estevan Point is too short to show any long-term trends. During the period of overlap in 1992 and 1993, the CO₂ concentration values and the amplitude of the monthly record from Estevan Point are similar to those from Cape St. James. The 1993 records from Estevan Point show the expected seasonal oscillation: minimum concentrations are measured during August, and maximum values, during the late winter and spring.

Atmospheric CO₂ concentrations from Estevan Point.

CITE AS: Trivett, N.B.A., V.C. Hudec, and C.S. Wong. 1994. Atmospheric CO₂ records from sites in the AES air sampling network. pp. 120-130. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric CO₂ records from sites in the AES air sampling network

N.B.A. Trivett, V.C. Hudec, and C.S. Wong (continued)

ESTEVAN POINT

Estevan Point
British Columbia, Canada
Samples are taken from
a lighthouse tower or from
a rocky beach
49°23' N, 126°33' W
39 m above or at MSL

Atmospheric Concentrations of CO₂CO₂ concentrations^a at Estevan Point (ppmv)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
Evacuated Flasks													
1992						359.41	354.10	351.23	350.63	356.43	355.97		
1993	359.67		360.00	361.30		359.92	353.85	348.49	354.05	358.03			
Pressurized Flasks													
1993	359.50	363.79	362.42	362.06		358.94	353.25	349.58	352.24	356.32	356.83		
1994	359.13												

^aAtmospheric CO₂ concentrations are expressed in parts per million by volume (ppmv) and reported in the Scripps Institution of Oceanography X85 manometric mole fraction scale. Monthly values represent the arithmetic mean of the paired flask values for a given month as calculated by CDIAC. Annual means are the arithmetic means of the monthly values and are calculated by CDIAC. Annual means are provided only for years with complete monthly records.

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SABLE ISLAND

Trends

The sampling site at Sable Island, off the coast of Nova Scotia, was established in 1975. The flask data from Sable Island show an increase in the annual atmospheric CO₂ concentration from 334.49 parts per million by volume (ppmv) in 1977 (the first full year of data) to 356.02 ppmv in 1990. For Sable Island, Trivett and Higuchi (1989) reported that the mean annual rate of increase, obtained from the slope of a least-squares regression line through the annual averages, was 1.48 ppmv per year.

Atmospheric CO₂ concentrations from Sable Island.

CITE AS: Trivett, N.B.A., V.C. Hudec, and C.S. Wong. 1994. Atmospheric CO₂ records from sites in the AES air sampling network. pp. 120–130. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric CO₂ records from sites in the AES air sampling network

N.B.A. Trivett, V.C. Hudec, and C.S. Wong (continued)

SABLE ISLAND

Sable Island
Nova Scotia, Canada
Dry summit of a sea ridge
43°56' N, 60°01' W
5 m above MSL

Atmospheric Concentrations of CO₂CO₂ concentrations^a at Sable Island (ppmv)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1975			336.04	336.63	335.01					330.51	336.93	335.61	
1976		338.22	337.10	338.33				322.64	325.21	333.63	333.20	334.98	
1977	337.20	337.31	339.70	337.27	337.45	331.12	330.48	327.53	328.60	334.22	335.99	337.03	334.49
1978	337.39	340.03	342.21	344.53	338.02	334.00	328.95	328.99	325.67	335.83	339.94	339.78	336.28
1979	342.17	340.05	341.09		340.71	338.95	330.28	330.20	328.57			339.94	
1980	343.36	342.36	342.55	344.09	342.03	340.37	337.65	329.09	331.45	340.53	343.42	342.02	339.91
1981		354.25	346.61	342.31				328.11	340.49	339.33	340.02		
1982	348.87	347.06	346.94	347.25	345.08	339.20	340.54	331.00	336.38	341.00	339.91		
1983			347.89		347.30	344.11	340.60		333.22	341.10	343.97	347.73	
1984	350.03	346.66	350.24	349.83	350.22	346.14	343.88	336.77		341.67	347.32	350.66	
1985	349.82	354.66	351.94	349.11	349.47	344.48	344.05	337.24	337.19	344.35	347.12	349.70	346.59
1986	353.08	351.14	350.50	352.29	349.25	347.78	343.22	349.90	340.03	346.82	348.91	352.58	348.79
1987	350.47	352.49	352.74	350.69	352.49		342.01	343.07	341.34	345.18	354.02	356.50	
1988	358.72	356.76	355.92	358.05	354.78	351.70	347.78	342.94	347.05	352.25	353.02	356.66	352.97
1989	364.09	359.25	359.88	360.11	360.94	354.81	354.66	342.45	348.60	356.38	358.01	357.18	356.36
1990	361.62	359.95	357.92	358.79	355.69	354.76	357.51	346.82	347.90	352.82	358.05	360.39	356.02
1991	359.74	361.09		360.68	361.23	357.21	359.12	348.91	351.52			361.09	
1992		363.84		360.96	362.29	361.32	355.90		350.63	356.91		362.47	
1993	361.89		364.21	362.82			351.84		352.46	360.87			

^aAtmospheric CO₂ concentrations are expressed in parts per million by volume (ppmv) and reported in the Scripps Institution of Oceanography X85 manometric mole fraction scale. Monthly values represent the arithmetic mean of the paired flask values for a given month as calculated by CDIAC. Annual means are the arithmetic means of the monthly values and are calculated by CDIAC. Annual means are provided only for years with complete monthly records.

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Atmospheric CO₂ record from in situ measurements at Amsterdam Island

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91198 Gif Sur Yvette Cedex, France

Period of Record

1980–92

Methods

Air samples are collected continuously through an air intake located at the top of a tower, 9 m above ground and 70 m above mean sea level. The air is dried by means of a cryogenic water trap. Until 1990, determinations of CO₂ were made by using two Hartmann-Braun URAS 2T nondispersive infrared (NDIR) analyzers. Since 1991, CO₂ determinations have been made using a Siemens ULTRAMAT 5F NDIR. Standard gases in use from October 1980 to December of 1984 were CO₂-in-N₂ mixtures certified by Scripps Institution of Oceanography (SIO). The scale in N₂ was corrected for the carrier gas effect to obtain a correct scale for air during all of this period. Since March 1985, CO₂-in-air mixtures certified by SIO have been used. The primary gas standards used for CO₂ determinations at the Centre des Faibles Radioactivites' Laboratoire mixte CNRS-CEA have been certified by SIO. Collaborative efforts with SIO have been conducted to check for carrier gas effects. Hourly mean CO₂ concentrations are compared with hourly mean meteorological conditions (i.e., wind direction and velocity). For the samples to be considered indicative of background air conditions, the following criteria must be met: (1) wind direction must be from 260–300° and wind velocity must be >8 m/s, or wind direction must be from 300–360° or 0–50° and wind velocity must be ≥5 m/s and (2) the individual hourly means must be part of a sequence of four consecutive hours where the above conditions are met. The wind criteria are indicative of maritime air masses, and cancel southerly winds, which are frequent. Data are reported in the Centre des Faibles Radioactivites' 1990 scale. During the fall of 1990, the scale was intercalibrated within 0.05 parts per million (ppm) with the New Zealand DSIR laboratory and is in good agreement with the last SIO scale available. Currently, the Centre des Faibles Radioactivites is waiting for a more direct calibration through the use of standards recently certified by SIO. For further details on the sampling methods, reference gases, and data selection criteria, see Gaudry et al. (1983, 1991).

Amsterdam Island
Indian Ocean
Island seashore cliff
37°47' S, 77°31' E
70 m above MSL

CITE AS: Gaudry, A., P. Monfray, G. Bonsang, V. Kazan, G. Polian, and G. Lambert. 1994. Atmospheric CO₂ record from in situ measurements at Amsterdam Island. pp. 131–134. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

AMSTERDAM ISLAND

Trends

The Centre des Faibles Radioactivites has been monitoring atmospheric CO₂ concentrations since May 1980 at the station of Amsterdam Island, Territoire des Terres Australes et Antarctiques Francaises. The station, 5000 km off South Africa, is part of the Background Air Pollution Monitoring Network (BAPMoN) of the World Meteorological Organization (WMO). The sampling point is located at the north-northwest end of the island, on the edge of a 55-m high cliff. For further details on the site and sampling methods at Amsterdam Island see Gaudry et al. (1983).

The yearly mean concentrations increased from 338.6 parts per million (ppm) in 1981 to 354.2 ppm in 1992; however, the annual rate of increase varied significantly during this period. The modulation of this increase rate is recognized to be well in phase with the Southern Oscillation Index (SOI) or the Sea Surface Temperature Anomaly, both observed during El Niño Southern Oscillation events (1982–83 and 1987–88) (Ascensio-Parvy et al. 1984; Gaudry et al. 1987; Gaudry et al. 1991).

The seasonal variations display a very weak peak-to-trough magnitude and present two maxima and minima: January maximum (+0.13 ppm); May minimum (–0.35 ppm); August maximum (+0.34 ppm); November minimum (–0.07 ppm) (Monfray et al. 1987; unpublished data).

Nonseasonal variations are not significantly influenced by fast advections from South Africa (Gaudry et al. 1991). The same has recently been recognized for seasonal variations.

Monthly atmospheric CO₂ concentrations at Amsterdam Island.

CITE AS: Gaudry, A., P. Monfray, G. Bonsang, V. Kazan, G. Polian, and G. Lambert. 1994. Atmospheric CO₂ record from in situ measurements at Amsterdam Island. pp. 131–134. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric CO₂ record from in situ measurements at Amsterdam Island

A. Gaudry, P. Monfray, G. Bonsang, V. Kazan, G. Polian, and G. Lambert (continued)

AMSTERDAM ISLAND

Atmospheric Concentrations of CO₂CO₂ concentrations^a at Amsterdam Island (ppmv)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1980					337.3	337.5	337.7	337.8	337.8	337.8	337.8	338.0	337.7
1981	338.4	338.4	338.3	338.3	338.5	338.2	338.4	339.0	338.7	338.8	338.9	339.1	338.6
1982	339.2	339.3	339.4	339.2	339.0	339.1	339.2	340.0	339.9	339.7	339.7	339.6	339.4
1983	340.0	340.3	340.3	340.6	340.8	341.1	341.8	341.9	341.9	341.8	341.8	342.2	341.2
1984	341.9	341.6	341.7	341.7	341.6	341.9	342.0	342.6	343.2	342.8	342.7	342.7	342.2
1985	343.6 ^b	343.7 ^b	343.5 ^b	343.6	343.4	343.5	343.8	344.2	344.2	344.2	344.1	344.2	343.8
1986	344.4	344.6	344.7	344.3	344.4	344.7	345.1	345.6	345.6	345.8	345.8	346.7 ^b	345.1
1987	346.2	346.3	346.1	346.1	346.4	346.8	347.2	347.6	347.7	347.9	348.0	348.6	347.1
1988	349.2	348.5	348.3	348.2	348.4	348.6	349.5	350.1	349.5	350.5	350.0	350.0 ^b	349.2
1989	350.2 ^b	350.1 ^b	349.9	350.0	349.9	350.1	350.7	351.0	351.1	351.0	350.7	351.4	350.5
1990	351.2	351.5	351.2	351.2	351.5	351.7	352.0	352.4	352.4	352.6	352.7	352.9	351.9
1991	352.8 ^b	352.7	352.9	352.9	352.8	352.9	353.4	353.6	353.4	353.4	353.4	353.3	353.2
1992	353.7	353.6	353.6	353.6	353.7	354.2	354.6	354.9	354.9	354.8	354.5	354.7	354.2

^aMonthly and annual mean values correspond to background conditions at Amsterdam Island (program conducted by the Centre des Faibles Radioactivités).

^bSimulated values are calculated by using the long-term trend and the mean seasonal variations.

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Atmospheric CO₂ records from sites in the UBA air sampling network

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Umweltbundesamt, Frankfurter Str. 135, 63067 Offenbach/Main, Germany

| Brotjacklriegel • Deuselbach • Schauinsland • Waldhof • Westerland

Period of Record

1972–93 (varies by site)

Methods

Air samples are collected from air intake lines. Continuous monitoring of atmospheric CO₂ is accomplished by alternating a flowing sample of ambient air with two reference gases of known concentrations. Determinations of CO₂ are made using a Siemens ULTRAMAT-3 nondispersive infrared gas analyzer. Before entering the analyzer, all gases are dried by passing them through a glass water vapor trap immersed in a cold alcohol bath. Mixtures of CO₂-in-N₂ are used for calibration gases. At Schauinsland, CO₂-in-air calibration gases were used until September 1, 1991. More details about the UBA air sampling network and the methods used are provided in Grosch et al. (1981), Levin (1991), and Levin et al. (1994).

Only technically biased values resulting from calibration problems or equipment malfunctions are removed. Daily values are calculated on the basis of half-hourly mean values. Carrier gas corrections have been determined experimentally and applied on the basis of five CO₂-in-air standards calibrated by Scripps Institution of Oceanography in 1988. The relative precision of the half-hourly readings is ~1 part per million by volume (ppmv).

*Umweltbundesamt
monitoring sites.*

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BROTJACKLRIEGEL

Trends

Annual atmospheric CO₂ concentrations at Brotjacklriegel rose from 331.63 parts per million by volume (ppmv) in 1972 to 353.12 ppmv in 1988. Because of the site's forest location, the monthly atmospheric CO₂ record from Brotjacklriegel exhibits very large seasonal amplitude. This amplitude reached almost 40 ppmv in 1985. Minimum mixing ratios are recorded at Brotjacklriegel during July–September; maximum values, during November–March.

Monthly atmospheric CO₂ concentrations at Brotjacklriegel.

Atmospheric CO₂ records from sites in the UBA air sampling network

W. Fricke and M. Wallasch (continued)

BROTJACKLRIEGEL*Brotjacklriegel**Germany**Mountain peak in a low mountain range, forest environment**48°49' N, 13°13' E**1016 m above MSL***Atmospheric Concentrations of CO₂**CO₂ concentrations^a at Brotjacklriegel (ppmv)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1972	340.04	339.83	336.54	334.28	329.83	324.61	325.80	322.31	324.28	332.15	335.43	334.46	331.63
1973	339.82	340.86	340.71	336.45	332.34	326.92	326.52	324.34	329.21	334.23	336.88	338.97	333.94
1974	340.08	342.78	340.75	335.10	333.02	329.94	328.00	330.63	327.84	335.25	337.94	337.29	334.89
1975	335.64	337.58	339.98	336.97	329.09	327.21	326.32	328.68	331.65	341.42	351.37	346.06	336.00
1976	339.55	343.53	343.77	340.52	334.19	329.45	331.41	324.24	328.65	339.22	342.93	340.65	336.51
1977	343.74	340.73	340.95	339.36	333.72	331.41	323.94	325.44	332.07	339.34	341.35	342.92	336.25
1978	345.48	348.89	346.42	344.39	339.94	335.63	324.92	326.38	330.09	338.12	339.12	341.64	338.42
1979	347.95	346.22	343.22	343.44	337.44	333.01	330.55	328.75	329.75	337.22	344.43	342.99	338.75
1980	347.58	347.70	349.21	346.55	339.47	336.10	331.15	329.95	332.17	338.50	346.96	347.72	341.09
1981	347.23	349.04	345.79	344.68	339.78	334.31	332.22	332.45	337.57	341.54	347.02	349.18	341.73
1982													
1983													
1984	357.09	361.37	361.92	360.47	347.95	341.72	340.60	339.69	343.61	347.44	356.06	361.81	351.64
1985	363.08	358.42	378.08	355.11		343.50	338.40	338.15	340.42	349.76	364.76	364.18	
1986	360.02	364.88	365.89	358.79	348.01	340.82	337.57					357.04	
1987	361.14	366.87	361.29	360.47	349.14	347.10			348.31	355.52	353.97	361.26	
1988	356.55	353.93	352.57	351.61	352.02	351.60	347.61	345.41	348.53	356.38	361.85	359.33	353.12
1989						351.28	353.15	352.87	356.42	358.86	365.50	363.31	
1990	357.60	358.56	360.88	359.77	350.88	350.15	347.77				364.09	360.42	
1991	359.66	369.81	368.14	362.83									

^aAtmospheric CO₂ concentrations are expressed in parts per million by volume (ppmv) and reported in the WMO X74 manometric mole fraction scale. Monthly means are derived from hourly and daily means which have been selected to represent baseline (background) conditions. Annual means are simply the arithmetic mean of the monthly values calculated by CDIAC. Annual means are provided only for years with complete monthly records.

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DEUSELBACH

Trends

Annual atmospheric CO₂ concentrations at Deuselbach rose from 340.82 parts per million by volume (ppmv) in 1972 to 363.76 ppmv in 1989. The monthly atmospheric CO₂ record from Deuselbach is influenced by local agricultural activities and photosynthetic depletion but does not exhibit the large seasonal amplitude observed at other UBA monitoring sites. Minimum monthly atmospheric CO₂ mixing ratios at Deuselbach are typically observed in August but may appear as early as June. Maximum values are seen in the record for November–March.

Monthly atmospheric CO₂ concentrations at Deuselbach.

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Atmospheric CO₂ records from sites in the UBA air sampling network

W. Fricke and M. Wallasch (continued)

*Deuselbach
Germany*

*Low mountain range,
rural area with frequent
agricultural activities*

49°46' N, 7°03' E

480 m above MSL

DEUSELBACH

Atmospheric Concentrations of CO₂CO₂ concentrations^a at Deuselbach (ppmv)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1972	347.73	350.26	342.43	336.82	336.24	335.52	335.11	334.37	335.66	341.45	347.83	346.39	340.82
1973	349.17	343.90	345.04	341.78	337.04	333.31	333.39	333.13	335.05	343.10	342.79	347.00	340.39
1974	343.28	345.85	352.70	343.29	337.46	335.03	333.15	332.31	330.44	339.42	342.82	341.62	339.78
1975	342.62	344.78	345.97	342.05	338.31	334.82	329.83	333.83	331.51	340.97	347.51	347.24	339.95
1976	342.97	352.15	345.80	343.74	337.46	334.77	339.32	330.85	336.13	345.04	348.87	350.38	342.29
1977	346.45	343.40	344.50	342.57	342.61	340.68	335.31	341.41	338.51	348.04	344.16	351.76	343.28
1978	347.13	355.83	344.75	347.54	342.14	336.13	335.98	332.66	335.16	345.16	355.39	349.88	343.98
1979	355.04	357.85	349.92	349.63	345.32	340.19	339.77	335.54	337.00	346.87	348.79	348.39	346.19
1980	354.25	352.58	355.84	349.00	345.02	341.20	337.59	340.58	337.55	344.46	351.86	349.88	346.65
1981	353.05	356.86	349.43	353.00	340.71	337.07	340.28	340.66	338.91	346.40	350.84	358.45	347.14
1982													
1983													
1984	352.54	360.71	359.40	357.74	352.09	345.28	343.94	345.06	345.87	350.63	360.03	357.46	352.56
1985	364.48	357.82	360.82	353.89	351.45	344.86	337.50	335.34	338.49	348.98	357.03	356.32	350.58
1986	352.62	363.11	365.66	361.50	358.44	349.44	347.26	348.49	349.66	359.61	358.43	355.78	355.83
1987	368.52	366.74	358.66	360.03	358.50	354.49	363.52	354.49	354.01	360.39	368.49	362.98	360.90
1988	358.42	360.35	360.26	360.94	358.56	358.80	356.20	355.57	354.41	363.68	365.75	365.45	359.87
1989	371.00	369.36	364.11	365.88	359.92	359.81	360.75	358.33	359.10	363.87	365.46	367.52	363.76
1990	370.41	365.58	367.20	361.67	358.76	355.38	357.43	357.29	358.32	363.88			
1991											379.39	371.30	
1992	368.00												

^aAtmospheric CO₂ concentrations are expressed in parts per million by volume (ppmv) and reported in the WMO X74 manometric mole fraction scale. Monthly means are derived from hourly and daily means which have been selected to represent baseline (background) conditions. Annual means are simply the arithmetic mean of the monthly values calculated by CDIAC. Annual means are provided only for years with complete monthly records.

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SCHAUINSLAND

Trends

Annual atmospheric CO₂ concentrations at Schauinsland rose from 330.10 parts per million by volume (ppmv) in 1972 to 357.13 ppmv in 1992. This represents a growth rate of approximately 1.4 ppmv per year. The Schauinsland site is considered the least contaminated of the UBA sites. The monthly atmospheric CO₂ record from Schauinsland is influenced by photosynthetic depletion but does not exhibit the large seasonal amplitude observed at other UBA monitoring sites. The seasonal amplitude is generally 15–18 ppmv. Minimum monthly atmospheric CO₂ mixing ratios at Schauinsland are typically observed in July–September; maximum values, in November–March.

Monthly atmospheric CO₂ concentrations at Schauinsland.

Atmospheric CO₂ records from sites in the UBA air sampling network

W. Fricke and M. Wallasch (continued)

SCHAUINSLAND

Schauinsland
Germany

Mountain peak in the Black Forest
mountain range, forest environment
47°55' N, 7°55' E
1205 m above MSL

Atmospheric Concentrations of CO₂CO₂ concentrations^a at Schauinsland (ppmv)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1972	335.12	338.93	337.00	334.85	329.39	325.36	327.92	322.00	321.68	329.03	328.61	331.27	330.10
1973	334.51	335.19	335.41	335.21	328.68	324.74	322.87	324.25	325.88	330.96	332.99	335.15	330.49
1974	333.80	340.60	339.89	335.78	330.99	327.17	324.68	327.72	326.85	332.61	333.67	332.43	332.18
1975	332.96	335.11	339.93	338.74	332.83	328.51	321.12	325.86	328.12	333.51	340.57	336.92	332.85
1976	339.40	343.87	338.35	338.08	330.52	326.18	328.25	323.31	326.60	333.85	338.88	337.58	333.74
1977	340.50	337.82	336.15	338.72	333.63	330.26	322.83	325.54	327.45	334.13	337.50	339.25	333.65
1978	343.59	345.16	341.58	344.18	339.91	331.18	325.87	324.56	327.09	336.09	338.25	341.92	336.62
1979	345.11	350.73	340.99	341.15	334.74	331.01	324.87	326.89	329.34	337.77	340.16	342.13	337.07
1980	345.78	344.58	348.06	344.64	339.13	334.79	331.31	329.97	331.46	338.14	343.85	342.63	339.53
1981	345.50	348.05	344.63	348.63	340.48	335.84	333.37	333.73	334.13		344.33	348.34	
1982													
1983													
1984	349.83	355.04	356.65	355.48	347.84	340.14	338.23	338.40	340.23	343.75	347.40	350.39	346.95
1985	355.67	353.04	355.82	351.09	347.01	340.64	339.01	337.02	338.94	344.88	355.96	349.61	347.39
1986	352.07	362.31	358.02	355.64	348.24	343.16	339.27	338.61	339.73	345.86	350.15	351.87	348.74
1987	361.46	361.04	358.07	353.73	349.36	347.39	345.53	342.42	345.45	348.92	356.09	358.99	352.37
1988	354.11	358.28	357.63	357.49	351.61	346.67	344.96	343.62	347.34	353.36	356.82	358.49	352.53
1989	356.60	357.38	357.67	357.94	349.79	346.28	349.10	349.51	350.77	353.91	357.44	358.29	353.72
1990	358.01	358.37	360.98	360.20	351.92	351.32	348.24	349.66	349.00	355.98	360.52	363.09	355.61
1991	361.10	366.46	364.55	362.22	359.81	354.40	349.37	350.11	353.28	356.10	360.82	360.13	358.20
1992	363.47	363.08	364.27	361.70	356.69	352.09	349.95	349.90	348.95	358.33	356.47	360.67	357.13

^aAtmospheric CO₂ concentrations are expressed in parts per million by volume (ppmv) and reported in the WMO X74 manometric mole fraction scale. Monthly means are derived from hourly and daily means which have been selected to represent baseline (background) conditions. Annual means are simply the arithmetic mean of the monthly values calculated by CDIAC. Annual means are provided only for years with complete monthly records.

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WALDHOF

Trends

Annual atmospheric CO₂ concentrations at Waldhof rose from 346.82 parts per million by volume (ppmv) in 1972 to 372.09 ppmv in 1993. The Waldhof site is subject to pollution sources; consequently, the monthly atmospheric CO₂ record exhibits a large seasonal amplitude.

Monthly atmospheric CO₂ concentrations at Waldhof.

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Atmospheric CO₂ records from sites in the UBA air sampling network

W. Fricke and M. Wallasch (continued)

Waldhof
Germany

*Agricultural and forest environment
on the North German lowland, subject
to pollution sources*

52°48' N, 10°46' E

74 m above MSL

WALDHOF

Atmospheric Concentrations of CO₂CO₂ concentrations^a at Waldhof (ppmv)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1972	350.37	352.37	346.17	338.61	340.94	343.91	348.01	340.06	349.99	350.52	347.75	353.13	346.82
1973	355.41	343.65	347.05	342.99	344.45	342.78	343.86	344.36	343.95	349.31	341.82	348.66	345.69
1974	348.61	346.99	345.92	340.09	341.50	342.50	340.32		341.04	340.66	348.21	339.03	
1975	339.89	346.16	341.92	344.27	340.71	337.19	340.16	343.94	339.67	347.36	352.65	346.55	343.37
1976	341.73	357.18	348.31	342.99	342.19	344.18	339.84	338.74	344.73	354.94	348.66	349.59	346.09
1977	353.44	350.94	346.03	341.25	342.74	343.74	342.19	347.08	344.84	361.17	343.23	353.04	347.47
1978	354.10	358.22	346.53	348.55	349.57	350.64	342.97	345.24	338.46	354.78	357.63	353.84	350.04
1979	358.95	357.69	349.16	350.11	351.59	346.24	343.47	348.18	349.50	350.95	352.19	350.31	350.70
1980	371.61	359.52	359.96	352.48	351.29	353.75	348.24	349.01	356.84	348.12	351.82		
1981	357.33	359.13	352.58	353.11	353.49	348.93	348.67	345.08	358.68	351.05	346.90	360.95	352.99
1982	369.67	359.07	358.61			345.90	346.88	348.09	350.36	359.31	354.51	356.15	
1983	356.81	363.36	356.60	355.84	355.51	356.43	352.13	356.01	348.62	353.21	368.95	368.63	357.68
1984	358.76	365.28	359.67	364.67		351.85	352.69	361.49	352.27	356.61	368.92	365.35	
1985	370.19	365.06	366.93	357.69	358.90			354.91	351.49	361.17	364.59	361.85	
1986	359.93	363.69	366.05	361.37	360.33	355.96	358.69	354.24	355.79	362.35	364.95	362.44	360.48
1987	368.52	372.51	362.26	366.74	358.72	360.53	362.41		362.06	362.69	369.45	366.52	
1988	372.18	366.03	369.65	374.24	369.97	371.88	363.05	364.15	358.60	368.50	366.25	363.33	367.32
1989	370.48	368.50	366.22	364.06	363.97	362.69		365.81	369.70	366.98	377.02	376.69	
1990	370.29	366.17	366.71	367.61	367.25	365.47	361.06	366.25	361.70	372.19	373.75	371.84	367.52
1991	368.67	376.61	383.30	371.82	367.85	365.40	362.03	368.77	367.46	383.68	382.70	373.07	372.61
1992	372.72	372.93	370.71	372.61	365.95	362.59	368.23	365.42	366.21	368.35	368.58	374.52	369.07
1993	368.12	379.20	373.58	372.96	373.53	368.65	366.28	368.81	368.01	372.49	382.11	371.34	372.09

^aAtmospheric CO₂ concentrations are expressed in parts per million by volume (ppmv) and reported in the WMO X74 manometric mole fraction scale. Monthly means are derived from hourly and daily means which have been selected to represent baseline (background) conditions. Annual means are simply the arithmetic mean of the monthly values calculated by CDIAC. Annual means are provided only for years with complete monthly records.

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WESTERLAND

Trends

Annual atmospheric CO₂ concentrations at Westerland rose from 333.66 parts per million by volume (ppmv) in 1973 to 359.06 ppmv in 1990. The monthly atmospheric CO₂ record from Westerland shows a seasonal pattern similar to other UBA sites; minimum values are recorded during July–September; maximum mixing ratios, during November–March.

Monthly atmospheric CO₂ concentrations at Westerland.

Atmospheric CO₂ records from sites in the UBA air sampling network

W. Fricke and M. Wallasch (continued)

Westerland
Germany
Coastal station on
Island of Sylt (North Sea)
54°56' N, 8°19' E
12 m above MSL

WESTERLAND**Atmospheric Concentrations of CO₂**CO₂ concentrations^a at Westerland (ppmv)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1972											332.77	348.37	
1973	344.91	335.08	336.62	333.98	332.36	329.01	326.92	326.31	328.50	335.30	336.01	338.92	333.66
1974	345.47	342.23	344.26	340.83	337.48	333.42	331.07	331.42	332.48	334.16	341.35	334.81	337.42
1975	341.52	348.52	342.79	341.30	334.38	332.21	331.15	328.39	329.10	342.53	343.96	335.30	337.60
1976	337.76	345.47	341.59	343.79	338.15	330.84	328.95	325.59	331.62	343.16	340.92	340.02	337.32
1977	348.79	345.76	341.17	337.38	335.91					352.98	336.25	351.94	
1978	348.50	353.58	346.62	340.34	340.78	335.86	335.44	329.99	331.12	341.28	344.98	350.62	341.59
1979	352.47	350.58	347.63	346.29	343.17	334.10	333.88	334.33	332.04	342.31	344.81	348.31	342.49
1980	355.73	354.06	350.73	346.14	342.89	341.14							
1981							337.32	336.84	340.80	346.56	347.58	356.37	
1982	363.78	359.82	351.74	349.37	350.47	342.75							
1983													
1984	352.91	356.88	355.17	356.58	351.48	345.50	342.57	344.54	344.55	348.24	363.63	359.59	351.80
1985	358.66	359.62	359.83	354.66	352.17	347.41	342.87	340.98	341.93	350.15	355.83	357.00	351.76
1986	356.38	356.34	360.66	356.57	352.66	347.17	344.98	341.57	341.15	351.48	352.95	355.96	351.49
1987	357.71	362.13	357.98	357.51	350.52	350.83	347.07	343.44	343.14	355.31	356.52	365.88	354.00
1988	367.27	361.43	359.93	364.58	356.19	350.93	347.96	344.71	346.92	361.61	359.55	358.25	356.61
1989	364.21	363.10	363.89	362.96	359.13	356.11	350.47	351.99	354.83	357.48	369.67	369.77	360.30
1990	366.27	364.18	362.26	362.23	359.30	353.67	348.71	347.53	349.58	361.72	365.22	368.05	359.06
1991	365.39	370.03	370.95	362.86	358.95	357.37	348.49		347.63	362.04	370.12	369.17	
1992	364.79	367.74	365.68		344.89	344.79	345.01	345.30	344.93	357.17	359.53	366.58	

^aAtmospheric CO₂ concentrations are expressed in parts per million by volume (ppmv) and reported in the WMO X74 manometric mole fraction scale. Monthly means are derived from hourly and daily means which have been selected to represent baseline (background) conditions. Annual means are simply the arithmetic mean of the monthly values calculated by CDIAC. Annual means are provided only for years with complete monthly records.

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| Garmisch-Partenkirchen • Wank Peak • Zugspitze

Period of Record

1978–92 (varies by station)

Methods—Garmisch-Partenkirchen

Ambient air has been measured continuously using a URAS 2T nondispersive infrared (NDIR) analyzer with a flowing reference gas. Every 24 hours, two CO₂-in-N₂ working standards are passed into the instrument for calibration. The water vapor content of both the ambient air and the calibration gases is conditioned to a dew point of about 1°C. The mixing ratios of the working standards are related to two primary CO₂-in-N₂ standards (312 and 387 ppmv) based on the 1974 Keeling scale (WMO X74 scale), which are kept in the laboratory. Details on the measurements through 1985 are given by Reiter et al. (1986). In 1987, the sampling site was displaced horizontally by about 0.5 km. Whereas the sample air intake was 10 m above ground at the former site, it is 5 m above ground at the current site.

Methods—Wank Peak

Ambient air has been measured continuously using a URAS 2T NDIR analyzer with flowing reference gas. Every 24 hours, two CO₂-in-N₂ working standards are passed into the instrument for calibration. The mixing ratios of the working standards are related to two primary CO₂-in-N₂ standards (312 and 387 ppmv) based on the 1974 Keeling scale (WMO X74 scale), which are kept in the laboratory. Details on the measurements through 1985 are discussed in Reiter et al. (1986).

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Methods—Zugspitze

Ambient air has been measured continuously using URAS NDIR analyzers. From 1982 to 1990 a URAS 2T analyzer was used. Currently, a URAS 3G analyzer equipped with a continuously flushed reference cell is used. Every 24 hours, two CO₂-in-N₂ working standards are passed into the instrument for calibration. The water vapor content of both the ambient air and the calibration gases is conditioned to a dew point of about 1°C. The mixing ratios of the working standards are related to two primary CO₂-in-N₂ standards (312 and 387 ppmv) based on the 1974 Keeling scale (WMO X74 scale), which are kept in the laboratory. Details about the measurements through 1985 are discussed in Reiter et al. (1986).

CITE AS: Sladkovic, R., H.E. Scheel, and W. Seiler. 1994. Atmospheric CO₂ records from sites operated by the Fraunhofer Institute for Atmospheric Environmental Research. pp. 148–156. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

GARMISCH-PARTENKIRCHEN

Trends

The monitoring site is located outside Garmisch-Partenkirchen on the grass-covered floor of the valley. The measurements performed at Garmisch-Partenkirchen are complemented by measurements at the nearby stations Wank Peak (1776 m above MSL) and Zugspitze (2937 m above MSL). Because of strong local influence (vegetation and meteorology), the CO₂ concentrations at Garmisch-Partenkirchen are higher and show greater seasonal amplitudes than the concentrations measured at Wank or Zugspitze. Previously reported monthly mean CO₂ concentrations for Garmisch-Partenkirchen (cf. *Trends '91*) were based on valid data (only technically invalid data had been eliminated). In contrast, the monthly values given here were calculated from day-time measurements only, because they are less biased by local influence. Moreover, the raw data were filtered visually with respect to obviously local or synoptic processes (such as vertical exchange or frontal passages, respectively). This procedure has yielded annual concentrations for Garmisch-Partenkirchen which are lower by 6.8 to 12.2 parts per million by volume (ppmv) than the previously reported values. A change of sampling conditions due to the transfer of the station cannot be completely ruled out; therefore, the time series obtained before 1987 and that obtained thereafter should be regarded separately.

According to the filtered data, the annual atmospheric CO₂ concentrations at Garmisch-Partenkirchen increased from 330.2 ppmv in 1978 to 345.1 ppmv in 1986 and from 347.6 ppmv in 1988 to 354.7 ppmv in 1992. Annual growth rates varied more strongly during the first period than during the second.

Monthly atmospheric CO₂ concentrations from Garmisch-Partenkirchen.

CITE AS: Sladkovic, R., H.E. Scheel, and W. Seiler. 1994. Atmospheric CO₂ records from sites operated by the Fraunhofer Institute for Atmospheric Environmental Research. pp. 148–156. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric CO₂ records from sites operated by the Fraunhofer Institute for Atmospheric Environmental Research

R. Sladkovic, H.E. Scheel, and W. Seiler (continued)

GARMISCH-PARTENKIRCHEN

Garmisch-Partenkirchen
Germany
Grassland valley
47°28' N, 11°03' E
740 m above MSL

Atmospheric Concentrations of CO₂

CO₂ concentrations^a at Garmisch-Partenkirchen (ppmv)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1978	334.85	336.71	331.84	329.78	331.59	319.12	320.90	316.68	330.36	330.98	333.23	345.84	330.16
1979	339.90	343.78	331.87	331.81	330.81	324.99	320.98	322.42	323.05	334.11	337.82	336.74	331.52
1980	349.84	341.31	341.49	342.00	336.98	333.82			326.03	333.47	341.97	344.03	
1981	346.23	348.48	342.09	338.21	332.95	330.02	328.65	325.66	329.75	332.10	337.35	344.69	336.35
1982	345.22	350.60	342.22	339.40	336.27	330.10	327.60	325.04	329.78	335.12	337.13	346.72	337.10
1983	343.13	352.92	343.54	338.51	337.47	334.73	331.98	331.69	332.56	338.04	348.51	355.08	340.68
1984	348.21	355.43	354.30	348.96	336.79	329.98	329.17	333.45	333.71	339.87	345.79	352.84	342.38
1985	364.17	356.66	355.14	344.54	340.07	335.13	333.69	326.88	326.63	345.12	357.12	349.47	344.55
1986	353.48	370.47	354.16	346.16	339.36	336.62	331.87	334.63	337.99	341.35	343.93	350.88	345.08
1987													
1988	352.22	353.94	353.84	349.92	342.65	339.51	336.89	336.88	341.58	348.60	353.73	361.78	347.63
1989	362.11	356.35	350.32	349.16	342.60	341.43	343.55	343.48	346.00	345.91	356.99	364.90	350.23
1990	362.42	353.58	355.09	353.27	344.98	344.91	340.81	341.77	342.65	350.36	355.92	367.91	351.14
1991	363.23	363.06	358.52	351.72	349.64	345.50	344.28	343.72	346.34	351.57	359.31	366.32	353.60
1992	364.13	358.92	357.04	355.21	348.52	347.71	345.46	346.52	349.58	355.21	358.20	369.27	354.65

^aAtmospheric CO₂ concentrations are expressed in parts per million by volume (ppmv) and reported in the WMO 1974 scale. Annual averages were calculated by CDIAC and are the arithmetic means of the monthly values. Annual means are provided only for years with complete monthly records.

CITE AS: Sladkovic, R., H.E. Scheel, and W. Seiler. 1994. Atmospheric CO₂ records from sites operated by the Fraunhofer Institute for Atmospheric Environmental Research. pp. 148-156. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

WANK PEAK

Trends

The monitoring site at Wank Peak (WMO-BAPMoN station) is located on the grass-covered, rounded top of the mountain, just above the timberline. Previously reported monthly mean CO₂ concentrations for Wank Peak (cf. *Trends '91*; WMO WDCGG Data Report, 1992) were based on valid data (only technically invalid data had been eliminated). In contrast, the monthly concentrations given here were calculated from filtered data that were considered indicative of background concentrations. Filtered data consist only of measurements collected during specified conditions of wind velocity (>4m/s) and wind direction (225°–315°). Measurements biased by local meteorology or by synoptic scale processes were removed from the data by visual inspection. The differences between the annual averages obtained from unfiltered data and the averages from filtered data are typically ~0.5 parts per million by volume (ppmv).

The mean annual CO₂ concentrations at Wank Peak increased from 334.2 ppmv in 1980 to 348.6 ppmv in 1992.

Monthly atmospheric CO₂ concentrations from Wank Peak.

CITE AS: Sladkovic, R., H.E. Scheel, and W. Seiler. 1994. Atmospheric CO₂ records from sites operated by the Fraunhofer Institute for Atmospheric Environmental Research. pp. 148–156. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites operated
by the Fraunhofer Institute for Atmospheric Environmental Research

R. Sladkovic, H.E. Scheel, and W. Seiler (continued)

WANK PEAK

Wank Peak
Germany
Mountain peak
47°30' N, 11°08' E
1776 m above MSL

Atmospheric Concentrations of CO₂

CO₂ concentrations^a at Wank Peak (ppmv)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1980	336.88	336.60	340.48	338.52	332.68	330.85	329.16	328.03	331.62	335.61	333.21	336.36	334.17
1981	336.44	336.57	336.37	336.23	334.19	330.47	327.54	325.83	329.17	331.67	336.91	336.09	333.12
1982	339.94	338.94	344.71	346.10	339.10	333.63	330.83	329.19	330.54	332.56	334.17	336.95	336.39
1983	336.82	340.60	340.68	341.78	339.00	334.82	333.28	330.48	331.53	334.86	338.44	337.60	336.66
1984	341.69	344.87	349.46	348.51	338.33	333.75	331.47	329.35	330.78	335.51	340.25	341.65	338.80
1985	343.03	342.11	344.28	341.27	338.53	333.44	329.12	327.63	327.77	332.87	338.74	339.71	336.54
1986	342.24	346.73	343.22										
1987													
1988							339.61	338.00	340.39	343.26	344.42	345.64	
1989	346.63	347.30	348.50	347.15	343.10	340.16	340.11	339.41	338.48	342.06	346.80		
1990	349.78	349.49	349.34	350.70	343.69	342.90	339.47	338.65	341.19	344.98	349.73	352.19	346.01
1991	349.02	352.28	351.79	352.83	349.56	345.72	342.44	341.63	342.66	345.71	350.31	350.56	347.88
1992	350.98	353.35	353.52	352.46	349.06	345.91	342.73	340.69	343.27	349.32	350.39	351.46	348.60

^aAtmospheric CO₂ concentrations are expressed in parts per million by volume (ppmv) and reported in the WMO 1974 scale. Annual averages were calculated by CDIAC and are the arithmetic means of the monthly values. Annual means are provided only for years with complete monthly records.

CITE AS: Sladkovic, R., H.E. Scheel, and W. Seiler. 1994. Atmospheric CO₂ records from sites operated by the Fraunhofer Institute for Atmospheric Environmental Research. pp. 148-156. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

ZUGSPITZE

Trends

The station at Zugspitze is located near the summit of the highest mountain of the German Alps. In 1990, the site of CO₂ sampling was changed from a location 250 m below the summit to a new monitoring station (2937 m above MSL) close to the mountain top. Compatibility of the results was seen from measurements conducted in parallel at the two sites for several months. Because of the high elevation of the mountain station, the CO₂ measurements at Zugspitze can be considered free of regional contamination most of the time. Previously reported monthly mean CO₂ concentrations for Zugspitze (cf. *Trends '91*; WMO WDCGG Data Report, 1992) were based on valid data (only technically invalid data had been eliminated). In contrast, the monthly concentrations given here were calculated from filtered data that were considered indicative of background concentrations. Filtered data consist only of measurements collected during specified conditions of wind velocity (>4 m/s) and wind direction (225°–315°). Measurements biased by local meteorology or by synoptic scale processes were removed from the data by visual inspection. The differences between the annual averages obtained from unfiltered data and the annual averages from filtered data are typically ~0.7 parts per million by volume (ppmv).

The mean annual CO₂ concentrations at Zugspitze increased from 333.7 ppmv in 1981 to 349.4 ppmv in 1992. Variations of the annual growth rates were less pronounced than at the nearby stations Wank Peak (1776 m above MSL) and Garmisch-Partenkirchen (740 m above MSL).

Monthly atmospheric CO₂ concentrations from Zugspitze.

CITE AS: Sladkovic, R., H.E. Scheel, and W. Seiler. 1994. Atmospheric CO₂ records from sites operated by the Fraunhofer Institute for Atmospheric Environmental Research. pp. 148–156. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites operated
by the Fraunhofer Institute for Atmospheric Environmental Research

R. Sladkovic, H.E. Scheel, and W. Seiler (continued)

*Zugspitze
Germany
Mountain peak
47°25' N, 10°59' E
2962 m above MSL*

ZUGSPITZE

Atmospheric Concentrations of CO₂

CO₂ concentrations^a at Zugspitze^a (ppmv)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1981	334.28	336.74	336.29	338.60	335.96	330.96	325.53	330.47	332.70	332.65	334.90	335.80	333.74
1982	334.80	335.72	338.05	340.69		329.58	330.46	328.42	328.73	332.15	334.41	336.60	
1983	338.97	340.59	340.40	342.19	339.99	336.80	333.60	330.78	333.45	335.56	336.48	339.52	337.36
1984	341.29	341.77	345.39	346.18	338.41	334.44	333.40	334.14	335.35	337.51	341.41	341.94	339.27
1985	344.46	342.93	343.71	342.69	341.06	336.17	331.64	331.03	331.97	336.18	340.71	340.06	338.55
1986	343.08	345.23	343.54	344.05	340.91	338.24	334.55		333.28	339.87	342.01	342.95	
1987	345.34	342.83	339.98	346.70	342.22	340.71	341.16	339.53	341.23	343.76	346.18	346.82	343.04
1988	346.21	345.89	346.49	348.06	346.04	342.59	340.21	339.41	340.75	343.38	345.18	345.60	344.15
1989	345.31	345.92	348.70	348.64	343.67	339.98	341.18	342.38	342.76	344.68	347.51		
1990	349.56	350.64	351.14	352.04	348.45	347.27	343.68	341.04	342.92	346.24	349.48	351.39	347.82
1991	349.58	351.42	352.53	353.19	351.11	348.13	344.21	344.26	344.88	346.48	348.88	350.29	348.75
1992	350.74	352.35	353.61	353.48	351.57	349.41	344.50	343.62	344.63	348.74	350.09	350.01	349.40

^aAtmospheric CO₂ concentrations are expressed in parts per million by volume (ppmv) and reported in the WMO 1974 scale. Annual averages were calculated by CDIAC and are the arithmetic means of the monthly values. Annual means are provided only for years with complete monthly records.

CITE AS: Sladkovic, R., H.E. Scheel, and W. Seiler. 1994. Atmospheric CO₂ records from sites operated by the Fraunhofer Institute for Atmospheric Environmental Research. pp. 148-156. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

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Period of Record

1984–93

Methods

Air samples are collected every 48 seconds from air intake lines located 10 m above ground. Until December 1990, samples were collected from lines located 4.5 m above ground. Determinations of CO₂ are made using a Hartmann and Braun URAS 3G infrared spectroscopy system. Mixtures of CO₂ in N₂, furnished by Messer and Griesheim, are used for calibration gases. More details about the sampling methods used at Osnabrück are provided in Forstreuter (1991a, 1991b; 1993), Overdieck (1986, 1991), and Overdieck and Forstreuter (1987).

Osnabrück
Westerberg, Germany
Urban (city of
approximately 160,000)
58°18' N, 8°2' E
95 m above MSL

CITE AS: Forstreuter, M., A. Tschuschke, and D. Overdieck. 1994. Atmospheric CO₂ record from Osnabrück. pp. 157–160. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

OSNABRÜCK

Trends

The monitoring at Osnabrück is conducted for research examining the vegetative response to elevated levels of CO₂. The monitoring of ambient air CO₂ concentration levels provides the control data for long-term field experiments about the effects that tropospheric CO₂ enrichment has on single plants, grassland model-ecosystems, and other vegetation types. Because these measurements are subject to local sources of contamination and because of the purpose of the measurements, they are not indicative of the background air conditions near Osnabrück. Despite the seasonal variability shown by these data, these measurements confirm the rising trend of atmospheric CO₂ concentrations seen at other regional sites.

Over the period of record, an annual increase of 1.3 ppmv in the atmospheric CO₂ concentration has been observed at Osnabrück. From 1984 to 1989 the increase in CO₂ concentration was greater than the average for the whole period. No further increase was observed in the period 1990–93.

Monthly atmospheric CO₂ concentrations from Osnabrück.

Atmospheric Carbon Dioxide
Atmospheric CO₂ record from Osnabrück

M. Forstreuter, A. Tschuschke, and D. Overdieck (continued)

OSNABRÜCK

Atmospheric Concentrations of CO₂

CO₂ concentrations^a at Osnabrück (ppmv)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1984								352	342	354	362	357	
1985	379		346	349	346	332	357	353	337	350	348	341	
1986	333	344	363	359	358	354	353	344	356	367	374	364	356
1987	376	365	359	371	365	364	353	352	360	373	378	397	368
1988	385	371	375	382	374	371	370	350	351	348	356	358	366
1989	354	364	366	353	349	367	383	372	387	374	394	385	371
1990	360	348	359									363	
1991	371	384	373	365	358	353	353	357	358	365	372	378	366
1992	368	372	365	366	360	356	357	355	372	366	364	372	364
1993	367	395	380		354	351	349	349	359	360	376	348	

^aAtmospheric CO₂ concentrations are expressed in parts per million by volume (ppmv). Annual averages are based on available monthly means.

CITE AS: Forstreuter, M., A. Tschuschke, and D. Overdieck. 1994. Atmospheric CO₂ record from Osnabrück. pp. 157–160. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

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Atmospheric CO₂ record from in situ measurements at K-Puszt**L. Haszpra**

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Period of Record

1981–92

Methods

Air samples are collected continuously through an air intake located at the top of a tower, 10 m above ground. For technical reasons, no measurements were made at K-Puszt between October 1984 and June 1985, between December 1985 and June 1986, or between January 1987 and August 1988. The air to be analyzed is saturated by water vapor at room temperature and cooled to 4°C. Determinations of CO₂ are made through the use of a Siemens Ultramat 3 nondispersive infrared (NDIR) analyzer. The analyzer continuously gets air saturated at 4°C. Since April 1984, concentration values have been recorded by a digital data acquisition system. Before April 1984, half-hour concentration values were determined manually from stripchart records.

Data are reported in the WMO 1974 mole fraction scale and are believed to be accurate to within 0.5 parts per million (ppm). Only technically false data are removed from the data record.

CITE AS: Haszpra, L. 1994. Atmospheric CO₂ record from in situ measurements at K-Puszt. pp. 161–164. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

L. Haszpra (continued)

K-PUSZTA

Trends

The yearly mean atmospheric CO₂ concentration at K-Puszt, Hungary, increased from 351.6 parts per million (ppm) in 1981 to 369.8 ppm in 1992. Because the K-Puszt station is located in a clearing of a forested area on the Hungarian Great Plain, it is subject to significant biospheric effects. As a result, the record from K-Puszt shows high seasonal and interannual variability.

Monthly atmospheric CO₂ concentrations at K-Puszt.

CITE AS: Haszpra, L. 1994. Atmospheric CO₂ record from in situ measurements at K-Puszt. pp. 161-164. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric Carbon Dioxide

Atmospheric CO₂ record from in situ measurements at K-Puszt

L. Haszpra (continued)

K-PUSZTA

Atmospheric Concentrations of CO₂

CO ₂ concentrations ^a at K-Puszt (ppmv)													
Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1981						349.4	341.7	346.3	357.4	353.9	354.9	357.5	351.6
1982	362.0				353.8					362.0	360.0	358.0	359.2
1983	356.0	357.0	356.0	355.0	353.0	347.0	348.0			356.0	365.0	364.0	355.7
1984	363.0	360.0	357.0	357.4	354.5	353.9		351.3	352.3				356.1
1985						356.3	360.1	355.3	357.2	359.1	361.4		358.2
1986				360.8	361.2	356.3			354.5	356.8			357.9
1987													
1988								365.0	370.0	370.6	373.3	368.1	369.4
1989	369.4	371.5	367.3	362.7	363.2			367.2	369.9	372.8	377.7	369.3	369.1
1990	371.9	370.1	365.1	364.6	368.9	365.4							367.7
1991		379.4	381.2	372.5	367.0	366.7	360.9	376.5	371.8	368.9	373.1	376.9	372.3
1992	372.7	369.4	370.8							367.9	367.1	370.9	369.8

^aAtmospheric CO₂ concentrations are expressed in parts per million by volume (ppmv).

CITE AS: Haszpra, L. 1994. Atmospheric CO₂ record from in situ measurements at K-Puszt. pp. 161-164. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

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Atmospheric CO₂ record from flask measurements at Lampedusa Island

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Period of Record

1992–93

Methods

Lampedusa Station rests on a rocky seashore on the eastern tip of Lampedusa Island, situated south of Sicily in the middle of the Mediterranean Sea. Air samples at Lampedusa Station are collected each Friday in two pairs of 2-L glass flasks. Flasks are evacuated at the ENEA-CNR laboratory in Rome and then pressurized to 280–300 kPa with ambient air at the sampling site. Determinations of CO₂ are made at the ENEA-CNR laboratory by using a Siemens Ultramat 5E nondispersive infrared gas analyzer. Water vapor is removed first at the sampling site by using a chemical trap (Magnesium Perchlorate); then prior to measurement, water vapor is removed again, by means of a chemical water vapor trap immersed in a cold (–70°C) alcohol bath. From the inception of the monitoring program at Lampedusa Station, CO₂-in-synthetic air calibration gases have been used. Values are based on the absolute X85 Scripps scale.

If CO₂ mixing ratios for a flask pair differ by more than 0.5 ppmv the values are rejected. More details on the sampling methods and selection criteria are discussed in Ciattaglia et al. (1993).

CITE AS: Ciattaglia, L., and P. Chamard. 1994. Atmospheric CO₂ record from flask measurements at Lampedusa Island. pp. 165–168. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

LAMPEDUSA ISLAND

Trends

The first air samples at Lampedusa Station were collected in 1992. The 1993 annual atmospheric CO₂ concentration of 359.70 parts per million by volume (ppmv) was calculated from 52 flask pair averages. The record from Lampedusa Station exhibits a seasonal pattern with maximum values measured during spring and minimum values recorded during the northern summer.

Monthly concentrations of atmospheric CO₂ at Lampedusa Island.

CITE AS: Ciattaglia, L., and P. Chamard. 1994. Atmospheric CO₂ record from flask measurements at Lampedusa Island. pp.165–168. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric CO₂ record from flask measurements at Lampedusa Island

L. Ciattaglia and P. Chamard (continued)

LAMPEDUSA ISLAND

Atmospheric Concentrations of CO₂CO₂ concentrations^a at Lampedusa Island (ppmv)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1992					358.55	358.34	352.19	352.05	350.31	354.30	357.97	362.18	
1993	361.09	364.44	366.53	362.57	360.95	358.18	355.65	355.22	353.70	356.05	360.65	361.39	359.70

^aAtmospheric CO₂ concentrations are expressed in parts per million by volume (ppmv) and reported in the Scripps Institution of Oceanography X85 mole fraction scale. Monthly averages were calculated by CDIAC and represent the arithmetic mean of the available flask pair averages for a given month. Annual averages were also calculated by CDIAC by taking the arithmetic mean of the monthly values in years where values exist for all months.

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L. Ciattaglia and P. Chamard (continued)

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Atmospheric CO₂ record from in situ measurements at Mt. Cimone

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Period of Record

1979–93

Methods

Continuous atmospheric CO₂ measurements have been carried out at Mt. Cimone since 1979. Since December 1988, air samples have also been collected approximately once per week in a pair of 2-L, electropolished, stainless steel cylindrical flasks. From 1979 until December 1988, a Hartmann and Braun URAS-2T NDIR gas analyzer was used for CO₂ determinations. Currently, CO₂ determinations are made through the use of a Siemens Ultramat-5E NDIR gas analyzer. Water vapor is eliminated by passing the air through a U-tube placed in an alcohol bath at -600°C. Calibration of the Ultramat-5E is accomplished by using two CO₂-in-air working standard gases, whose concentrations are checked 10 days apart against three CO₂-in-air mixtures that serve as secondary standards. The secondary standards are checked every 6 months against five other CO₂-in-air primary standards. Hourly CO₂ values are routinely plotted together with wind data. Anomalous concentrations and those affected by instrument failures or local sources are rejected. Atmospheric CO₂ concentrations from Mt. Cimone are reported in the 1985 WMO/Scripps mole fraction scale. For further details on the measurement apparatus and sampling techniques used at Mt. Cimone, see Cundari et al. (1990).

Personnel from Mt. Cimone have been involved in an intercalibration exercise with the Canadian Atmospheric Environment Service to resolve carrier gas drift problems. The secondary and primary standards were compared with the Scripps Institution of Oceanography (SIO) mixtures using a Round Robin Test approach; the standards differed from the SIO mixtures by 0.17 parts per million by volume (ppmv) or less.

CITE AS: Colombo, T., and R. Santaguida. 1994. Atmospheric CO₂ record from in situ measurements at Mt. Cimone. pp. 169–172. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

MT. CIMONE

Trends

Mt. Cimone observatory, a station of the Italian Meteorological Service, has been participating in the WMO-BAPMoN program since 1978. The atmospheric CO₂ record from Mt. Cimone represents the longest continuous record available for the Mediterranean area. From 1980 to 1993, the annual mean atmospheric CO₂ concentration at Mt. Cimone rose from 336.99 parts per million by volume (ppmv) to 357.00 ppmv. The annual increase was ~1.5 ppmv per year. The seasonal oscillation for this same time period has a mean amplitude of 13.4 ppmv. This seasonal amplitude is attributable to photosynthetic depletion from vegetation below the timberline at Mt. Cimone and to the relationship between CO₂ concentrations and wind direction. Ciattaglia et al. (1987) found a relationship between the behavior of selected CO₂ data with prevailing winds [i.e., SW (180–2900) and NE (0–900) winds] and episodes of Sahara dust transport: during winter, NE winds bring the high CO₂ concentrations on measurement site, whereas SW winds are characterized by lower concentrations; during summer, the situation is reversed. During the cold season, Saharan transports are characterized by low CO₂ and by small record variability, whereas, when these episodes occur during hot periods, CO₂ concentrations show values above average.

Monthly atmospheric CO₂ concentrations at Mt. Cimone.

CITE AS: Colombo, T., and R. Santaguida. 1994. Atmospheric CO₂ record from in situ measurements at Mt. Cimone. pp. 169–172. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric CO₂ record from in situ measurements at Mt. Cimone

T. Colombo and R. Santaguida (continued)

MT. CIMONE

Atmospheric Concentrations of CO₂^aCO₂ concentrations^a at Mt. Cimone (ppmv)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1979			341.43	341.93	336.94	333.84	329.65	327.15	328.52	334.27	336.82	337.52	
1980	340.87	339.83	342.27	342.51	338.27	335.52	330.14	328.81	331.17	335.03	339.05	340.43	336.99
1981	341.47	343.11	342.39	342.51	339.49	335.28	330.77	330.30	333.55	336.80	339.41	343.18	338.19
1982	341.70	344.38	345.68	345.70	340.80	336.66	334.65	332.40	335.15	339.26	341.19	345.18	340.23
1983	342.38	346.18	345.00	344.24	342.32	338.34	336.03	335.00	336.57	339.86	343.97	345.61	341.29
1984	346.32	349.44	351.33	350.59	346.43	344.35	336.29	335.19	337.59	342.26	344.90	346.91	344.30
1985	349.92	348.17	350.62	350.51	345.93	341.43	337.67	337.16	339.40	344.07	349.49	347.40	345.15
1986	349.41	351.41	352.29	350.75	348.37	342.96	337.22	338.53	340.90	346.28	348.95	350.52	346.47
1987	351.94	353.75	354.79	352.61	350.39	347.38	341.64	341.64	342.19	345.69	350.39	352.36	348.73
1988	353.23	355.16	355.36	355.01	352.81	347.37	343.28	345.32	344.46	350.14	353.79	354.79	350.89
1989	353.81	355.02	356.88	357.86	352.27	349.46	347.59	345.98	348.31	351.16	354.34	355.34	352.34
1990	355.72	356.43	358.46	358.73	353.69	351.13	347.29	346.04	348.81	353.13	356.36	360.08	353.84
1991	357.57	360.65	360.80	360.54	357.84	353.22	348.33	346.74	350.57	353.54	358.22	359.33	355.61
1992	358.51	359.76	361.38	359.93	355.99	352.49	346.46	347.58	348.74	354.82	355.87	358.68	355.02
1993	358.88	361.44	362.98	361.42	357.77	353.10	350.94	350.55	350.79	355.25	361.05	359.83	357.00

^aAtmospheric CO₂ concentrations are expressed in parts per million by volume (ppmv). Annual averages are based on monthly means.

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Period of Record

1970–93

Methods

Determinations of atmospheric CO₂ mixing ratios are made using a Siemens Ultramat-3 nondispersive infrared (NDIR) gas analyzer. The NDIR CO₂ analyzer is connected via a gas manifold consisting of stainless steel tubing and computer-controlled solenoid switches to 12 gas cylinders and 2 sample air lines. The NDIR analyzer compares ambient air CO₂ mixing ratios relative to known CO₂ mixing ratios in tanks of compressed reference gases. The analyzer operates in a differential mode, with a “zero” reference gas of CO₂ mixing ratio 20 to 30 parts per million (ppm) below ambient air CO₂ levels flowing continuously through one cell of the analyzer at ~10 mL/min. When atmospheric CO₂ is measured, a diaphragm pump pulls air through a sampling line at ~5 L/min. A small fraction of this (180 mL/min) is dried cryogenically to a temperature of approximately –70° Celsius and passed through the sample cell of the CO₂ analyzer. Both the “zero” and sample gas are exhausted into the observatory building.

Operation of the analyzer system is controlled by a computer that switches gas from cylinders or sample air lines into the analyzer sample gas cell. For each calibration gas measurement, the computer monitors the analyzer voltage every second until the standard deviation of 60 consecutive values is below 0.02 ppmv. In some cases, stability is not reached within 5 min, so the computer repeats the previous gas followed by the gas that did not stabilize. All data for the final 60 s of each calibration gas are recorded in a computer file, whether or not stability was achieved.

In the early years of measurement at Baring Head, CO₂-in-nitrogen calibration gases, prepared by the Scripps Institution of Oceanography (SIO) were used. Since 1985 both

*Baring Head
New Zealand
Seashore coastal cliff
41°24' S, 174°54' E
85 m above MSL*

CITE AS: Manning, M.R., A.J. Gomez, and K.P. Pohl. 1994. Atmospheric CO₂ record from in situ measurements at Baring Head. pp. 174–178. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric CO₂ record from in situ measurements at Baring Head

M.R. Manning, A.J. Gomez, and K.P. Pohl (continued)

CO₂-in-natural-air mixtures prepared at SIO and CO₂-in-synthetic-air mixtures prepared commercially have been used for calibration. In all cases concentrations were assigned by SIO. No significant difference has been observed between these two types of calibration gas, but since 1992 only natural-air mixtures have been used. Further details of sampling methods and calibration gases are available as unpublished reports from the authors.

A small amount of data are removed from the record where there is some evidence of malfunction. This is assisted by using at least one of the calibration gases as a "surveillance" gas and noting any periods where its apparent concentration differs from that assigned by SIO. Data management procedures allow the choice of "surveillance" and "calibration" gases to be made retrospectively. Baseline data are selected from the remaining data based on steadiness of the CO₂ concentration and on wind direction. At Baring Head maritime well mixed air masses come from the Southerly direction, and a baseline event is normally defined as one in which the local wind direction is from the South and the standard deviation of minute-by-minute CO₂ concentrations is <0.1 ppmv for 6 or more hours.

The CO₂ concentrations shown here are given in a preliminary version of the X93 SIO 1993 mole fraction scale. This scale is identical with the SIO X85 scale for all measurements before 1986.

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BARING HEAD

Trends

The annual atmospheric CO₂ concentration at Baring Head, New Zealand (including data from Makara for the period November 1970 to March 1972) rose from 325.06 parts per million by volume (ppmv) in 1971 to 354.90 ppmv in 1993. The monthly CO₂ record from Baring Head is typical of Southern Hemisphere sites: it shows small seasonal amplitude, maxima occur from August to October, and minima occur from February to April.

Monthly atmospheric CO₂ concentrations at Baring Head.

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Atmospheric CO₂ record from in situ measurements at Baring Head

M.R. Manning, A.J. Gomez, and K.P. Pohl (continued)

BARING HEAD

Atmospheric Concentrations of CO₂CO₂ concentrations^a at Baring Head (ppmv)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1970 ^b											324.59	324.63	
1971 ^b	324.82	324.70	324.47	324.61	324.85	324.83	325.07	325.36	325.25	325.60	325.51	325.65	325.06
1972 ^b	325.38	325.18	325.51									325.94	
1973	326.25	326.60	326.87	327.13	327.11	327.29	327.89	328.37	328.55	328.60	328.88	328.54	327.67
1974	328.53	327.99	327.84	327.88	328.41	328.55	329.04	329.33	329.46	329.57	329.57	329.61	328.82
1975	329.47	329.09	329.03	329.26	329.65	330.02	330.01	330.18	330.34		330.66	330.04	
1976	330.67	330.57	330.38	330.02	330.47	330.61	331.50	331.67	331.19	331.47	331.77	331.67	331.00
1977	331.26	331.44	331.15	331.91	332.01	331.87	332.54	332.87	332.91	333.07	333.12	332.37	332.21
1978		332.76	333.25	333.00	333.31	333.39	333.89	334.30	334.17	335.01		333.68	
1979		333.75	333.64	333.99	334.43	334.83	334.99	335.44	335.78	335.72		335.65	
1980		335.16	335.69	335.45	336.21	336.65		337.45		337.55	337.91	337.63	
1981	337.47	336.75	337.30	337.44	337.56	338.03	338.51	338.64	338.84	338.69	338.29	338.57	338.01
1982	338.77	338.67	338.83	338.93		339.41	339.61	340.34	340.25	340.26	340.12	339.92	
1983	339.57	339.66	339.79	340.01	340.64	340.64	341.44	342.02	341.89	342.00	341.90	341.80	340.95
1984	341.69	341.67	341.54	341.53	341.81	342.19	342.71		342.91	343.13	343.08	342.74	
1985	342.04	342.09	342.51	342.58	343.03	343.36		344.01	344.28	344.07	343.88	344.00	
1986		344.12	344.03		344.61	344.90	345.19	345.55	345.68	345.56	345.61	345.56	
1987	345.89	345.51	345.60		346.19	347.02	347.33		348.11	348.08	348.06		
1988		347.84	347.97	348.12	348.30	349.00	349.55	349.59	349.82				
1989	349.95	350.71	350.18	350.41	350.52	350.32	350.42	351.16	351.16	351.05	351.23	350.96	350.67
1990	350.85		350.40	350.71		351.35	352.20	352.29	352.61	352.64	352.60	352.41	
1991	352.09	352.42	352.08	352.30	352.72	353.11	353.21			353.56	353.47	353.08	
1992	353.05	352.84		353.18	353.50	354.18	354.38	354.87	354.75	354.69	354.19	354.46	
1993	354.10	353.94	354.03	354.52	354.26	355.05	355.34	355.75	355.85		355.66	355.39	

^aAtmospheric CO₂ concentrations are expressed in parts per million by volume (ppmv) and reported in the preliminary Scripps Institution of Oceanography X93 manometric mole fraction scale. This scale is identical with the X85 scale for all measurements before 1986. Monthly means are derived from hourly and daily means selected to represent baseline (background) conditions. Annual means are simply the arithmetic mean of the monthly values calculated by CDIAC. Annual means are provided only for years with complete monthly records.

^bData for the period November 1970 to March 1972 are from measurements at Makara, a site on the west coast of New Zealand just north of Wellington. The site was moved to its present cliff top location at Baring Head in 1972 and data collection was re-established in December 1972. There is some evidence that the Makara site was affected by CO₂ uptake into surrounding pasture land.

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Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the Main Geophysical Observatory air sampling network

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Bering Island • Kotelnny Island • Kyzylcha • Station "C" • Teriberka Station

Period of Record

1983–93 (varies by site)

Methods

Air is collected generally four times per month in pairs of 1.5-L stainless steel electropolished flasks with one greaseless stainless steel stopcock. Sampling is performed by opening the stopcock of the flasks, which have been evacuated at the central laboratory at the Main Geophysical Observatory (MGO). The air is not dried during sample collection. Attempts are made to obtain samples when the wind speed is >5 m/s and the wind direction corresponds to the predetermined "clean air" sector.

After the air samples are collected, the flasks are mailed to the central laboratory at the MGO once per month for CO₂ determinations, which are made through the use of a URAS-2T nondispersive infrared gas analyzer. Storage times between sample collection and analysis range from 2 to 6 months. Air samples are dried cryogenically before analysis.

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Atmospheric CO₂ records from sites in the Main Geophysical
Observatory air sampling network

A.M. Brounshtein, A.A. Shashkov, N.N. Paramonova, V.I. Privalov, and Y.A. Starodubtsev (continued)

The URAS-2T nondispersive infrared gas analyzer is calibrated by using CO₂-in-synthetic air reference gases. All gases were initially calibrated at the Scripps Institution of Oceanography (SIO) against the primary standards maintained by the World Meteorological Organization (WMO) and against NOAA/GMCC standards in 1981. In 1988 and 1989, MGO reference gases were compared with a NOAA/GMCC set of three travelling CO₂-in-air gas standards. During 1990–93, 13 series of calibrations were performed against a set of 5 CO₂-in-air-standards provided by the Atmospheric Environment Service (AES) of Canada. On the basis of these calibration experiments, all MGO data were recalculated to a new scale that is closely related to the WMO X87 scale through the AES standards. A 2-year field comparison program with AES, involving a regular exchange of air samples from Alert and Teriberka, showed that data from both programs are comparable within 0.2 parts per million (ppm).

Concentration values for both flasks in a pair are accepted if the difference between the values is <1 ppmv. More details about the sampling methods and selection criteria are provided in Brounshtein et al. (1985, 1988a, 1988b, 1988c) and in Shashkov and Paramonova (in press).

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BERING ISLAND

Trends

The period of record at Bering Island is too short to identify any long-term trends in atmospheric CO₂ concentrations; however, the yearly mean atmospheric CO₂ concentration at Bering Island rose from approximately 346 parts per million by volume (ppmv) in 1986 to 362.6 ppmv in 1993. Measurements from this station are considered indicative of maritime air masses.

Monthly atmospheric CO₂ concentrations at Bering Island.

CITE AS: Brounshtein, A.M., A.A. Shashkov, N.N. Paramonova, V.I. Privalov, and Y.A. Starodubtsev. 1994. Atmospheric CO₂ records from sites in the Main Geophysical Observatory air sampling network. pp. 180–192. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric CO₂ records from sites in the Main Geophysical Observatory air sampling network

A.M. Brounshtein, A.A. Shashkov, N.N. Paramonova, V.I. Privalov, and Y.A. Starodubtsev (continued)

BERING ISLAND

Bering Island
Russia
Island seashore
55°12' N, 165°59' E
13 m above MSL

Atmospheric Concentrations of CO₂

CO₂ concentrations^a at Bering Island (ppmv)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1986							337.5	336.9	345.4	349.4	351.8	354.9	
1987	353.2	353.7	355.1	357.0	359.0	354.1	343.0	336.2	340.1				
1988	358.7	357.9	357.6	356.9	358.4		345.1	343.5		355.6	357.3	359.3	
1989	357.9	360.3	359.0	360.8	361.1	356.4	345.9	344.8	349.5	355.6	356.8		
1990		363.2	361.0	362.2	361.3	354.2	347.9	342.0		356.2	359.3	360.6	
1991	360.3	361.1	362.4	363.7	363.4	357.5	350.3	346.3	348.9	357.8	361.6	359.4	357.7
1992		363.3	364.0	364.1	365.1	352.2	349.9	345.5	351.5	357.4	361.3	359.8	
1993	368.1	363.7	367.2	364.7	358.3	359.2	357.3			362.0	361.6	363.7	

^aAtmospheric CO₂ concentrations are expressed in parts per million by volume (ppmv). Monthly averages are calculated from available individual flask measurements for a given month. Annual averages are based on monthly means. All flask measurements have been adjusted for concentration drift during storage time. The data scale presented here is based on initial manometric calibrations at the Scripps Institution of Oceanography (SIO) Central CO₂ Laboratory in 1981 and on calibration experiments during 1990–93 against a set of CO₂-in-air standards provided by the Atmospheric Environment Service (AES) of Canada. This scale is closely related to the SIO X87 mole fraction scale through AES standards.

Note: None of the reference gases used by the Main Geophysical Observatory (MGO) has a CO₂ concentration >355 ppmv. As a result, a linear extrapolation procedure has been applied to calculate concentration values for air samples with concentrations >355 ppmv up to mid-1992. Since August 1992, one of the AES calibration gases has been used along with the MGO reference gases to avoid extrapolation. The investigators estimate that the extrapolation error for measurements before 1992 does not exceed 0.15 ppmv.

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Atmospheric CO₂ records from sites in the Main Geophysical
Observatory air sampling network

A.M. Brounshtein, A.A. Shashkov, N.N. Paramonova, V.I. Privalov, and Y.A. Starodubtsev (continued)

KOTELNY ISLAND

Trends

The period of record at Kotelny Island is too short to identify any long-term trends in atmospheric CO₂ concentrations; however, the yearly mean atmospheric CO₂ concentration at Kotelny Island rose from 356.08 parts per million by volume (ppmv) in 1988 to 358.8 ppmv in 1993. The record from Kotelny Island exhibits a pronounced seasonal oscillation due to photosynthetic depletion during the growing season. Because Kotelny Island is the northernmost Russian sampling site, measurements from this site serve as a useful comparison to other northern sites (e.g., Alert, Northwest Territories).

Monthly atmospheric CO₂ concentrations at Kotelny Island.

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Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the Main Geophysical Observatory air sampling network

A.M. Brounshtein, A.A. Shashkov, N.N. Paramonova, V.I. Privalov, and Y.A. Starodubtsev (continued)

KOTELNY ISLAND

*Kotelny Island
Russia*

*Coastal tundra
76°06' N, 137°54' E
5 m above MSL*

Atmospheric Concentrations of CO₂

CO₂ concentrations^a at Kotelny Island (ppmv)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1986						352.6		340.7	340.8	349.0	354.1	354.1	
1987	356.3	356.9		357.4	358.7	358.0	348.6		343.1	345.7	350.3	354.4	
1988	357.7	358.2	359.6	359.8	359.6	357.7	349.4	347.8	348.8	354.2	357.2	361.4	356.0
1989	360.1	361.0	362.2	362.0	359.4	360.7	356.1	350.4	348.2	350.8	358.4	357.7	357.3
1990	359.5	361.1	363.2	364.8	361.6	357.2	352.0	346.7	349.4	351.1	357.2		
1991	362.7		363.5	361.6	362.0	360.7	353.5	348.8	353.9	357.3	359.4	362.2	
1992	364.5	363.1	368.3	367.9	364.7	362.8	355.7	348.7	347.9		362.5		
1993	364.8	362.6	364.2	364.4	365.0	361.1	351.0	351.1	350.4	353.8			

^aAtmospheric CO₂ concentrations are expressed in parts per million by volume (ppmv). Monthly averages are calculated from available individual flask measurements for a given month. Annual averages are based on monthly means. All flask measurements have been adjusted for concentration drift during storage time. The data scale presented here is based on initial manometric calibrations at the Scripps Institution of Oceanography (SIO) Central CO₂ Laboratory in 1981 and on calibration experiments during 1990–93 against a set of CO₂-in-air standards provided by the Atmospheric Environment Service (AES) of Canada. This scale is closely related to the SIO X87 mole fraction scale through AES standards.

Note: None of the reference gases used by the Main Geophysical Observatory (MGO) has a CO₂ concentration >355 ppmv. As a result, a linear extrapolation procedure has been applied to calculate concentration values for air samples with concentrations >355 ppmv up to mid-1992. Since August 1992, one of the AES calibration gases has been used along with the MGO reference gases to avoid extrapolation. The investigators estimate that the extrapolation error for measurements before 1992 does not exceed 0.15 ppmv.

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Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the Main Geophysical Observatory air sampling network

A.M. Brounshtein, A.A. Shashkov, N.N. Paramonova, V.I. Privalov, and Y.A. Starodubtsev (continued)

KYZYLCHA

Trends

In late 1989, air sampling began at the Russian site of Kyzylcha, located in the Republic of Uzbekistan. Unfortunately, the desert site at Kyzylcha has been out of operation since mid-1991 due to financial difficulties in Russia. The annual mean value of 359.02 parts per million by volume (ppmv) for 1990, the lone full year of operation, is higher than measurements from other monitoring programs at this latitude [e.g., Niwot Ridge (354.7 ppmv in 1990) and Tae-ahn Peninsula]. The brief atmospheric CO₂ mixing ratio record from Kyzylcha shows a seasonal pattern indicative of northerly sites.

Monthly atmospheric CO₂ concentrations at Kyzylcha.

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Atmospheric CO₂ records from sites in the Main Geophysical Observatory air sampling network

A.M. Brounshtein, A.A. Shashkov, N.N. Paramonova, V.I. Privalov, and Y.A. Starodubtsev (continued)

KYZYLCHA

Kyzylcha
Republic of Uzbekistan
Desert
40°52' N, 66°09' E
340 m above MSL

Atmospheric Concentrations of CO₂

CO₂ concentrations^a at Kyzylcha (ppmv)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1989												365.51	
1990	362.20	361.55	363.44	358.15	363.44	350.71	351.22	351.81	350.90	368.47	363.03	363.32	359.02
1991	364.55	367.86	367.01	361.65	366.93	357.25	354.31	352.32					

^aAtmospheric CO₂ concentrations are expressed in parts per million by volume (ppmv). Monthly averages are calculated from available individual flask measurements for a given month. Annual averages are based on monthly means. All flask measurements have been adjusted for flask drifting. The data presented here in ppmv are based on manometric calibrations at the Scripps Institution of Oceanography (SIO) Central CO₂ Laboratory in 1982. This scale is generally referred to as the SIO X83 mole fraction scale. E.V. Faber [Main Geophysical Observatory (MGO), St. Petersburg, Russia] and R.A. Achmedzhanov (Physical Department, Samarkand State University, Samarkand, Republic of Uzbekistan) contributed to the collection of these measurements. Achmedzhanov supervised the sampling program at Kyzylcha.

Note: None of the reference gases used by MGO has a CO₂ concentration >355 ppmv. As a result, a linear extrapolation procedure has been applied to calculate concentration values for air samples with concentrations >355 ppmv up to mid-1992. Since August 1992, one of the AES calibration gases has been used along with the MGO reference gases to avoid extrapolation. The investigators estimate that the extrapolation error for measurements before 1992 does not exceed 0.15 ppmv.

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Atmospheric CO₂ records from sites in the Main Geophysical
Observatory air sampling network

A.M. Brounshtein, A.A. Shashkov, N.N. Paramonova, V.I. Privalov, and Y.A. Starodubtsev (continued)

STATION "C"

Trends

An open ocean site in the North Atlantic, east of Greenland, was established in 1968 and was operated in cooperation with NOAA's National Weather Service through 1973. The Main Geophysical Observatory collected flask samples at the site from January 1983 through October 1990. The yearly mean atmospheric CO₂ concentration at Station "C" rose from 348.15 parts per million by volume (ppmv) in 1985 to 354.33 ppmv in 1989.

Monthly atmospheric CO₂ concentrations at Station "C."

CITE AS: Brounshtein, A.M., A.A. Shashkov, N.N. Paramonova, V.I. Privalov, and Y.A. Starodubtsev. 1994. Atmospheric CO₂ records from sites in the Main Geophysical Observatory air sampling network. pp. 180–192. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric Carbon Dioxide

Atmospheric CO₂ records from sites in the Main Geophysical
Observatory air sampling network

A.M. Brounshtein, A.A. Shashkov, N.N. Paramonova, V.I. Privalov, and Y.A. Starodubtsev (continued)

STATION "C"

Station "C"
North Atlantic Ocean
Open ocean
52°45' N, 35°30' W
5 m above MSL

Atmospheric Concentrations of CO₂

CO₂ concentrations^a at Station "C" (ppmv)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1983	348.05	347.94	350.56		348.49		342.63	335.64	335.88	340.14	344.69	345.46	
1984		345.97	346.08	350.16	349.56	349.00	339.80	339.45	339.06	344.33	346.77	347.03	
1985	350.14	352.41	353.00	352.47	351.20	351.60	344.02	340.20	339.41	344.23	348.82	350.25	348.15
1986	351.86	350.20	351.81	354.77	355.26	353.27	343.51	344.69	343.27	344.96	349.32	351.41	349.53
1987	353.22	353.00	352.76	354.12	354.24	353.46	347.35	340.81	344.94	345.96	351.06	353.83	350.40
1988	357.25	356.38	356.60	355.44	356.23	352.15	350.82	345.79	345.05	350.42	352.32	355.95	352.87
1989	357.08	357.25	357.82	359.36	356.18	352.83	352.89	348.52	348.26	353.48	354.07	354.28	354.33
1990	355.66	357.71	358.85	358.32	358.44			352.16	355.28	352.24			

^aAtmospheric CO₂ concentrations are expressed in parts per million by volume (ppmv). Monthly averages are calculated from available individual flask measurements for a given month. Annual averages are based on monthly means. All flask measurements have been adjusted for concentration drift during storage time. The data scale presented here is based on initial manometric calibrations at the Scripps Institution of Oceanography (SIO) Central CO₂ Laboratory in 1981 and on calibration experiments during 1990–93 against a set of CO₂-in-air standards provided by the Atmospheric Environment Service (AES) of Canada. This scale is closely related to the SIO X87 mole fraction scale through AES standards.

Note: None of the reference gases used by the Main Geophysical Observatory (MGO) has a CO₂ concentration >355 ppmv. As a result, a linear extrapolation procedure has been applied to calculate concentration values for air samples with concentrations >355 ppmv up to mid-1992. Since August 1992, one of the AES calibration gases has been used along with the MGO reference gases to avoid extrapolation. The investigators estimate that the extrapolation error for measurements before 1992 does not exceed 0.15 ppmv.

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Atmospheric CO₂ records from sites in the Main Geophysical Observatory air sampling network

A.M. Brounshtein, A.A. Shashkov, N.N. Paramonova, V.I. Privalov, and Y.A. Starodubtsev (continued)

TERIBERKA STATION

Trends

The period of record at Teriberka Station is too short to identify any long-term trends in atmospheric CO₂ concentrations; however, the yearly mean atmospheric CO₂ concentration at Teriberka Station rose from 354.8 parts per million by volume (ppmv) in 1989 to 358.7 ppmv in 1993.

Monthly atmospheric CO₂ concentrations at Teriberka Station.

CITE AS: Brounshtein, A.M., A.A. Shashkov, N.N. Paramonova, V.I. Privalov, and Y.A. Starodubtsev. 1994. Atmospheric CO₂ records from sites in the Main Geophysical Observatory air sampling network. pp. 180-192. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric CO₂ records from sites in the Main Geophysical
Observatory air sampling network

A.M. Brounshtein, A.A. Shashkov, N.N. Paramonova, V.I. Privalov, and Y.A. Starodubtsev (continued)

TERIBERKA STATION

Teriberka Station
RussiaCoastal tundra peninsula
69°12' N, 35°06' E
40 m above MSLAtmospheric Concentrations of CO₂CO₂ concentrations^a at Teriberka Station (ppmv)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1988				360.1	357.3	352.3	345.8	344.3	349.4	352.2	356.2	360.2	
1989	361.8	360.8	362.5	359.9	357.6	352.5	345.8	345.2	345.2	352.7	355.6	358.3	354.8
1990	360.9	361.5	360.8	360.2	360.0	354.5	344.3	344.7	349.9	353.0	359.2	361.7	355.9
1991	361.9	361.3	366.2	362.7	360.7	356.4	350.2	348.8	350.8	356.6	361.4	362.4	358.3
1992	362.0	364.9	364.9	364.6	362.1	356.7	349.2	347.6	350.0	355.6	359.8	359.9	358.1
1993	361.9	362.5	361.1	363.4	361.0	357.2	350.0	347.3	351.2	358.2	363.1	367.7	358.7

^aAtmospheric CO₂ concentrations are expressed in parts per million by volume (ppmv). Monthly averages are calculated from available individual flask measurements for a given month. Annual averages are based on monthly means. All flask measurements have been adjusted for concentration drift during storage time. The data scale presented here is based on initial manometric calibrations at the Scripps Institution of Oceanography (SIO) Central CO₂ Laboratory in 1981 and on calibration experiments during 1990–93 against a set of CO₂-in-air standards provided by the Atmospheric Environment Service (AES) of Canada. This scale is closely related to the SIO X87 mole fraction scale through AES standards.

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Atmospheric CO₂ records from sites in the Main Geophysical
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A.M. Brounshtein, A.A. Shashkov, N.N. Paramonova, V.I. Privalov, and Y.A. Starodubtsev (continued)

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M.R. Manning, W.H. Melhuish

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Period of Record

1954–93

Methods

Trays containing ~2 L of 5 normal NaOH carbonate-free solution are typically exposed for intervals of 1–2 weeks, and the atmospheric CO_2 absorbed during that time is recovered by acid evolution. Considerable fractionation occurs during absorption into the NaOH solution, and the standard fractionation correction (Stuiver and Polach 1977) is used to determine a $\Delta^{14}\text{C}$ value corrected to $\delta^{13}\text{C} = -25$ per mil (‰).

Some samples reported here were taken using BaOH solution or with extended tray exposure times. These variations in procedure do not appear to affect the results (Manning et al. 1990). A few early measurements were made by bubbling air through columns of NaOH for several hours. These samples have higher $\delta^{13}\text{C}$ values. Greater details on the sampling methods are provided in Manning et al. (1990) and Rafter and Fergusson (1959).

Wellington
New Zealand
41°18' S, 174°48' E

CITE AS: Manning, M.R., and W.H. Melhuish. 1994. Atmospheric $\Delta^{14}\text{C}$ record from Wellington. pp. 193–202. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

WELLINGTON

Trends

These measurements of ^{14}C in atmospheric CO_2 at Wellington constitute one of the longest isotopic records available, particularly for the Southern Hemisphere, and support the overall decline in atmospheric $^{14}\text{CO}_2$ reported by others. The ^{14}C record for Wellington in 1965 shows a peak occurring roughly 1 year later than that observed in the Northern Hemisphere (Nydal and Lovseth 1983; Levin et al. 1985).

Manning et al. (1990) reported a seasonal component for the Wellington record and a cycle of decreasing amplitude for the seasonal component. Manning et al. (1990) reported that up to 1980, the cycle had a maximum in March and a minimum in August along with a negative anomaly in December. The amplitude of the cycle for this period decreased steadily from a peak-to-peak range of 20‰ in 1966 to 3‰ in 1980. From 1980 onwards, Manning et al. (1990) found that a different cycle emerged: the new cycle had an amplitude of ~5‰, a maximum in July–August, and a minimum in January.

$\Delta^{14}\text{C}$ values measured in atmospheric CO_2 at Wellington.

CITE AS: Manning, M.R., and W.H. Melhuish. 1994. Atmospheric $\Delta^{14}\text{C}$ record from Wellington. pp. 193–202. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric Carbon Dioxide
Atmospheric $\Delta^{14}\text{C}$ record from Wellington

M.R. Manning and W.H. Melhuish (continued)

WELLINGTON

$\Delta^{14}\text{C}$ Values Measured in Atmospheric CO_2^a

Year	Month	Day	$\delta^{13}\text{C}$ (per mil)	$\Delta^{14}\text{C}$ (per mil)	Err ^b	Lab number ^c	Exposure days ^d
1954	12	15	-9.4	-17.7	7.6	NZ2100	
1955	2	22	-9.4	-10.1	7.7	NZ2099	
1955	4	14	-9.4	-1.4	7.6	NZ2098	
1955	5	10	-24.9	-10.3	7.8	NZ2097	
1955	6	15	-9.4	-4.1	5.9	NZ2102	
1955	9	7	-8.8	-11.9	4.0	NZ2103	
1955	12	15	-8.8	0.1	5.4	NZ2104	
1956	2	19	-8.8	5.6	3.9	NZ2105	
1956	6	15	-25.0	37.9	4.8	NZ2107	
1956	9	25	-25.8	10.1	4.8	NZ2108	
1956	10	21	-9.0	13.6	4.7	NZ2110	
1956	10	22	-9.2	18.1	4.7	NZ2109	
1957	1	27	-9.0	18.3	3.7	NZ2111	
1957	1	27	-10.1	24.9	3.7	NZ2112	
1957	4	28	-10.6	39.0	4.7	NZ2113	
1957	4	28	-9.8	41.5	4.7	NZ2114	
1957	5	22	-24.8	16.6	4.8	NZ2115	
1957	7	23	-9.4	44.9	3.9	NZ2120	
1957	7	23	-9.6	43.4	3.9	NZ2118	
1957	8	27	-24.8	51.4	4.0	NZ2116	
1957	10	9	-12.5	46.3	5.1	NZ2122	
1957	11	6	-9.7	51.6	4.7	NZ2124	
1957	11	26	-8.8	62.0	4.6	NZ2123	
1958	3	18	-9.4	67.5	4.0	NZ2126	
1958	3	18	-10.1	76.2	4.0	NZ2125	
1958	7	4	-25.0	81.1	3.8	NZ2128	
1958	8	28	-25.0	77.8	3.8	NZ2127	
1958	9	29	-24.8	93.9	3.5	NZ2129	
1958	10	9	-24.6	116.9	4.6	NZ2130	
1958	12	23	-25.0	110.1	3.8	NZ2131	
1959	1	17	-25.0	121.1	3.8	NZ2132	
1959	3	2	-25.0	126.0	4.6	NZ2133	
1959	4	11	-25.1	137.2	3.8	NZ2134	
1959	6		-25.9	132.8	3.8	NZ2136	
1959	7	13	-25.2	150.1	3.8	NZ2135	
1959	8	13	-25.0	141.8	4.5	NZ2137	
1959	10	1	-26.4	164.6	4.5	NZ2138	
1959	11	19	-24.5	171.4	4.5	NZ2139	
1959	12	19	-25.0	181.7	4.5	NZ2140	
1960	1	21	-25.2	181.8	4.5	NZ2141	
1960	4	14	-23.4	187.9	4.5	NZ2142	
1960	7	14	-24.0	187.4	4.5	NZ2143	
1960	9	1	-22.8	193.7	4.5	NZ2145	
1960	9	29	-22.5	195.9	4.5	NZ2144	
1960	11	13	-26.4	198.4	4.5	NZ2147	
1960	12	19	-24.5	193.7	4.5	NZ2146	
1961	1	20	-25.5	194.9	4.5	NZ2148	
1961	3	10	-24.9	207.1	5.1	NZ2149	
1961	4	14	-25.0	201.9	4.5	NZ2150	
1961	5	26	-26.3	196.7	4.5	NZ2151	
1961	7	6	-25.1	198.3	9.5	NZ2263	
1961	8	19	-25.3	197.9	6.3	NZ2262	
1961	10	3	-24.7	182.8	5.0	NZ2152	
1961	11	11	-23.8	237.2	9.4	NZ2264	
1961	12	19	-25.1	227.3	9.4	NZ2265	

Atmospheric Carbon Dioxide

Atmospheric $\Delta^{14}\text{C}$ record from Wellington

M.R. Manning and W.H. Melhuish (continued)

WELLINGTON

$\Delta^{14}\text{C}$ Values Measured in Atmospheric CO_2 (continued)^a

Year	Month	Day	$\delta^{13}\text{C}$ (per mil)	$\Delta^{14}\text{C}$ (per mil)	Err ^b	Lab number ^c	Exposure days ^d
1962	1	19	-24.6	197.4	5.0	NZ2268	
1962	3	2	-23.4	207.3	7.5	NZ2266	
1962	4	25	-24.5	214.3	5.1	NZ2267	
1962	5	25	-24.5	189.4	9.5	NZ2269	
1962	9	28	-24.5	233.5	4.4	NZ2155	
1962	11	9	-24.0	250.4	5.9	NZ2270	
1962	12	20	-28.4	266.6	3.9	NZ2153	
1963	1	18	-25.9	265.5	3.9	NZ2154	
1963	3	1	-23.6	269.7	3.9	NZ2156	
1963	3	1	-23.6	266.4	3.8	NZ2159	
1963	4	14	-23.5	280.9	3.8	NZ2160	
1963	4	14	-23.5	284.3	3.9	NZ2157	
1963	5	26	-24.2	313.2	4.1	NZ2163	
1963	7	6	-24.7	331.1	4.1	NZ2161	
1963	8	17	-24.7	355.6	4.3	NZ2162	
1963	9	29	-23.7	405.2	3.8	NZ2164	
1963	11	10	-24.7	374.8	4.1	NZ2165	
1963	12	20	-24.7	429.5	3.8	NZ2166	
1964	1	17	-23.1	445.7	3.8	NZ2167	
1964	3	1	-22.8	472.5	4.0	NZ2168	
1964	4	11	-23.7	500.3	4.0	NZ2169	
1964	5	23	-25.9	498.3	3.9	NZ2170	
1964	7	3	-24.7	542.4	3.7	NZ2171	
1964	8	15	-24.6	567.4	4.0	NZ2173	
1964	10	3	-25.4	507.0	3.9	NZ2172	
1964	11	6	-24.7	621.9	3.9	NZ2174	
1964	12	17	-19.9	615.7	3.9	NZ2175	
1965	1	15	-22.0	689.4	7.5	NZ2271	
1965	2	27	-23.6	633.6	3.9	NZ2176	
1965	4	8	-23.9	634.1	3.9	NZ2178	
1965	5	21	-21.4	615.2	3.8	NZ2177	
1965	7	2	-25.7	694.5	3.9	NZ2180	
1965	8	13	-23.9	614.1	3.9	NZ2179	
1965	9	24	-25.2	634.2	4.0	NZ2181	
1965	11	6	-18.1	625.7	4.0	NZ2182	
1965	12	24	-24.9	634.4	3.9	NZ2183	
1966	2	4	-24.6	647.3	3.9	NZ2184	
1966	3	8	-26.4	646.5	3.9	NZ2185	
1966	4	2	-23.9	631.8	3.6	NZ2186	
1966	5	20	-26.1	622.1	3.8	NZ2189	
1966	6	10	-25.0	612.4	4.2	NZ2188	
1966	7	6	-23.2	612.2	4.4	NZ2187	
1966	8	19	-24.8	590.8	3.9	NZ2190	
1966	9	9	-26.8	625.2	3.8	NZ2191	
1966	10	7	-23.8	614.8	3.9	NZ2192	
1966	11	5	-25.1	614.9	4.2	NZ2193	
1966	12	11	-24.8	627.8	3.9	NZ2194	
1967	1	9	-24.6	616.4	3.9	NZ2195	
1967	2	24	-23.0	602.9	4.4	NZ2196	
1967	4	8	-23.4	609.0	3.8	NZ2197	
1967	5	6	-23.7	596.5	3.8	NZ2198	
1967	6	10	-23.7	580.0	6.3	NZ2272	
1967	6	10	-23.7	595.9	5.4	NZ2273	
1967	7	19	-24.4	571.3	3.8	NZ2199	
1967	10	6	-23.1	575.1	3.8	NZ2200	

Atmospheric Carbon Dioxide
Atmospheric $\Delta^{14}\text{C}$ record from Wellington

M.R. Manning and W.H. Melhuish (continued)

WELLINGTON

$\Delta^{14}\text{C}$ Values Measured in Atmospheric CO_2 (continued)^a

Year	Month	Day	$\delta^{13}\text{C}$ (per mil)	$\Delta^{14}\text{C}$ (per mil)	Err ^b	Lab number ^c	Exposure days ^d
1967	11	10	-25.7	586.0	5.2	NZ2274	
1967	12	9	-24.4	579.6	3.9	NZ2201	
1968	1	13	-23.9	583.0	3.9	NZ2202	
1968	2	11	-24.5	582.5	3.9	NZ2203	
1968	3	11	-22.5	572.8	3.6	NZ2204	
1968	4	6	-23.9	547.6	3.7	NZ2205	
1968	5	31	-24.8	560.5	3.9	NZ2206	
1968	6	7	-24.6	561.7	3.9	NZ2207	
1968	7	5	-26.3	550.4	3.9	NZ2208	
1968	8	9	-24.7	538.1	3.9	NZ2209	
1968	8	30	-23.8	535.5	3.8	NZ2210	
1968	9	6	-23.7	531.5	3.9	NZ2211	
1968	10	4	-24.6	532.8	3.9	NZ2212	
1968	10	18	-24.7	537.6	3.9	NZ2213	
1968	11	2	-25.3	541.9	3.9	NZ3470	
1968	11	8	-26.9	541.2	3.9	NZ2214	
1968	12	6	-23.8	539.6	3.9	NZ2215	
1969	1	10	-24.3	539.1	3.9	NZ2217	
1969	2	7	-23.1	537.7	3.8	NZ2216	
1969	3	8	-23.3	550.4	3.8	NZ2218	
1969	4	13	-23.4	545.4	3.8	NZ2222	
1969	5	2	-23.1	530.4	4.0	NZ2220	
1969	5	9	-22.8	539.6	3.9	NZ2221	
1969	6	7	-23.4	525.2	4.2	NZ2223	
1969	7	11	-23.2	526.3	3.9	NZ2219	
1969	8	9	-23.0	522.8	3.9	NZ2224	
1969	9	5	-23.5	544.9	3.8	NZ2225	
1969	10	10	-25.2	531.2	3.9	NZ2226	
1969	11	3	-23.2	523.0	3.9	NZ2227	
1969	12	5	-22.5	510.2	3.9	NZ2228	
1970	1	9	-22.5	510.2	3.9	NZ2229	
1970	3	6	-22.5	535.3	3.9	NZ2230	
1970	4	10	-22.1	520.4	3.9	NZ2232	
1970	5	9	-22.4	513.5	3.9	NZ2231	
1970	6	6	-23.3	516.2	3.9	NZ2233	
1970	7	10	-23.8	505.9	3.9	NZ2234	
1970	8	7	-23.6	497.4	3.5	NZ2235	
1970	9	11	-24.5	508.0	3.9	NZ2236	
1970	10	10	-24.3	498.6	3.9	NZ2237	
1970	11	6	-23.3	497.6	4.0	NZ2238	
1970	12	23	-22.7	495.6	3.9	NZ2239	
1971	1	10	-22.3	500.6	3.9	NZ2240	
1971	2	5	-23.8	494.7	3.7	NZ2241	
1971	3	5	-24.6	508.3	3.9	NZ2242	
1971	4	9	-24.8	501.0	3.9	NZ2243	
1971	5	7	-24.9	499.7	3.9	NZ2244	
1971	6	11	-24.6	499.0	3.9	NZ2245	
1971	7	9	-25.9	494.2	4.1	NZ2246	
1971	8	8	-23.5	483.3	4.0	NZ2248	
1971	9	10	-24.5	478.8	4.5	NZ2247	
1971	10	10	-24.0	492.5	3.9	NZ2249	
1971	12	3	-24.8	479.3	3.9	NZ2251	
1972	1	9	-23.9	484.5	3.6	NZ2252	
1972	2	6	-24.7	491.6	4.0	NZ2253	

Atmospheric Carbon Dioxide

Atmospheric $\Delta^{14}\text{C}$ record from Wellington

M.R. Manning and W.H. Melhuish (continued)

WELLINGTON

$\Delta^{14}\text{C}$ Values Measured in Atmospheric CO_2 (continued)^a

Year	Month	Day	$\delta^{13}\text{C}$ (per mil)	$\Delta^{14}\text{C}$ (per mil)	Err ^b	Lab number ^c	Exposure days ^d
1972	3	17	-22.5	474.8	7.4	NZ2282	
1972	3	31	-23.8	482.4	3.6	NZ2250	
1972	4	20	-22.6	468.1	3.6	NZ2254	
1972	5	4	-23.0	469.5	5.1	NZ2286	
1972	6	10	-24.4	470.1	5.1	NZ2287	
1972	7	7	-24.0	465.9	5.1	NZ2288	
1972	9	1	-24.7	450.3	5.1	NZ2289	
1972	10	7	-24.4	449.9	6.7	NZ2283	
1972	12	8	-24.9	447.3	4.7	NZ2285	
1973	2	10	-24.3	453.9	5.1	NZ2291	
1973	3	9	-23.6	442.8	3.3	NZ2255	
1973	7	6	-24.7	435.0	3.7	NZ2256	
1973	8	11	-24.5	427.1	3.3	NZ2257	
1973	9	7	-24.4	415.9	3.7	NZ2258	
1973	10	6	-24.1	426.0	3.3	NZ2259	
1973	11	9	-23.4	434.3	3.7	NZ2260	
1973	12	7	-23.3	417.2	3.2	NZ2261	
1974	1	11	-23.2	412.8	3.5	NZ3565	
1974	2	1	-23.0	405.1	3.3	NZ3566	
1974	3	8	-22.2	418.5	3.3	NZ3567	
1974	4	4	-23.0	417.2	3.3	NZ3568	
1974	5	10	-23.3	386.8	3.3	NZ3572	
1974	6	7	-23.3	359.7	3.3	NZ4052	
1974	7	6	-23.3	394.5	3.3	NZ4057	
1974	8	7	-24.8	392.3	3.7	NZ4058	
1974	9	6	-23.4	405.0	3.3	NZ4062	
1974	10	5	-23.2	398.7	4.7	NZ3848	
1974	11	8	-22.8	401.7	3.3	NZ4065	
1974	12	8	-23.4	393.7	3.3	NZ4074	
1975	1	10	-22.2	396.3	3.3	NZ4076	
1975	2	7	-23.4	399.0	3.7	NZ4078	
1975	3	7	-23.3	400.6	3.3	NZ4083	
1975	4	5	-23.4	397.7	3.3	NZ4088	
1975	5	10	-23.2	389.1	3.7	NZ4090	
1975	6	20	-23.9	384.5	3.3	NZ4092	
1975	7	9	-23.1	377.3	3.3	NZ4094	
1975	8	10	-24.9	378.1	3.7	NZ4108	
1975	9	12	-26.2	367.5	3.7	NZ4110	
1975	10	3	-23.6	354.0	8.8	NZ4121	
1975	10	10	-22.4	365.3	3.3	NZ4119	
1975	11	15	-23.0	363.8	3.7	NZ4122	
1975	12	5	-23.6	370.8	3.7	NZ4124	
1976	1	13	-23.8	373.4	3.7	NZ4126	
1976	2	6	-24.3	368.1	3.3	NZ4135	
1976	3	6	-23.7	366.7	3.1	NZ4137	
1976	4	10	-23.0	346.1	3.3	NZ4145	
1976	5	10	-22.9	359.6	3.3	NZ4140	
1976	6	6	-25.0	360.9	3.4	NZ4144	
1976	7	4	-22.2	365.0	5.0	NZ4302	
1976	8	15	-23.9	343.3	3.7	NZ5659	
1976	10	11	-22.9	344.2	5.1	NZ5673	
1976	11	4	-25.3	346.5	3.3	NZ5675	
1976	12	10	-23.6	329.6	3.7	NZ5678	
1977	1	3	-24.5	332.9	3.7	NZ5679	
1977	2	11	-24.3	347.0	5.3	NZ5688	

Atmospheric Carbon Dioxide
Atmospheric $\Delta^{14}\text{C}$ record from Wellington

M.R. Manning and W.H. Melhuish (continued)

WELLINGTON

$\Delta^{14}\text{C}$ Values Measured in Atmospheric CO_2 (continued)^a

Year	Month	Day	$\delta^{13}\text{C}$ (per mil)	$\Delta^{14}\text{C}$ (per mil)	Err ^b	Lab number ^c	Exposure days ^d
1977	3	11	-24.7	335.4	4.5	NZ5690	
1977	5	6	-24.8	332.9	3.3	NZ5697	
1977	6	12	-24.1	335.6	4.7	NZ5699	
1977	7	15	-22.4	331.5	3.7	NZ5900	
1977	8	13	-24.1	323.6	3.3	NZ5702	
1977	9	9	-24.8	317.6	3.3	NZ5707	
1977	10	1	-28.1	335.1	3.4	NZ5730	
1977	10	7	-24.2	322.0	3.7	NZ5731	
1977	11	11	-23.4	325.0	3.7	NZ5732	
1978	5	2	-24.6	314.6	3.7	NZ5866	
1978	6	11	-25.8	310.4	3.7	NZ5867	
1978	6	30	-25.9	314.8	3.7	NZ5868	
1978	8	4	-25.2	308.8	3.2	NZ5869	
1978	9	8	-18.0	309.0	5.1	NZ5870	
1978	10	7	-25.5	321.3	8.9	NZ5871	
1978	11	10	-25.4	308.1	3.3	NZ5872	
1979	1	12	-24.9	310.2	3.3	NZ5910	
1979	3	17	-24.7	302.8	3.3	NZ5911	
1979	4	7	-25.3	304.2	3.7	NZ5912	
1979	5	9	-24.9	296.2	3.2	NZ5913	
1979	6	3	-24.5	292.3	3.3	NZ5914	
1979	7	10	-24.9	298.6	3.8	NZ5915	
1979	8	12	-25.4	284.0	3.8	NZ5916	
1979	10	5	-25.3	282.9	3.7	NZ5956	
1979	11	3	-25.2	303.5	3.8	NZ5957	
1979	12	9	-24.3	276.4	3.3	NZ5958	
1980	2	12	-25.3	282.3	3.3	NZ5959	
1980	3	8	-25.1	289.0	3.8	NZ5960	
1980	4	4	-24.8	277.6	3.3	NZ5961	
1980	5	8	-23.7	279.4	3.3	NZ5969	
1980	6	16	-23.5	239.1	7.9	NZ5971*	
1980	7	6	-25.4	281.5	3.7	NZ6008	
1980	8	1	-25.0	274.3	3.7	NZ6009	
1980	9	5	-24.8	278.1	3.3	NZ6010	
1980	10	9	-25.5	282.7	3.7	NZ6011	
1980	11	11	-25.6	272.9	3.2	NZ6012	
1980	12	4	-25.4	268.6	3.4	NZ6013	
1981	1	10	-24.7	266.0	3.7	NZ6014	
1981	2	6	-25.4	260.9	3.7	NZ6015	
1981	3	12	-24.0	264.1	4.7	NZ6016	
1981	4	10	-25.2	270.9	3.3	NZ6017	
1981	5	7	-24.5	352.2	3.3	NZ6421*	
1981	6	6	-26.2	263.3	3.7	NZ6062	
1981	8	9	-26.1	259.5	3.3	NZ6063	
1981	9	4	-25.1	258.0	5.1	NZ6064	
1981	10	2	-26.0	256.8	3.3	NZ6065	
1981	11	1	-25.4	254.7	3.7	NZ6066	
1981	12	3	-25.4	254.8	3.2	NZ6067	
1982	4	2	-25.4	385.6	3.7	NZ6432*	
1982	5	9	-23.5	245.2	3.2	NZ6449	
1982	6	5	-25.0	248.5	3.2	NZ6450	
1982	7	8	-23.3	249.2	3.8	NZ6451	
1982	9	2	-25.8	241.3	3.2	NZ6459	
1982	12	6	-25.2	235.5	3.4	NZ6523	
1983	1	17	-24.1	233.6	3.7	NZ6527	

Atmospheric Carbon Dioxide

Atmospheric $\Delta^{14}\text{C}$ record from Wellington

M.R. Manning and W.H. Melhuish (continued)

WELLINGTON

$\Delta^{14}\text{C}$ Values Measured in Atmospheric CO_2 (continued)^a

Year	Month	Day	$\delta^{13}\text{C}$ (per mil)	$\Delta^{14}\text{C}$ (per mil)	Err ^b	Lab number ^c	Exposure days ^d
1983	2	7	-24.9	227.4	3.7	NZ6528	
1983	3	6	-25.8	233.9	3.3	NZ6529	
1983	5	19	-2.2	398.4	15.5	NZ6623*	
1983	6	7	-25.2	235.6	3.7	NZ6530	
1983	8	19	-25.0	235.0	3.7	NZ6538	
1983	10	15	-24.9	221.2	3.7	NZ6539	
1983	10	29	-7.3	290.0	9.6	NZ6624*	
1984	1	15	-25.0	217.5	3.3	NZ6540	
1984	2	5	-24.2	230.3	3.8	NZ6549	
1984	5	8	-25.3	214.0	3.8	NZ6816	
1984	6	10	-25.9	244.8	4.5	NZ6815*	
1984	7	9	-25.3	214.5	3.8	NZ6817	
1984	8	3	-26.4	238.0	4.4	NZ6807	
1984	9	10	-25.4	208.1	3.5	NZ6820	
1984	11	11	-25.4	206.9	2.7	NZ6821	
1984	12	2	-26.4	216.8	3.3	NZ6831	
1985	2	2	-26.5	206.9	3.3	NZ6847	
1985	3	24	-25.4	209.8	3.8	NZ6858	
1985	7	2	-27.2	216.1	9.4	NZ7257	7
1985	8	5	-25.7	212.4	6.4	NZ7277	7
1985	9	5	-25.8	202.8	6.4	NZ7272	8
1985	10	29	-26.0	203.5	4.8	NZ7408	6
1985	11	28	-26.6	205.1	4.8	NZ7409	8
1986	1	6	-23.7	204.6	3.8	NZ7264	28
1986	2	10	-26.0	203.3	6.4	NZ7286	16
1986	3	27	-25.9	199.4	5.5	NZ7382	7
1986	4	1	-25.6	189.1	6.3	NZ7395	7
1986	4	28	-23.5	183.5	7.2	NZ7417	11
1986	7	8	-25.8	194.5	4.9	NZ7410	8
1986	8	6	-26.5	188.3	4.1	NZ7412	7
1986	9	3	-26.1	200.5	4.1	NZ7413	7
1986	10	1	-26.0	193.8	4.8	NZ7430	7
1986	11	4	-25.5	190.9	4.8	NZ7431	6
1986	12	3	-25.6	189.2	4.8	NZ7432	8
1986	12	31	-25.5	186.5	4.8	NZ7454	7
1987	5	6	-25.5	185.8	4.8	NZ7455	9
1987	6	5	-25.8	176.3	5.4	NZ7456	13
1988	7	8	-25.4	175.7	6.4	NZ7582	14
1988	8	12	-25.6	176.1	6.7	NZ7583	7
1988	9	16	-26.5	167.3	5.9	NZ7650	7
1988	10	20	-26.3	178.4	7.9	NZ7651	6
1988	11	22	-24.9	178.6	3.2	NZ7816	7
1988	12	13	-24.6	169.2	3.5	NZ7817	6
1989	1	25	-23.5	175.4	3.6	NZ7818	7
1989	2	14	-24.7	167.2	3.8	NZ7819	10
1989	4	18	-24.8	196.1	3.6	NZ7820	8
1989	5	17	-25.0	162.8	3.5	NZ7821	8
1989	6	21	-24.84	164.5	3.5	NZ7822	7
1989	7	28	-22.52	164.6	3.8	NZ7823	12
1989	8	21	-24.20	160.5	3.8	NZ7824	10
1989	9	21	-17.80	145.7	3.7	NZ7825*	13
1989	11	1	-26.51	194.0	3.9	NZ7826	7
1989	12	7	-24.81	161.0	3.8	NZ7827	11
1990	1	16	-24.50	154.0	3.9	NZ7828	9
1990	2	15	-23.70	173.7	3.5	NZ7829	7

Atmospheric Carbon Dioxide
Atmospheric $\Delta^{14}\text{C}$ record from Wellington

M.R. Manning and W.H. Melhuish (continued)

WELLINGTON

$\Delta^{14}\text{C}$ Values Measured in Atmospheric CO_2 (continued)^a

Year	Month	Day	$\delta^{13}\text{C}$ (per mil)	$\Delta^{14}\text{C}$ (per mil)	Err ^b	Lab number ^c	Exposure days ^d
1990	3	16	-24.56	119.3	4.4	NZ7830*	7
1990	4	18	-27.47	164.1	3.8	NZ7831	8
1990	7	8	-23.41	160.4	3.9	NZ7833	8
1990	8	13	-25.42	159.0	4.7	NZ7834	7
1990	9	14	-24.58	162.3	3.3	NZ7835	7
1990	11	6	-26.71	162.9	4.8	NZ7842	7
1990	12	10	-24.22	162.9	3.5	NZ7843	9
1991	1	9	-23.83	154.1	3.8	NZ7844	12
1991	2	13	-23.00	157.2	4.1	NZ7845	9
1991	3	14	-25.66	169.0	3.6	NZ7846	8
1991	4	25	-26.00	164.9	11.9	NZ7847	8
1991	5	16	-24.93	163.0	6.7	NZ7867	13
1991	6	14	-22.20	164.2	3.4	NZ7868	12
1991	7	13	-22.82	162.6	5.7	NZ7869	13
1991	8	26	-21.00	158.5	3.3	NZ7870	12
1991	9	13	-22.70	155.3	3.5	NZ7871	12
1991	10	10	-23.40	162.6	2.9	NZ7872	14
1991	11	29	-24.35	149.8	3.6	NZ7904	14
1992	1	24	-24.20	155.9	4.5	NZ7905	7
1992	2	19	-24.00	156.5	3.2	NZ7906	7
1992	4	1	-22.90	161.4	2.7	NZ7907	8
1992	4	24	-21.20	165.6	3.2	NZ7908	13
1992	5	21	-22.30	142.7	5.7	NZ7909*	13
1992	7	15	-24.50	160.9	6.0	NZ7981	28
1992	8	19	-25.64	139.0	4.5	NZ7982	8
1992	10	3	-21.22	149.2	4.8	NZ7983	11
1992	10	16	-18.90	143.3	3.2	NZ8005*	25
1992	12	18	-18.10	146.7	3.8	NZ8006*	39
1993	2	15	-21.12	140.3	2.9	NZ8007	16
1993	3	23	-20.50	132.6	3.5	NZ8008	16
1993	5	5	-25.05	135.0	3.7	NZ8071	8
1993	6	29	-22.40	125.6	3.1	NZ8072	23

^a $\Delta^{14}\text{C}$ values are expressed in per mil and corrected to $\delta^{13}\text{C} = -25$ per mil.

^bErr is twice the estimated standard deviation in the $\Delta^{14}\text{C}$ value based on ^{14}C -counting statistics and routine checks of consistency for other samples in the same lab.

^cAn asterisk denotes a sample known or suspected to be contaminated.

^dUntil July 1985, date typically is the midpoint of a 7-day exposure period. For the remainder of the record, date refers to the start date, and the last column reflects the number of days that the sampling trays were exposed.

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| Schauinsland • Vermunt

Period of Record

1959–92

Methods

The sampling methods were modified twice during the period of observation (Levin et al. 1985). From 1959 through November 1965, three dishes with 1.5 L of 0.5 normal sodium hydroxide (NaOH) carbonate-free solution were exposed to the atmosphere for ~3 days, and the atmospheric CO_2 absorbed during that time was recovered by acid evolution. From November 1965 through May 1975, samples were collected by pumping fresh air continuously for 10 days through a box containing 1.5 L of a 0.5 normal NaOH solution. With this method, the atmospheric CO_2 is absorbed nearly quantitatively in the NaOH solution. The method has been described by Münnich and Vogel (1959). Since May 1975, a technique described by Levin et al. (1980) has been used. Air has been pumped through a rotating glass tube filled with a packed bed of Raschig rings (hard glass) to enlarge the surface of the absorbing NaOH solution (200 ml of 4 normal NaOH). The CO_2 absorption is quantitative and samples represent mean values of 10 days to 2 weeks. In the laboratory, the samples are extracted from the NaOH solution in a vacuum system by adding hydrochloric or sulfuric acid. The CO_2 gas samples were purified over charcoal and counted in a proportional counter (Schoch et al. 1980). Considerable fractionation occurs during static absorption into the NaOH solution. The dynamic absorption method used since 1976 at the Schauinsland station also provides reliable atmospheric $\delta^{13}\text{CO}_2$ values with a typical error of $\pm 0.1\%$ (Levin et al., 1994).

More details on the sampling methods and laboratory procedures are provided in Levin et al. (1985), Münnich (1957), Schoch et al. (1980), and Levin et al. (1980).

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$\Delta^{14}\text{CO}_2$ records from sites in Central Europe

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SCHAUINSLAND

Trends

Levin et al. (1985) consider this time series representative of the higher altitude $^{14}\text{CO}_2$ level over central Europe. On the basis of close agreement between the $^{14}\text{CO}_2$ records from Schauinsland and Vermunt, they noted that the two records are indicative of the $^{14}\text{CO}_2$ level of tropospheric CO_2 above central Europe. Levin et al. (1994) also reported the mean anthropogenic $^{14}\text{CO}_2$ depletion for the Schauinsland station was approximately $\Delta^{14}\text{C} = -7\text{‰}$ (-5‰ in summer and -10‰ in winter).

$\Delta^{14}\text{C}$ values measured in atmospheric CO_2 at Schauinsland.

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$\Delta^{14}\text{CO}_2$ records from sites in Central Europe

I. Levin, B. Kromer, H. Schoch-Fischer, M. Bruns, M. Münnich, D. Berdau,
J.C. Vogel, and K.O. Münnich (continued)

SCHAUINSLAND

Schauinsland
Germany
Black Forest mountain
range close to Schauinsland
Summit, forest environment
47°55' N, 7°55' E
1205 m above MSL

 $\Delta^{14}\text{C}$ Values Measured in Atmospheric CO_2

Analysis no.	Sample no.	Sampling period ^a						$\Delta^{14}\text{C}$ (‰) ^b	$\delta^{13}\text{C}$ (‰) ^c	
		d	mo	yr	–	d	mo			yr
Hd-4155	SCH-1	9	12	76	–	23	12	76	320 ± 8	–7.98
Hd-4158	SCH-2	23	12	76	–	6	1	77	320 ± 5	–7.91
Hd-4161	SCH-3	6	1	77	–	20	1	77	332 ± 6	–7.98
Hd-4173	SCH-4	20	1	77	–	3	2	77	321 ± 6	–7.91
Hd-4178	SCH-5	3	2	77	–	18	2	77	325 ± 8	–7.97
Hd-4176	SCH-6	18	2	77	–	7	3	77	345 ± 6	–7.92
Hd-4215	SCH-7	15	3	77	–	29	3	77	326 ± 7	–7.92
Hd-4218	SCH-8	29	3	77	–	13	4	77	327 ± 7	–8.11
Hd-4306	SCH-9	13	4	77	–	6	5	77	333 ± 5	–7.88
Hd-4308	SCH-10	6	5	77	–	31	5	77	337 ± 5	–7.56
Hd-4307	SCH-11	31	5	77	–	26	6	77	341 ± 5	–7.50
Hd-4309	SCH-12	26	6	77	–	18	7	77	337 ± 5	–7.37
Hd-4475	SCH-13	18	7	77	–	15	8	77	327 ± 7	–7.40
Hd-4476	SCH-14	15	8	77	–	4	9	77	336 ± 5	–7.50
Hd-4468	SCH-15	4	9	77	–	27	9	77	342 ± 5	–7.47
Hd-4629	SCH-16	26	10	77	–	21	11	77	342 ± 5	–7.75
Hd-4630	SCH-17	21	11	77	–	25	12	77	308 ± 5	–7.83
Hd-4632	SCH-18	25	12	77	–	30	1	78	312 ± 5	–8.15
Hd-4633	SCH-19	30	1	78	–	9	3	78	309 ± 6	–8.69
Hd-4885	SCH-20	9	3	78	–	29	3	78	319 ± 5	–8.32
Hd-4867	SCH-21	29	3	78	–	9	4	78	333 ± 6	–8.54
Hd-4873	SCH-22	18	4	78	–	7	5	78	317 ± 8	–7.92
Hd-4874	SCH-23	7	5	78	–	5	6	78	323 ± 8	–8.10
Hd-4915	SCH-24	7	6	78	–	3	7	78	343 ± 8	–7.88
Hd-4916	SCH-25	3	7	78	–	13	7	78	339 ± 8	–7.77
Hd-4917	SCH-26	13	7	78	–	26	7	78	331 ± 8	–7.31
Hd-4920	SCH-27	26	7	78	–	8	8	78	340 ± 6	–7.39
Hd-4984	SCH-28	15	8	78	–	29	8	78	344 ± 5	–7.27
Hd-4985	SCH-29	29	8	78	–	12	9	78	337 ± 9	–7.20
Hd-4986	SCH-30	12	9	78	–	26	9	78	315 ± 11	–7.31
Hd-4987	SCH-31	26	9	78	–	10	10	78	311 ± 8	–8.04
Hd-5003	SCH-32	10	10	78	–	24	10	78	308 ± 10	–7.72
Hd-5074	SCH-33	24	10	78	–	5	11	78	334 ± 8	–8.39
Hd-5087	SCH-34	5	11	78	–	18	11	78	328 ± 8	–7.69
Hd-5075	SCH-35	18	11	78	–	1	12	78	323 ± 9	–11.53 ^d
Hd-5076	SCH-36	1	12	78	–	15	12	78	306 ± 11	–7.88
Hd-5088	SCH-37	15	12	78	–	31	12	78	318 ± 7	–8.25
Hd-5181	SCH-38	31	12	78	–	14	1	79	307 ± 5	–8.12
Hd-5182	SCH-39	14	1	79	–	30	1	79	298 ± 5	–8.55
Hd-5183	SCH-40	30	1	79	–	12	2	79	306 ± 5	–8.60
Hd-5194	SCH-41	20	2	79	–	5	3	79	293 ± 5	–8.39

$\Delta^{14}\text{CO}_2$ records from sites in Central Europe

I. Levin, B. Kromer, H. Schoch-Fischer, M. Bruns, M. Münnich, D. Berdau,
J.C. Vogel, and K.O. Münnich (continued)

SCHAUINSLAND

 $\Delta^{14}\text{C}$ Values Measured in Atmospheric CO_2 (continued)

Analysis no.	Sample no.	Sampling period ^a						$\Delta^{14}\text{C}$ (‰) ^b	$\delta^{13}\text{C}$ (‰) ^c	
		d	mo	yr	–	d	mo			yr
Hd-5195	SCH-42	5	3	79	–	18	3	79	298 ± 5	–7.89
Hd-5258	SCH-44	31	3	79	–	13	4	79	292 ± 6	–8.50
Hd-5259	SCH-45	13	4	79	–	26	4	79	309 ± 5	–8.36
Hd-5274	SCH-46	26	4	79	–	8	5	79	292 ± 5	–8.45
Hd-5275	SCH-47	8	5	79	–	21	5	79	352 ± 5	–8.22
Hd-5331	SCH-48	21	5	79	–	6	6	79	283 ± 4	–8.01
Hd-5339	SCH-49	6	6	79	–	19	6	79	291 ± 5	–7.50
Hd-5340	SCH-50	19	6	79	–	3	7	79	294 ± 5	–7.42
Hd-5343	SCH-51	3	7	79	–	15	7	79	288 ± 7	–7.47
Hd-5328	SCH-52	15	7	79	–	26	7	79	309 ± 6	–8.00
Hd-5485	SCH-54	9	8	79	–	24	8	79	299 ± 4	–7.51
Hd-5500	SCH-55	24	8	79	–	5	9	79	288 ± 6	–7.40
Hd-5480	SCH-56	5	9	79	–	18	9	79	298 ± 5	–7.44
Hd-5501	SCH-57	18	9	79	–	1	10	79	307 ± 6	–7.48
Hd-5493	SCH-58	1	10	79	–	10	10	79	294 ± 6	–7.57
Hd-5579	SCH-59	12	10	79	–	27	10	79	297 ± 5	–7.96
Hd-5574	SCH-60	27	10	79	–	10	11	79	290 ± 4	–7.90
Hd-5726	SCH-61	10	11	79	–	24	11	79	281 ± 4	–8.02
Hd-5581	SCH-62	24	11	79	–	10	12	79	296 ± 3	–8.37
Hd-5727	SCH-63	10	12	79	–	21	12	79	280 ± 4	–8.00
Hd-5825	SCH-64	2	1	80	–	18	1	80	269 ± 8	–8.29
Hd-5807	SCH-65	18	1	80	–	2	2	80	295 ± 8	–8.41
Hd-5806	SCH-66	2	2	80	–	17	2	80	271 ± 6	–8.01
Hd-5826	SCH-67	17	2	80	–	3	3	80	265 ± 5	–8.95
Hd-5935	SCH-68	11	3	80	–	24	3	80	249 ± 4	–8.88
Hd-5936	SCH-69	24	3	80	–	6	4	80	260 ± 3	–7.74
Hd-5941	SCH-70	6	4	80	–	19	4	80	259 ± 4	–8.90
Hd-5942	SCH-71	20	4	80	–	2	5	80	267 ± 5	–8.39
Hd-5970	SCH-73	2	6	80	–	14	6	80	271 ± 2	–8.06
Hd-5971	SCH-74	14	6	80	–	24	6	80	269 ± 4	–7.71
Hd-5956	SCH-75	24	6	80	–	7	7	80	283 ± 4	–8.52
Hd-5972	SCH-76	7	7	80	–	17	7	80	278 ± 6	–6.93 ^d
Hd-5954	SCH-77	17	7	80	–	4	8	80	275 ± 5	–7.35
Hd-6038	SCH-78	7	8	80	–	18	8	80	267 ± 4	–7.90
Hd-6039	SCH-79	18	8	80	–	29	8	80	264 ± 5	–7.24
Hd-6058	SCH-80	29	8	80	–	8	9	80	264 ± 4	–7.81
Hd-6059	SCH-81	8	9	80	–	22	9	80	267 ± 3	–7.69
Hd-6054	SCH-82	22	9	80	–	14	10	80	270 ± 3	–6.76 ^d
Hd-6222	SCH-83	14	10	80	–	27	10	80	273 ± 4	–7.95
Hd-6223	SCH-84	27	10	80	–	7	11	80	256 ± 3	–9.02
Hd-6224	SCH-85	7	11	80	–	18	11	80	258 ± 4	–8.94
Hd-6225	SCH-86	18	11	80	–	1	12	80	257 ± 7	–8.91
Hd-6270	SCH-87	10	12	80	–	29	12	80	262 ± 5	–8.04
Hd-6267	SCH-88	29	12	80	–	12	1	81	254 ± 4	–8.04
Hd-6271	SCH-89	12	1	81	–	22	1	81	230 ± 4	–7.85
Hd-6388	SCH-90	22	1	81	–	4	2	81	269 ± 3	–8.43
Hd-6389	SCH-91	4	2	81	–	16	2	81	273 ± 4	–8.28
Hd-6390	SCH-92	16	2	81	–	1	3	81	247 ± 3	–9.50
Hd-6391	SCH-93	1	3	81	–	13	3	81	255 ± 5	–9.15
Hd-6392	SCH-94	13	3	81	–	27	3	81	251 ± 3	–8.61
Hd-6527	SCH-95	3	4	81	–	16	4	81	244 ± 4	–8.23

$\Delta^{14}\text{CO}_2$ records from sites in Central Europe

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 $\Delta^{14}\text{C}$ Values Measured in Atmospheric CO_2 (continued)

Analysis no.	Sample no.	Sampling period ^a						$\Delta^{14}\text{C}$ (‰) ^b	$\delta^{13}\text{C}$ (‰) ^c	
		d	mo	yr	–	d	mo			yr
Hd-6525	SCH-96	16	4	81	–	30	4	81	257 ± 4	–8.76
Hd-6526	SCH-97	30	4	81	–	15	5	81	242 ± 5	–8.55
Hd-6874	SCH-98	10	7	81	–	24	7	81	273 ± 5	–7.53
Hd-6875	SCH-99	24	7	81	–	7	8	81	267 ± 5	–7.52
Hd-6952	SCH-101	28	1	82	–	12	2	82	241 ± 6	–7.00 ^d
Hd-6953	SCH-102	12	2	82	–	3	3	82	231 ± 3	–7.18 ^d
Hd-7304	SCH-103	3	3	82	–	17	3	82	244 ± 5	–7.68
Hd-7305	SCH-104	17	3	82	–	1	4	82	234 ± 5	–8.44
Hd-7306	SCH-105	1	4	82	–	15	4	82	246 ± 4	–8.29
Hd-7307	SCH-106	15	4	82	–	27	4	82	230 ± 3	–8.29
Hd-7310	SCH-107	27	4	82	–	11	5	82	239 ± 5	–7.97
Hd-7422	SCH-108	18	5	82	–	2	6	82	250 ± 3	–7.74
Hd-7423	SCH-109	2	6	82	–	16	6	82	238 ± 4	–7.95
Hd-7424	SCH-110	16	6	82	–	2	7	82	244 ± 4	–7.67
Hd-7425	SCH-111	2	7	82	–	19	7	82	246 ± 4	–7.17
Hd-7499	SCH-112	30	7	82	–	17	8	82	245 ± 4	–7.73
Hd-7500	SCH-113	17	8	82	–	31	8	82	243 ± 5	–7.28
Hd-7508	SCH-114	31	8	82	–	15	9	82	237 ± 2	–7.50
Hd-7509	SCH-115	15	9	82	–	7	10	82	243 ± 2	–7.69
Hd-7658	SCH-116	7	10	82	–	25	10	82	242 ± 3	–8.47
Hd-7659	SCH-117	25	10	82	–	8	11	82	238 ± 5	–7.82
Hd-7660	SCH-118	8	11	82	–	29	11	82	236 ± 5	–8.35
Hd-7661	SCH-119	29	11	82	–	15	12	82	233 ± 4	–8.23
Hd-7662	SCH-120	15	12	82	–	10	1	83	231 ± 4	–8.06
Hd-7807	SCH-121	26	1	83	–	15	2	83	224 ± 2	–8.22
Hd-7808	SCH-122	15	2	83	–	7	3	83	223 ± 3	–8.28
Hd-7809	SCH-123	7	3	83	–	6	4	83	231 ± 3	–8.28
Hd-7810	SCH-124	6	4	83	–	29	4	83	233 ± 6	–8.15 ^d
Hd-7843	SCH-125	29	4	83	–	9	5	83	238 ± 4	–8.08 ^d
Hd-7857	SCH-126	9	5	83	–	19	5	83	220 ± 4	–8.09
Hd-8024	SCH-127	1	6	83	–	16	6	83	234 ± 4	–7.76
Hd-8025	SCH-128	16	6	83	–	1	7	83	217 ± 4	–7.61
Hd-8026	SCH-129	1	7	83	–	22	7	83	223 ± 4	–7.69
Hd-8034	SCH-130	22	7	83	–	12	8	83	207 ± 4	–7.76
Hd-8114	SCH-131	12	8	83	–	24	8	83	231 ± 4	–7.77
Hd-8115	SCH-132	24	8	83	–	5	9	83	230 ± 4	–8.57 ^d
Hd-8120	SCH-133	5	9	83	–	16	9	83	237 ± 4	–7.81
Hd-8121	SCH-134	16	9	83	–	27	9	83	224 ± 4	–7.74
Hd-8188	SCH-135	27	9	83	–	7	10	83	218 ± 4	–7.77
Hd-8187	SCH-136	7	10	83	–	21	10	83	230 ± 4	–7.86
Hd-8202	SCH-137	21	10	83	–	9	11	83	215 ± 3	–7.97
Hd-8266	SCH-138	9	11	83	–	25	11	83	212 ± 4	–8.38
Hd-8267	SCH-139	25	11	83	–	7	12	83	210 ± 4	–8.89
Hd-8276	SCH-140	7	12	83	–	20	12	83	211 ± 4	–8.54
Hd-8365	SCH-141	20	12	83	–	2	1	84	210 ± 4	–9.06 ^d
Hd-8388	SCH-142	2	1	84	–	10	1	84	201 ± 4	–8.20
Hd-8389	SCH-143	10	1	84	–	26	1	84	218 ± 4	–9.06
Hd-8366	SCH-144	26	1	84	–	2	2	84	210 ± 5	–8.00
Hd-8474	SCH-145	7	2	84	–	13	2	84	207 ± 4	–8.31
Hd-8461	SCH-146	13	2	84	–	20	2	84	199 ± 4	–8.37
Hd-8447	SCH-147	20	2	84	–	5	3	84	187 ± 3	–9.43 ^d

$\Delta^{14}\text{C}$ records from sites in Central Europe

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J.C. Vogel, and K.O. Münnich (continued)

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 $\Delta^{14}\text{C}$ Values Measured in Atmospheric CO_2 (continued)

Analysis no.	Sample no.	Sampling period ^a						$\Delta^{14}\text{C}$ (‰) ^b	$\delta^{13}\text{C}$ (‰) ^c	
		d	mo	yr	–	d	mo			yr
Hd-8448	SCH-148	5	3	84	–	19	3	84	193 ± 4	–9.68 ^d
Hd-8494	SCH-149	19	3	84	–	2	4	84	202 ± 4	–8.77
Hd-8577	SCH-151	6	4	84	–	16	4	84	190 ± 3	–9.02
Hd-8578	SCH-152	16	4	84	–	30	4	84	203 ± 3	–8.85 ^d
Hd-8579	SCH-153	7	5	84	–	14	5	84	202 ± 3	–8.59
Hd-8580	SCH-154	14	5	84	–	25	5	84	210 ± 3	–7.97 ^d
Hd-8634	SCH-155	25	5	84	–	11	6	84	210 ± 4	–7.78
Hd-8662	SCH-156	11	6	84	–	26	6	84	216 ± 3	–7.76
Hd-5789	SCH-157	25	6	84	–	9	7	84	208 ± 4	–7.53
Hd-8774	SCH-158	9	7	84	–	23	7	84	206 ± 2	–7.55
Hd-8776	SCH-159	23	7	84	–	6	8	84	211 ± 4	–7.65
Hd-8790	SCH-160	6	8	84	–	20	8	84	203 ± 4	–7.76
Hd-8909	SCH-161	20	8	84	–	3	9	84	209 ± 3	–6.52 ^d
Hd-8857	SCH-162	7	9	84	–	24	9	84	209 ± 4	–7.80
Hd-8936	SCH-163	24	9	84	–	4	10	84	198 ± 13	–7.59
Hd-8937	SCH-164	4	10	84	–	15	10	84	206 ± 4	–7.79
Hd-8946	SCH-165	15	10	84	–	30	10	84	216 ± 4	–7.86
Hd-9008	SCH-166	30	10	84	–	13	11	84	205 ± 2	–8.1 ^d
Hd-9014	SCH-167	13	11	84	–	26	11	84	207 ± 2	–8.31
Hd-9015	SCH-168	26	11	84	–	10	12	84	203 ± 2	–8.33 ^d
Hd-9111	SCH-169	10	12	84	–	21	12	84	206 ± 4	–7.92
Hd-9112	SCH-170	21	12	84	–	14	1	85	190 ± 4	–8.43
Hd-9122	SCH-171	14	1	85	–	28	1	85	194 ± 4	–8.52
Hd-9162	SCH-172	28	1	85	–	11	2	85	199 ± 4	–8.27
Hd-9364	SCH-173	11	2	85	–	25	2	85	192 ± 3	–8.29
Hd-9365	SCH-174	25	2	85	–	6	3	85	190 ± 5	–8.40
Hd-9366	SCH-175	6	3	85	–	18	3	85	184 ± 4	–8.70
Hd-9367	SCH-176	18	3	85	–	2	4	85	195 ± 4	–8.49
Hd-9368	SCH-177	2	4	85	–	15	4	85	198 ± 4	–8.22
Hd-9387	SCH-178	15	4	85	–	29	4	85	186 ± 4	–8.55
Hd-9528	SCH-179	29	4	85	–	13	5	85	194 ± 4	–8.32
Hd-9529	SCH-180	13	5	85	–	28	5	85	196 ± 4	–7.88
Hd-9530	SCH-181	28	5	85	–	10	6	85	200 ± 4	–7.72
Hd-9531	SCH-182	10	6	85	–	24	6	85	203 ± 4	–7.58
Hd-9648	SCH-183	24	6	85	–	8	7	85	205 ± 4	–8.05
Hd-9649	SCH-184	8	7	85	–	22	7	85	191 ± 4	–7.86
Hd-9650	SCH-185	22	7	85	–	5	8	85	199 ± 4	–7.71
Hd-9651	SCH-186	5	8	85	–	19	8	85	208 ± 4	–7.62
Hd-9829	SCH-187	19	8	85	–	2	9	85	202 ± 4	–7.90
Hd-9828	SCH-188	2	9	85	–	16	9	85	193 ± 4	–8.14
Hd-9830	SCH-189	16	9	85	–	30	9	85	197 ± 4	–8.33 ^d
Hd-9858	SCH-190	30	9	85	–	14	10	85	204 ± 4	–8.45 ^d
Hd-9974	SCH-191	14	10	85	–	28	10	85	187 ± 4	–8.7 ^d
Hd-9975	SCH-192	28	10	85	–	18	11	85	195 ± 4	–8.14 ^d
Hd-9976	SCH-193	18	11	85	–	2	12	85	174 ± 4	–9.48 ^d
Hd-9977	SCH-194	2	12	85	–	16	12	85	188 ± 4	–9.04 ^d
Hd-9997	SCH-195	16	12	85	–	13	1	86	189 ± 4	–5.97 ^d
Hd-10123	SCH-196	13	1	86	–	27	1	86	192 ± 4	–9.66 ^d
Hd-10124	SCH-197	27	1	86	–	3	2	86	195 ± 4	–10.32 ^d
Hd-10125	SCH-198	3	2	86	–	17	2	86	163 ± 4	–9.58 ^d
Hd-10126	SCH-199	17	2	86	–	3	3	86	184 ± 4	–9.05

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 $\Delta^{14}\text{C}$ Values Measured in Atmospheric CO_2 (continued)

Analysis no.	Sample no.	Sampling period ^a						$\Delta^{14}\text{C}$ (‰) ^b	$\delta^{13}\text{C}$ (‰) ^c	
		d	mo	yr	–	d	mo			yr
Hd-10181	SCH-200	3	3	86	–	17	3	86	161 ± 4	–8.96
Hd-10182	SCH-201	17	3	86	–	1	4	86	189 ± 4	–8.20
Hd-10183	SCH-202	1	4	86	–	14	4	86	174 ± 4	–9.02
Hd-10222	SCH-203	14	4	86	–	28	4	86	191 ± 4	–8.50
Hd-10398	SCH-204	28	4	86	–	12	5	86	182 ± 4	–8.26
Hd-10399	SCH-205	12	5	86	–	26	5	86	186 ± 5	–8.47
Hd-10400	SCH-206	26	5	86	–	9	6	86	182 ± 2	–8.89 ^d
Hd-10401	SCH-207	9	6	86	–	23	6	86	180 ± 5	–8.03
Hd-10406	SCH-208	23	6	86	–	7	7	86	186 ± 5	–8.21 ^d
Hd-10490	SCH-209	7	7	86	–	21	7	86	186 ± 2	–7.83 ^d
Hd-10491	SCH-210	21	7	86	–	4	8	86	192 ± 2	–7.75 ^d
Hd-10494	SCH-211	4	8	86	–	18	8	86	193 ± 4	–7.66
Hd-10562	SCH-212	18	8	86	–	2	9	86	190 ± 2	–8.72 ^d
Hd-10563	SCH-213	2	9	86	–	15	9	86	184 ± 4	–7.77
Hd-10564	SCH-214	15	9	86	–	29	9	86	180 ± 4	–7.84
Hd-10583	SCH-215	29	9	86	–	13	10	86	182 ± 3	–8.62 ^d
Hd-10661	SCH-216	13	10	86	–	27	10	86	188 ± 3	–8.50
Hd-10662	SCH-217	27	10	86	–	10	11	86	185 ± 2	–8.61 ^d
Hd-10673	SCH-218	10	11	86	–	24	11	86	180 ± 3	–8.64 ^d
Hd-10710	SCH-219	24	11	86	–	8	12	86	179 ± 3	–8.08
Hd-10711	SCH-220	8	12	86	–	22	12	86	178 ± 2	–8.64 ^d
Hd-10724	SCH-221	22	12	86	–	2	1	87	181 ± 3	–8.71
Hd-10801	SCH-222	2	1	87	–	19	1	87	161 ± 2	–8.98 ^d
Hd-10802	SCH-223	19	1	87	–	2	2	87	176 ± 3	–8.36
Hd-10813	SCH-224	2	2	87	–	16	2	87	173 ± 3	–8.27
Hd-10868	SCH-225	16	2	87	–	2	3	87	157 ± 2	–8.85
Hd-10869	SCH-226	2	3	87	–	16	3	87	167 ± 3	–9.31
Hd-10875	SCH-227	16	3	87	–	30	3	87	164 ± 4	–8.18
Hd-10876	SCH-228	30	3	87	–	13	4	87	172 ± 4	–8.38
Hd-11028	SCH-229	13	4	87	–	27	4	87	169 ± 3	–8.03
Hd-11029	SCH-230	27	4	87	–	11	5	87	172 ± 2	–8.18
Hd-11032	SCH-231	11	5	87	–	25	5	87	180 ± 2	–7.98
Hd-11033	SCH-232	25	5	87	–	9	6	87	182 ± 3	–7.83
Hd-11037	SCH-233	9	6	87	–	22	6	87	180 ± 3	–7.76
Hd-11253	SCH-234	22	6	87	–	13	7	87	186 ± 4	–7.92 ^d
Hd-11254	SCH-235	13	7	87	–	3	8	87	188 ± 4	–7.9 ^d
Hd-11255	SCH-236	3	8	87	–	17	8	87	189 ± 4	–7.58
Hd-11256	SCH-237	17	8	87	–	3	9	87	184 ± 4	–7.73
Hd-11258	SCH-238	3	9	87	–	14	9	87	187 ± 5	–7.56
Hd-11259	SCH-239	14	9	87	–	28	9	87	180 ± 4	–7.68
Hd-11369	SCH-240	28	9	87	–	12	10	87	175 ± 5	–7.81
Hd-11370	SCH-241	12	10	87	–	26	10	87	182 ± 4	–7.84
Hd-11371	SCH-242	26	10	87	–	9	11	87	172 ± 4	–8.25
Hd-11372	SCH-243	9	11	87	–	23	11	87	184 ± 4	–8.26
Hd-11438	SCH-244	23	11	87	–	7	12	87	164 ± 4	–8.56
Hd-11439	SCH-245	7	12	87	–	21	12	87	174 ± 4	–8.21
Hd-11442	SCH-246	21	12	87	–	4	1	88	178 ± 3	–8.01
Hd-11539	SCH-248	18	1	88	–	1	2	88	179 ± 4	–8.14
Hd-11540	SCH-249	1	2	88	–	15	2	88	168 ± 4	–8.29
Hd-11549	SCH-250	15	2	88	–	29	2	88	168 ± 4	–8.49
Hd-11620	SCH-252	14	3	88	–	28	3	88	174 ± 4	–8.25

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$\Delta^{14}\text{C}$ Values Measured in Atmospheric CO_2 (continued)

Analysis no.	Sample no.	Sampling period ^a						$\Delta^{14}\text{C}$ (‰) ^b	$\delta^{13}\text{C}$ (‰) ^c	
		d	mo	yr	–	d	mo			yr
Hd-11621	SCH-253	28	3	88	–	11	4	88	156 ± 3	–8.47
Hd-11630	SCH-254	11	4	88	–	25	4	88	167 ± 3	–8.32
Hd-11701	SCH-255	25	4	88	–	9	5	88	165 ± 4	–8.13
Hd-11702	SCH-256	9	5	88	–	24	5	88	167 ± 4	–7.91
Hd-11703	SCH-257	24	5	88	–	6	6	88	174 ± 4	–7.89
Hd-11767	SCH-258	10	6	88	–	20	6	88	175 ± 4	–7.51
Hd-11867	SCH-259	20	6	88	–	4	7	88	162 ± 4	–7.73
Hd-11868	SCH-260	4	7	88	–	18	7	88	171 ± 4	–7.75
Hd-11879	SCH-261	18	7	88	–	1	8	88	164 ± 4	–7.73
Hd-11880	SCH-262	1	8	88	–	15	8	88	167 ± 4	–7.77
Hd-12010	SCH-263	15	8	88	–	28	8	88	173 ± 3	–7.88
Hd-12013	SCH-264	28	8	88	–	12	9	88	164 ± 4	–7.81
Hd-12020	SCH-265	12	9	88	–	26	9	88	161 ± 4	–7.85
Hd-12021	SCH-266	26	9	88	–	10	10	88	173 ± 4	–8.00
Hd-12101	SCH-267	10	10	88	–	24	10	88	171 ± 4	–7.94
Hd-12102	SCH-268	24	10	88	–	7	11	88	162 ± 4	–8.29
Hd-12162	SCH-269	7	11	88	–	21	11	88	159 ± 4	–8.26
Hd-12128	SCH-270	21	11	88	–	5	12	88	154 ± 3	–8.32
Hd-12131	SCH-271	5	12	88	–	19	12	88	159 ± 5	–8.52
Hd-12132	SCH-272	19	12	88	–	2	1	89	167 ± 4	–8.31
Hd-12277	SCH-273	2	1	89	–	16	1	89	166 ± 6	–8.50
Hd-12278	SCH-274	16	1	89	–	30	1	89	171 ± 4	–8.27
Hd-12283	SCH-275	30	1	89	–	13	2	89	167 ± 6	–8.34
Hd-12284	SCH-276	13	2	89	–	27	2	89	173 ± 4	–8.33
Hd-12525	SCH-277	27	2	89	–	13	3	89	176 ± 4	–8.75
Hd-12638	SCH-278	13	3	89	–	28	3	89	162 ± 4	–8.29
Hd-12648	SCH-279	28	3	89	–	10	4	89	161 ± 6	–8.28
Hd-12654	SCH-280	10	4	89	–	24	4	89	161 ± 6	–8.39
Hd-12661	SCH-281	24	4	89	–	8	5	89	161 ± 6	–8.37
Hd-12978	SCH-282	8	5	89	–	22	5	89	168 ± 4	–7.89
Hd-12979	SCH-283	22	5	89	–	5	6	89	162 ± 3	–7.98
Hd-13019	SCH-284	5	6	89	–	19	6	89	164 ± 3	–8.09
Hd-13027	SCH-285	19	6	89	–	3	7	89	156 ± 5	–8.00
Hd-12844	SCH-286	3	7	89	–	17	7	89	154 ± 4	–8.18
Hd-12845	SCH-287	17	7	89	–	31	7	89	150 ± 5	–8.03
Hd-12910	SCH-288	31	7	89	–	14	8	89	160 ± 4	–8.01
Hd-12911	SCH-289	14	8	89	–	28	8	89	157 ± 5	–7.90
Hd-12913	SCH-290	28	8	89	–	11	9	89	153 ± 5	–7.80
Hd-12914	SCH-291	12	9	89	–	25	9	89	161 ± 5	–7.99
Hd-12929	SCH-292	25	9	89	–	9	10	89	159 ± 4	–8.35
Hd-12930	SCH-293	9	10	89	–	23	10	89	159 ± 4	–8.23
Hd-13040	SCH-294	23	10	89	–	6	11	89	157 ± 3	–8.46
Hd-12993	SCH-295	6	11	89	–	20	11	89	153 ± 3	–8.39
Hd-12994	SCH-296	20	11	89	–	4	12	89	150 ± 3	–8.34
Hd-13076	SCH-297	4	12	89	–	18	12	89	148 ± 3	–8.36
Hd-13077	SCH-298	18	12	89	–	2	1	90	154 ± 3	–8.18
Hd-13085	SCH-299	2	1	90	–	15	1	90	158 ± 3	–8.93
Hd-13182	SCH-300	15	1	90	–	29	1	90	158 ± 5	–8.39
Hd-13183	SCH-301	29	1	90	–	12	2	90	148 ± 4	–8.44
Hd-13213	SCH-302	12	2	90	–	26	2	90	160 ± 2	–8.35
Hd-13214	SCH-303	26	2	90	–	12	3	90	153 ± 2	–8.08

$\Delta^{14}\text{CO}_2$ records from sites in Central Europe

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 $\Delta^{14}\text{C}$ Values Measured in Atmospheric CO_2 (continued)

Analysis no.	Sample no.	Sampling period ^a						$\Delta^{14}\text{C}$ (‰) ^b	$\delta^{13}\text{C}$ (‰) ^c	
		d	mo	yr	–	d	mo			yr
Hd-13194	SCH-304	12	3	90	–	26	3	90	146 ± 4	–8.09
Hd-13215	SCH-305	26	3	90	–	9	4	90	140 ± 3	–8.79
Hd-13256	SCH-306	9	4	90	–	23	4	90	150 ± 4	–8.20
Hd-13257	SCH-307	23	4	90	–	7	5	90	148 ± 4	–8.10
Hd-13345	SCH-308	7	5	90	–	21	5	90	143 ± 4	–8.09
Hd-13264	SCH-309	21	5	90	–	5	6	90	149 ± 4	–8.49
Hd-13265	SCH-310	5	6	90	–	25	6	90	153 ± 3	–8.15 ^d
Hd-13392	SCH-311	25	6	90	–	16	7	90	147 ± 3	–8.5 ^d
Hd-13418	SCH-312	16	7	90	–	30	7	90	144 ± 4	–7.89
Hd-13444	SCH-313	30	7	90	–	6	8	90	144 ± 5	–7.97
Hd-13407	SCH-314	13	8	90	–	28	8	90	157 ± 4	–7.80
Hd-13408	SCH-315	28	8	90	–	10	9	90	148 ± 3	–7.96
Hd-13445	SCH-316	10	9	90	–	24	9	90	139 ± 6	–7.81
Hd-13612	SCH-317	24	9	90	–	8	10	90	148 ± 5	–7.84
Hd-13622	SCH-318	8	10	90	–	22	10	90	140 ± 6	–7.87
Hd-13634	SCH-319	22	10	90	–	5	11	90	145 ± 5	–8.21
Hd-13635	SCH-320	5	11	90	–	19	11	90	146 ± 4	–8.20
Hd-13647	SCH-321	19	11	90	–	3	12	90	134 ± 5	–8.49
Hd-13582	SCH-322	3	12	90	–	17	12	90	137 ± 5	–8.62
Hd-13709	SCH-323	17	12	90	–	31	12	90	137 ± 5	–8.58
Hd-13680	SCH-324	31	12	90	–	14	1	91	142 ± 5	–8.08
Hd-13685	SCH-325	14	1	91	–	28	1	91	138 ± 3	–8.48
Hd-13731	SCH-326	28	1	91	–	11	2	91	137 ± 3	–8.57
Hd-13808	SCH-327	11	2	91	–	25	2	91	133 ± 4	–8.56
Hd-13809	SCH-328	25	2	91	–	11	3	91	129 ± 4	–8.36
Hd-13845	SCH-329	11	3	91	–	25	3	91	137 ± 5	–8.49
Hd-13846	SCH-330	25	3	91	–	8	4	91	132 ± 5	–8.73
Hd-13872	SCH-331	8	4	91	–	22	4	91	135 ± 6	–8.42
Hd-13987	SCH-332	22	4	91	–	6	5	91	131 ± 4	–8.32
Hd-13988	SCH-333	6	5	91	–	21	5	91	129 ± 3	–8.25
Hd-13999	SCH-334	21	5	91	–	3	6	91	140 ± 5	–8.01
Hd-14005	SCH-335	3	6	91	–	17	6	91	130 ± 3	–8.00
Hd-14012	SCH-336	17	6	91	–	1	7	91	141 ± 3	–7.75
Hd-14070	SCH-337	1	7	91	–	17	7	91	145 ± 5	–7.81
Hd-14115	SCH-338	17	7	91	–	29	7	91	143 ± 4	–7.88
Hd-14102	SCH-339	29	7	91	–	12	8	91	134 ± 3	–7.76
Hd-14183	SCH-340	12	8	91	–	26	8	91	142 ± 4	–7.76
Hd-14217	SCH-341	26	8	91	–	9	9	91	141 ± 6	–7.72
Hd-14260	SCH-342	9	9	91	–	23	9	91	127 ± 4	–8.06
Hd-14227	SCH-343	23	9	91	–	7	10	91	137 ± 3	–8.17
Hd-14202	SCH-344	7	10	91	–	21	10	91	124 ± 6	–8.15
Hd-14239	SCH-345	21	10	91	–	4	11	91	135 ± 6	–8.00
Hd-14378	SCH-346	4	11	91	–	18	11	91	144 ± 4	–8.44
Hd-14381	SCH-347	18	11	91	–	2	12	91	132 ± 5	–8.40
Hd-14388	SCH-348	2	12	91	–	16	12	91	141 ± 4	–8.33
Hd-14441	SCH-349	16	12	91	–	30	12	91	133 ± 3	–8.46
Hd-14504	SCH-350	30	12	91	–	13	1	92	133 ± 4	–8.17
Hd-14505	SCH-351	13	1	92	–	27	1	92	130 ± 4	–8.45
Hd-14467	SCH-352	27	1	92	–	10	2	92	125 ± 5	–8.54
Hd-14728	SCH-353	10	2	92	–	24	2	92	123 ± 4	–8.45
Hd-14729	SCH-354	24	2	92	–	9	3	92	124 ± 4	–8.42

$\Delta^{14}\text{CO}_2$ records from sites in Central Europe

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$\Delta^{14}\text{C}$ Values Measured in Atmospheric CO_2 (continued)

Analysis no.	Sample no.	Sampling period ^a							$\Delta^{14}\text{C}$ (‰) ^b	$\delta^{13}\text{C}$ (‰) ^c
		d	mo	yr	–	d	mo	yr		
Hd-14578	SCH-355	9	3	92	–	23	3	92	126 ± 4	–8.40
Hd-14607	SCH-356	23	3	92	–	6	4	92	129 ± 4	–8.73
Hd-14858	SCH-357	6	4	92	–	21	4	92	131 ± 4	–8.48
Hd-14859	SCH-358	21	4	92	–	4	5	92	124 ± 6	–8.48
Hd-14869	SCH-359	4	5	92	–	18	5	92	129 ± 5	–7.98
Hd-14870	SCH-360	18	5	92	–	1	6	92	134 ± 5	–7.79
Hd-14875	SCH-361	1	6	92	–	15	6	92	136 ± 5	–7.75
Hd-14876	SCH-362	15	6	92	–	29	6	92	133 ± 4	–7.77
Hd-15100	SCH-363	29	6	92	–	13	7	92	131 ± 5	–7.83
Hd-15056	SCH-364	13	7	92	–	27	7	92	141 ± 4	–7.81
Hd-15150	SCH-365	27	7	92	–	10	8	92	134 ± 5	–7.74
Hd-15202	SCH-366	10	8	92	–	24	8	92	141 ± 3	–7.56
Hd-15153	SCH-367	24	8	92	–	7	9	92	142 ± 3	–7.59
Hd-15170	SCH-369	21	9	92	–	5	10	92	133 ± 5	–7.98
Hd-15204	SCH-370	5	10	92	–	19	10	92	123 ± 4	–8.29
Hd-15232	SCH-371	19	10	92	–	2	11	92	131 ± 3	–7.97
Hd-15155	SCH-372	2	11	92	–	16	11	92	135 ± 3	–8.38
Hd-15176	SCH-373	16	11	92	–	30	11	92	132 ± 5	–8.32
Hd-15211	SCH-374	30	11	92	–	14	12	92	133 ± 3	–8.65
Hd-15212	SCH-375	14	12	92	–	28	12	92	121 ± 4	–8.79

^aInclusive dates are given for the sampling period: d = day; mo = month; and yr = year.

^bAll $\Delta^{14}\text{C}$ data are referred to NBS oxalic acid corrected for decay (Stuiver and Polach 1977). The data are corrected for isotopic fractionation on the basis of $\delta^{13}\text{C}$ analysis of the sample CO_2 .

^cThe $\delta^{13}\text{C}$ values are given relative to the V-PBD standard (Hut 1987).

^d $\delta^{13}\text{C}$ fractionated during sample collection.

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I. Levin, B. Kromer, H. Schoch-Fischer, M. Bruns, M. Münnich, D. Berdau,
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VERMUNT

Trends

The long-term $\Delta^{14}\text{CO}_2$ record from Vermunt exhibits the same $\Delta^{14}\text{CO}_2$ decline seen at other sampling locations around the world. According to Levin et al. (1985), the Vermunt record is representative of the higher altitude $^{14}\text{CO}_2$ level over central Europe. Levin et al. (1985) reported marked seasonal variations in the $^{14}\text{CO}_2$ levels at Vermunt in the early 1960s, up to ca $\Delta^{14}\text{CO}_2 = 200\text{‰}$, resulting mainly from springtime injections of bomb $^{14}\text{CO}_2$ from the stratosphere. Levin et al. (1985) reported that the peak to peak variations in $\Delta^{14}\text{CO}_2$ since 1976 were $\sim 20\text{‰}$, due largely to seasonal variations of the contribution of fossil fuel CO_2 at Vermunt.

$\Delta^{14}\text{C}$ values measured in atmospheric CO_2 at Vermunt.

CITE AS: Levin, I., B. Kromer, H. Schoch-Fischer, M. Bruns, M. Münnich, D. Berdau, J.C. Vogel, and K.O. Münnich. 1994. $\Delta^{14}\text{CO}_2$ records from sites in Central Europe. pp. 203–222. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

$\Delta^{14}\text{CO}_2$ records from sites in Central Europe

I. Levin, B. Kromer, H. Schoch-Fischer, M. Bruns, M. Münnich, D. Berdau,
J.C. Vogel, and K.O. Münnich (continued)

VERMUNT

Vermunt

Austria

Remote electric power station
situated at the upper water
reservoir of the Ill-Werke
47° N, 10° E

$\Delta^{14}\text{C}$ Values Measured in Atmospheric CO_2

Analysis no.	Sample no.	Sampling period ^a						$\Delta^{14}\text{C}$ (‰) ^b	$\delta^{13}\text{C}$ (‰) ^c	
		d	mo	yr	–	d	mo			yr
Hd-611	Ver-2	10	2	59	–	13	2	59	173 ± 7	–26.35
Hd-625	Ver-3	20	2	59	–	23	2	59	188 ± 7	–22.90
Hd-633	Ver-4	4	3	59	–	7	3	59	192 ± 7	–24.10
Hd-637	Ver-5	20	3	59	–	23	3	59	200 ± 7	–24.90
Hd-643	Ver-6	1	4	59	–	4	4	59	220 ± 6	–25.30
Hd-644	Ver-7	10	4	59	–	13	4	59	224 ± 7	–23.30
Hd-667	Ver-8	20	4	59	–	23	4	59	243 ± 7	–23.40
Hd-688	Ver-11	15	5	59	–	18	5	59	232 ± 9	–23.80
Hd-697	Ver-14	15	6	59	–	18	6	59	276 ± 7	–20.40
Hd-836	Ver-16	5	7	59	–	8	7	59	248 ± 7	–22.70
Hd-721	Ver-20	15	8	59	–	18	8	59	270 ± 10	–21.30
Hd-747	Ver-23	15	9	59	–	18	9	59	250 ± 6	–19.80
Hd-801	Ver-25	5	10	59	–	8	10	59	237 ± 9	–22.70
Hd-757	Ver-26	15	10	59	–	18	10	59	233 ± 9	–21.49
Hd-779	Ver-29	15	11	59	–	18	11	59	227 ± 4	–22.70
Hd-824	Ver-31	15	12	59	–	18	12	59	216 ± 7	–22.70
Hd-832	Ver-34	16	1	60	–	19	1	60	198 ± 7	–22.70
Hd-953	Ver-48	25	2	60	–	28	2	60	204 ± 5	–22.70
Hd-954	Ver-49	5	3	60	–	8	3	60	207 ± 7	–22.70
Hd-847	Ver-46	15	3	60	–	18	3	60	201 ± 8	–22.70
Hd-853	Ver-39	20	4	60	–	23	4	60	202 ± 7	–22.70
Hd-872	Ver-41	15	5	60	–	18	5	60	219 ± 6	–22.70
Hd-900	Ver-44	15	6	60	–	18	6	60	234 ± 5	–22.70
Hd-913	Ver-51	15	7	60	–	18	7	60	231 ± 6	–22.70
Hd-927	Ver-54	15	8	60	–	18	8	60	221 ± 7	–22.70
Hd-931	Ver-57	15	9	60	–	18	9	60	215 ± 8	–22.70
Hd-957	Ver-60	15	10	60	–	18	10	60	209 ± 7	–22.70
Hd-959	Ver-63	15	11	60	–	18	11	60	205 ± 7	–22.70
Hd-1061	Ver-66	15	12	60	–	18	12	60	209 ± 7	–22.70
Hd-998	Ver-68	15	1	61	–	18	1	61	202 ± 7	–22.70
Hd-1004	Ver-71	15	2	61	–	18	2	61	205 ± 9	–22.70
Hd-1014	Ver-74	15	3	61	–	18	3	61	220 ± 8	–22.70
Hd-1060	Ver-77	15	4	61	–	18	4	61	212 ± 7	–22.70
Hd-1036	Ver-80	15	5	61	–	18	5	61	215 ± 8	–22.70
Hd-1069	Ver-83	15	6	61	–	18	6	61	247 ± 8	–22.70
Hd-1079	Ver-86	15	7	61	–	18	7	61	227 ± 7	–22.70
Hd-1087	Ver-89	15	8	61	–	18	8	61	240 ± 6	–22.70
Hd-1108	Ver-92	20	9	61	–	23	9	61	205 ± 7	–22.70
Hd-1178	Ver-95	15	10	61	–	18	10	61	217 ± 6	–21.70
Hd-1180	Ver-101	15	12	61	–	18	12	61	238 ± 6	–24.70

$\Delta^{14}\text{CO}_2$ records from sites in Central EuropeI. Levin, B. Kromer, H. Schoch-Fischer, M. Bruns, M. Münnich, D. Berdau,
J.C. Vogel, and K.O. Münnich (continued)

VERMUNT

 $\Delta^{14}\text{C}$ Values Measured in Atmospheric CO_2 (continued)

Analysis no.	Sample no.	Sampling period ^a						$\Delta^{14}\text{C}$ (‰) ^b	$\delta^{13}\text{C}$ (‰) ^c	
		d	mo	yr	–	d	mo			yr
Hd-1222	Ver-104	16	1	62	–	19	1	62	262 ± 7	–23.60
Hd-1224	Ver-108	25	2	62	–	28	2	62	286 ± 5	–24.80
Hd-1242	Ver-111	25	3	62	–	28	3	62	304 ± 6	–24.00
Hd-1270	Ver-116	17	5	62	–	20	5	62	366 ± 6	–24.90
Hd-1307	Ver-125	25	7	62	–	28	7	62	393 ± 6	–21.40
Hd-1308	Ver-127	15	8	62	–	18	8	62	416 ± 6	–21.60
Hd-1344	Ver-128	15	9	62	–	18	9	62	393 ± 8	–24.80
Hd-1363	Ver-131	15	10	62	–	18	10	62	382 ± 6	–24.25
Hd-1387	Ver-134	15	11	62	–	18	11	62	408 ± 6	–25.10
Hd-1404	Ver-137	15	1	63	–	18	1	63	411 ± 6	–23.09
Hd-1416	Ver-142	15	2	63	–	18	2	63	473 ± 5	–24.00
Hd-1551	Ver-144	5	3	63	–	8	3	63	463 ± 7	–24.00
Hd-1430	Ver-145	16	3	63	–	19	3	63	509 ± 4	–23.80
Hd-1574	Ver-147	5	4	63	–	8	4	63	535 ± 6	–23.10
Hd-1442	Ver-148	15	4	63	–	18	4	63	599 ± 6	–23.40
Hd-1567	Ver-150	5	5	63	–	8	5	63	649 ± 5	–23.80
Hd-1470	Ver-151	15	5	63	–	18	5	63	645 ± 5	–21.90
Hd-1560	Ver-153	5	6	63	–	8	6	63	774 ± 5	–23.30
Hd-1480	Ver-154	15	6	63	–	18	6	63	821 ± 6	–23.30
Hd-1555	Ver-156	5	7	63	–	8	7	63	867 ± 7	–22.70
Hd-1495	Ver-157	15	7	63	–	18	7	63	893 ± 6	–20.60
Hd-1561	Ver-159	5	8	63	–	8	8	63	946 ± 6	–20.90
Hd-1506	Ver-160	15	8	63	–	18	8	63	989 ± 6	–21.95
Hd-1564	Ver-162	5	9	63	–	8	9	63	944 ± 6	–20.00
Hd-1518	Ver-163	15	9	63	–	18	9	63	844 ± 5	–20.60
Hd-1540	Ver-166	15	10	63	–	18	10	63	849 ± 5	–22.10
Hd-1554	Ver-169	15	11	63	–	18	11	63	812 ± 6	–22.80
Hd-1595	Ver-172	15	12	63	–	18	12	63	773 ± 6	–23.00
Hd-1611	Ver-175	15	1	64	–	18	1	64	800 ± 6	–23.50
Hd-1617	Ver-178	15	2	64	–	18	2	64	780 ± 6	–22.70
Hd-1622	Ver-181	15	3	64	–	18	3	64	777 ± 6	–24.27
Hd-1624	Ver-184	15	4	64	–	18	4	64	838 ± 6	–23.88
Hd-1640	Ver-187	15	5	64	–	18	5	64	895 ± 6	–20.30
Hd-1657	Ver-190	15	6	64	–	18	6	64	917 ± 6	–19.50
Hd-1675	Ver-193	15	7	64	–	18	7	64	887 ± 7	–20.70
Hd-1677	Ver-196	15	8	64	–	18	8	64	900 ± 6	–19.10
Hd-1684	Ver-202	15	9	64	–	18	9	64	854 ± 6	–19.50
Hd-1705	Ver-205	15	10	64	–	18	10	64	835 ± 6	–17.80
Hd-1718	Ver-198	15	11	64	–	18	11	64	778 ± 7	–18.50
Hd-1739	Ver-208	15	12	64	–	18	12	64	763 ± 6	–23.40
Hd-1741	Ver-211	15	1	65	–	18	1	65	766 ± 7	–20.20
Hd-1772	Ver-214	17	2	65	–	20	2	65	742 ± 6	–20.70
Hd-1776	Ver-217	15	3	65	–	18	3	65	748 ± 6	–20.70
Hd-1787	Ver-220	15	4	65	–	18	4	65	766 ± 6	–24.50
Hd-1796	Ver-223	15	5	65	–	18	5	65	746 ± 6	–24.00
Hd-1810	Ver-226	15	6	65	–	18	6	65	810 ± 6	–26.90
Hd-1826	Ver-229	25	7	65	–	28	7	65	787 ± 6	–22.50
Hd-1823	Ver-231	15	8	65	–	18	8	65	775 ± 6	–22.40
Hd-1837	Ver-234	25	9	65	–	28	9	65	763 ± 7	–22.70
Hd-1838	Ver-236	15	10	65	–	28	10	65	726 ± 7	–25.10
Hd-1850	Ver-239	16	11	65	–	19	11	65	729 ± 6	–23.10

$\Delta^{14}\text{CO}_2$ records from sites in Central Europe

I. Levin, B. Kromer, H. Schoch-Fischer, M. Bruns, M. Münnich, D. Berdau,
J.C. Vogel, and K.O. Münnich (continued)

VERMUNT

 $\Delta^{14}\text{C}$ Values Measured in Atmospheric CO_2 (continued)

Analysis no.	Sample no.	Sampling period ^a						$\Delta^{14}\text{C}$ (‰) ^b	$\delta^{13}\text{C}$ (‰) ^c	
		d	mo	yr	–	d	mo			yr
Hd-1867	Ver-243	15	12	65	–	18	12	65	696 ± 6	–7.60
Hd-1895	Ver-246	25	1	66	–	5	2	66	701 ± 6	–7.66
Hd-1887	Ver-248	15	2	66	–	25	2	66	691 ± 6	–7.65
Hd-1908	Ver-255	15	3	66	–	27	3	66	696 ± 6	–7.87
Hd-1916	Ver-258	15	4	66	–	25	4	66	708 ± 6	–7.98
Hd-1929	Ver-261	15	5	66	–	25	5	66	711 ± 6	–7.71
Hd-1951	Ver-264	15	6	66	–	25	6	66	725 ± 6	–7.38
Hd-1962	Ver-267	15	7	66	–	25	7	66	711 ± 7	–8.06
Hd-1973	Ver-270	15	8	66	–	25	8	66	711 ± 6	–7.02
Hd-2003	Ver-273	15	9	66	–	25	9	66	697 ± 5	–7.59
Hd-2019	Ver-276	15	10	66	–	25	10	66	661 ± 5	–7.70
Hd-2009	Ver-279	15	11	66	–	25	11	66	624 ± 5	–26.66
Hd-2012	Ver-281	5	12	66	–	15	12	66	660 ± 6	–8.36
Hd-2055	Ver-285	15	1	67	–	25	1	67	625 ± 6	–2.65
Hd-2058	Ver-288	15	2	67	–	25	2	67	633 ± 5	–8.77
Hd-2061	Ver-291	15	3	67	–	25	3	67	635 ± 5	–7.65
Hd-2113	Ver-293	15	4	67	–	25	4	67	633 ± 6	–7.64
Hd-2118	Ver-294	25	4	67	–	5	5	67	640 ± 7	–7.41
Hd-2121	Ver-297	15	7	67	–	25	7	67	631 ± 6	–6.97
Hd-2147	Ver-303	15	8	67	–	25	8	67	642 ± 6	–7.49
Hd-2196	Ver-306	15	9	67	–	25	9	67	600 ± 6	–9.02
Hd-2197	Ver-309	15	10	67	–	25	10	67	611 ± 6	–7.20
Hd-2198	Ver-312	15	11	67	–	25	11	67	607 ± 6	–7.70
Hd-2244	Ver-314	5	12	67	–	15	12	67	585 ± 6	–7.50
Hd-2259	Ver-315	25	1	68	–	5	2	68	596 ± 6	–11.52
Hd-2260	Ver-317	15	2	68	–	25	2	68	569 ± 6	–7.50
Hd-2271	Ver-320	15	3	68	–	25	3	68	570 ± 6	–7.79
Hd-2286	Ver-323	15	4	68	–	25	4	68	559 ± 6	–26.43
Hd-2261	Ver-321	25	4	68	–	5	5	68	578 ± 6	–26.79
Hd-2295	Ver-326	15	5	68	–	25	5	68	559 ± 6	–7.72
Hd-2296	Ver-329	15	6	68	–	25	6	68	573 ± 6	–7.84
Hd-2376	Ver-333	15	7	68	–	25	7	68	581 ± 7	–6.58
Hd-2377	Ver-332	15	8	68	–	25	8	68	555 ± 8	–7.50
Hd-2378	Ver-335	15	9	68	–	25	9	68	558 ± 8	–18.40
Hd-2379	Ver-338	15	10	68	–	25	10	68	552 ± 7	–15.67
Hd-2380	Ver-341	15	11	68	–	25	11	68	542 ± 6	–6.59
Hd-2433	Ver-344	15	12	68	–	26	12	68	549 ± 6	–8.06
Hd-2507	Ver-346	6	1	69	–	15	1	69	555 ± 7	–8.55
Hd-2512	Ver-350	25	2	69	–	26	2	69	532 ± 7	–9.05
Hd-2513	Ver-353	15	3	69	–	25	3	69	540 ± 7	–8.68
Hd-2514	Ver-356	15	4	69	–	25	4	69	544 ± 5	–7.50
Hd-2515	Ver-359	15	5	69	–	25	5	69	556 ± 6	–7.79
Hd-2827	Ver-361	5	6	69	–	15	6	69	556 ± 6	–8.10
Hd-2586	Ver-365	15	7	69	–	25	7	69	548 ± 6	–6.68
Hd-2585	Ver-368	15	8	69	–	25	8	69	530 ± 9	–7.72
Hd-2576	Ver-371	15	9	69	–	25	9	69	533 ± 8	–10.65
Hd-2814	Ver-373	5	10	69	–	15	10	69	552 ± 7	–7.52
Hd-2817	Ver-376	5	11	69	–	15	11	69	553 ± 8	–8.45
Hd-2818	Ver-379	11	12	69	–	16	12	69	544 ± 11	–8.48
Hd-2819	Ver-382	8	1	70	–	15	1	70	548 ± 7	–8.22

$\Delta^{14}\text{C}$ records from sites in Central Europe

I. Levin, B. Kromer, H. Schoch-Fischer, M. Bruns, M. Münnich, D. Berdau,
J.C. Vogel, and K.O. Münnich (continued)

VERMUNT

 $\Delta^{14}\text{C}$ Values Measured in Atmospheric CO_2 (continued)

Analysis no.	Sample no.	Sampling period ^a						$\Delta^{14}\text{C}$ (‰) ^b	$\delta^{13}\text{C}$ (‰) ^c	
		d	mo	yr	–	d	mo			yr
Hd-2828	Ver-384	24	1	70	–	5	2	70	540 ± 8	–8.73
Hd-2820	Ver-385	5	3	70	–	17	3	70	521 ± 6	–8.00
Hd-2821	Ver-388	5	4	70	–	15	4	70	527 ± 6	–8.43
Hd-2822	Ver-391	5	5	70	–	15	5	70	523 ± 5	–7.21
Hd-2823	Ver-394	5	6	70	–	15	6	70	540 ± 6	–7.29
Hd-2824	Ver-397	5	7	70	–	15	7	70	542 ± 6	–5.35
Hd-2829	Ver-400	5	8	70	–	15	8	70	531 ± 7	–7.03
Hd-2830	Ver-403	5	9	70	–	15	9	70	532 ± 5	–7.69
Hd-2831	Ver-406	5	10	70	–	15	10	70	526 ± 6	–7.75
Hd-2832	Ver-409	6	11	70	–	15	11	70	514 ± 7	–7.39
Hd-2833	Ver-412	5	12	70	–	16	12	70	515 ± 6	–7.98
Hd-2834	Ver-415	5	1	71	–	15	1	71	510 ± 7	–7.85
Hd-2835	Ver-418	5	2	71	–	15	2	71	493 ± 7	–5.02
Hd-2836	Ver-420	25	2	71	–	5	3	71	473 ± 8	–6.96
Hd-2837	Ver-423	5	4	71	–	15	4	71	506 ± 8	–7.52
Hd-2838	Ver-426	5	5	71	–	15	5	71	515 ± 8	–7.34
Hd-3013	Ver-429	5	6	71	–	15	6	71	516 ± 6	–7.67
Hd-3014	Ver-432	5	7	71	–	15	7	71	493 ± 7	–7.66
Hd-3015	Ver-435	5	8	71	–	15	8	71	521 ± 7	–7.50
Hd-3105	Ver-439	15	9	71	–	15	9	71	488 ± 7	–7.50
Hd-3049	Ver-441	6	10	71	–	16	10	71	503 ± 6	–8.17
Hd-3050	Ver-444	5	11	71	–	15	11	71	474 ± 4	–8.40
Hd-3051	Ver-447	5	12	71	–	15	12	71	498 ± 5	–9.19
Hd-3060	Ver-450	6	1	72	–	15	1	72	493 ± 9	–8.45
Hd-3061	Ver-453	5	2	72	–	15	2	72	472 ± 5	–8.42
Hd-3062	Ver-456	5	3	72	–	15	3	72	478 ± 6	–8.20
Hd-3063	Ver-459	5	4	72	–	15	4	72	471 ± 6	–7.85
Hd-3064	Ver-461	5	5	72	–	15	5	72	464 ± 6	–7.95
Hd-3067	Ver-464	25	5	72	–	5	6	72	483 ± 5	–7.90
Hd-3100	Ver-466	15	6	72	–	25	6	72	477 ± 6	–7.50
Hd-3101	Ver-469	15	7	72	–	25	7	72	474 ± 4	–7.83
Hd-3141	Ver-472	15	8	72	–	26	8	72	453 ± 6	–7.71
Hd-3143	Ver-477	15	10	72	–	26	10	72	461 ± 5	–7.99
Hd-3171	Ver-483	15	12	72	–	26	12	72	431 ± 0	–8.23
Hd-3178	Ver-486	15	1	73	–	25	1	73	426 ± 6	–8.53
Hd-3180	Ver-487	25	1	73	–	5	2	73	427 ± 6	–8.29
Hd-3184	Ver-488	5	2	73	–	15	2	73	442 ± 5	–8.17
Hd-3170	Ver-489	15	2	73	–	26	2	73	435 ± 5	–8.47
Hd-3185	Ver-490	26	2	73	–	6	3	73	435 ± 5	–7.41
Hd-3187	Ver-491	6	3	73	–	16	3	73	415 ± 6	–8.37
Hd-3190	Ver-492	16	3	73	–	26	3	73	428 ± 5	–7.68
Hd-3201	Ver-493	26	3	73	–	5	4	73	412 ± 5	–8.76
Hd-3202	Ver-494	5	4	73	–	15	4	73	432 ± 5	–8.26
Hd-3225	Ver-497	5	5	73	–	15	5	73	409 ± 5	–8.24
Hd-3261	Ver-504	16	7	73	–	25	7	73	417 ± 5	–7.64
Hd-3252	Ver-510	17	9	73	–	25	9	73	389 ± 5	–7.97
Hd-3264	Ver-514	25	9	73	–	7	10	73	438 ± 5	–8.05
Hd-3292	Ver-512	25	10	73	–	25	11	73	438 ± 5	–7.80
Hd-3297	Ver-517	25	11	73	–	17	12	73	402 ± 6	–8.32
Hd-3374	Ver-536	5	7	74	–	25	7	74	413 ± 4	–7.92
Hd-3418	Ver-541	25	8	74	–	16	9	74	392 ± 6	–8.13

$\Delta^{14}\text{CO}_2$ records from sites in Central Europe

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 $\Delta^{14}\text{C}$ Values Measured in Atmospheric CO_2 (continued)

Analysis no.	Sample no.	Sampling period ^a						$\Delta^{14}\text{C}$ (‰) ^b	$\delta^{13}\text{C}$ (‰) ^c	
		d	mo	yr	–	d	mo			yr
Hd-3452	Ver-545	3	10	74	–	26	10	74	401 ± 5	–8.38
Hd-3471	Ver-548	5	11	74	–	25	11	74	389 ± 6	–8.13
Hd-3536	Ver-550	25	11	74	–	25	12	74	366 ± 6	–11.05
Hd-3557	Ver-553	25	12	74	–	15	1	75	367 ± 6	–8.40
Hd-3555	Ver-555	5	2	75	–	25	2	75	371 ± 4	–8.10
Hd-3570	Ver-559	25	2	75	–	25	3	75	370 ± 7	–8.74
Hd-3594	Ver-562	5	4	75	–	5	5	75	370 ± 7	–8.06
Hd-3598	Ver-566	5	5	75	–	25	5	75	370 ± 6	–8.30
Hd-3725	Ver-585	4	11	75	–	25	11	75	369 ± 6	–8.33
Hd-3749	Ver-581	25	11	75	–	15	12	75	374 ± 5	–9.57
Hd-3816	Ver-592	25	1	76	–	5	2	76	362 ± 8	–8.33
Hd-3815	Ver-588	5	3	76	–	15	3	76	356 ± 6	–9.30
Hd-3819	Ver-589	16	3	76	–	25	3	76	354 ± 8	–9.88
Hd-6349	Ver-596	15	4	76	–	25	4	76	340 ± 5	–9.72
Hd-3827	Ver-595	16	5	76	–	25	5	76	356 ± 9	–9.53
Hd-6316	Ver-600	25	5	76	–	6	6	76	341 ± 4	–10.17
Hd-3846	Ver-601	6	6	76	–	17	6	76	341 ± 9	–9.26
Hd-3847	Ver-604	5	7	76	–	16	7	76	365 ± 7	–9.44
Hd-3963	Ver-605	16	7	76	–	27	7	76	372 ± 8	–8.84
Hd-6317	Ver-606	27	7	76	–	5	8	76	346 ± 5	–8.42
Hd-6354	Ver-608	15	8	76	–	25	8	76	343 ± 6	–7.68
Hd-3964	Ver-610	5	9	76	–	15	9	76	343 ± 8	–8.06
Hd-4055	Ver-616	15	9	76	–	25	9	76	365 ± 6	–7.94
Hd-4056	Ver-613	5	11	76	–	16	11	76	361 ± 5	–8.54
Hd-4124	Ver-617	16	11	76	–	25	11	76	337 ± 5	–8.60
Hd-4127	Ver-619	5	12	76	–	15	12	76	331 ± 5	–8.90
Hd-4128	Ver-620	15	12	76	–	25	12	76	331 ± 6	–8.52
Hd-4129	Ver-622	6	1	77	–	15	1	77	337 ± 6	–8.52
Hd-4182	Ver-623	15	1	77	–	26	1	77	339 ± 4	–8.86
Hd-4184	Ver-625	5	2	77	–	15	2	77	342 ± 5	–8.80
Hd-4187	Ver-626	15	2	77	–	25	2	77	338 ± 5	–8.68
Hd-4192	Ver-628	5	3	77	–	15	3	77	340 ± 5	–8.52
Hd-4267	Ver-629	18	3	77	–	26	3	77	347 ± 5	–8.58
Hd-4268	Ver-630	26	3	77	–	15	4	77	327 ± 5	–8.69
Hd-4269	Ver-632	15	4	77	–	7	5	77	327 ± 5	–8.58
Hd-4313	Ver-635	7	5	77	–	15	5	77	340 ± 5	–8.61
Hd-4406	Ver-638	25	5	77	–	5	6	77	347 ± 5	–8.03
Hd-4316	Ver-636	5	6	77	–	15	6	77	340 ± 4	–8.48
Hd-4411	Ver-640	15	6	77	–	26	6	77	337 ± 6	–8.15
Hd-4441	Ver-641	6	7	77	–	26	7	77	335 ± 7	–8.53
Hd-4447	Ver-643	26	7	77	–	15	8	77	340 ± 6	–8.34
Hd-4458	Ver-645	15	8	77	–	25	8	77	331 ± 6	–8.38
Hd-4449	Ver-646	25	8	77	–	5	9	77	335 ± 5	–7.88
Hd-4513	Ver-647	15	10	77	–	26	10	77	338 ± 5	–10.30
Hd-4517	Ver-649	26	10	77	–	5	11	77	325 ± 6	–9.42
Hd-4608	Ver-651	9	12	77	–	15	12	77	314 ± 7	–8.84
Hd-4610	Ver-652	15	12	77	–	26	12	77	315 ± 7	–8.15
Hd-4614	Ver-654	7	1	78	–	15	1	78	334 ± 6	–8.69
Hd-4622	Ver-655	15	1	78	–	25	1	78	309 ± 4	–9.33
Hd-4664	Ver-656	25	1	78	–	6	2	78	327 ± 5	–9.06

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J.C. Vogel, and K.O. Münnich (continued)

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 $\Delta^{14}\text{C}$ Values Measured in Atmospheric CO_2 (continued)

Analysis no.	Sample no.	Sampling period ^a						$\Delta^{14}\text{C}$ (‰) ^b	$\delta^{13}\text{C}$ (‰) ^c	
		d	mo	yr	–	d	mo			yr
Hd-4803	Ver-657	6	2	78	–	15	2	78	339 ± 6	–9.74
Hd-4831	Ver-658	15	2	78	–	26	2	78	308 ± 6	–9.57
Hd-4832	Ver-659	26	2	78	–	6	3	78	312 ± 5	–10.11
Hd-4834	Ver-660	6	3	78	–	16	3	78	314 ± 6	–11.72
Hd-4837	Ver-661	16	3	78	–	25	3	78	331 ± 5	–9.68
Hd-4838	Ver-662	25	3	78	–	5	4	78	326 ± 5	–9.93
Hd-4842	Ver-663	5	4	78	–	16	4	78	323 ± 5	–10.30
Hd-4843	Ver-664	16	4	78	–	26	4	78	320 ± 5	–10.00
Hd-4880	Ver-671	26	4	78	–	7	5	78	318 ± 4	–9.77
Hd-4881	Ver-672	7	5	78	–	16	5	78	310 ± 5	–9.40
Hd-4887	Ver-673	16	5	78	–	25	5	78	323 ± 8	–9.57
Hd-4886	Ver-674	25	5	78	–	6	6	78	334 ± 6	–9.57
Hd-4892	Ver-676	15	6	78	–	25	6	78	334 ± 8	–9.02
Hd-4949	Ver-671	25	6	78	–	5	7	78	322 ± 9	–9.40
Hd-4951	Ver-672	5	7	78	–	15	7	78	309 ± 7	–8.72
Hd-4952	Ver-673	15	7	78	–	25	7	78	324 ± 7	–8.35
Hd-4953	Ver-674	25	7	78	–	5	8	78	326 ± 8	–8.00
Hd-4993	Ver-675	5	8	78	–	16	8	78	342 ± 8	–8.57
Hd-4994	Ver-676	16	8	78	–	26	8	78	346 ± 6	–7.52
Hd-5080	Ver-665	26	8	78	–	5	9	78	321 ± 11	–8.51
Hd-5078	Ver-666	5	9	78	–	26	9	78	336 ± 8	–9.31
Hd-5083	Ver-668	26	9	78	–	5	10	78	315 ± 14	–9.96
Hd-5090	Ver-669	5	10	78	–	16	10	78	339 ± 7	–8.27
Hd-5091	Ver-670	16	10	78	–	25	10	78	320 ± 8	–9.35
Hd-5108	Ver-677	25	10	78	–	5	11	78	330 ± 8	–9.80
Hd-5112	Ver-678	5	11	78	–	25	11	78	322 ± 7	–9.65
Hd-5112	Ver-680	25	11	78	–	15	12	78	322 ± 7	–9.65
Hd-5206	Ver-683	26	12	78	–	6	1	79	298 ± 6	–3.08
Hd-5208	Ver-684	6	1	79	–	25	1	79	306 ± 6	–8.80
Hd-5209	Ver-686	25	1	79	–	5	2	79	308 ± 6	–8.45
Hd-5226	Ver-687	5	2	79	–	26	2	79	296 ± 5	–8.14
Hd-5239	Ver-689	26	2	79	–	5	3	79	295 ± 7	–8.74
Hd-5240	Ver-690	5	3	79	–	16	3	79	299 ± 6	–8.92
Hd-5242	Ver-691	16	3	79	–	25	3	79	353 ± 7	–8.73
Hd-5243	Ver-692	25	3	79	–	16	4	79	290 ± 5	–8.87
Hd-5406	Ver-695	25	4	79	–	5	5	79	284 ± 5	–8.89
Hd-5417	Ver-696	5	5	79	–	15	5	79	300 ± 6	–8.55
Hd-5418	Ver-697	15	5	79	–	27	5	79	291 ± 7	–8.25
Hd-5422	Ver-698	27	5	79	–	10	6	79	295 ± 6	–8.58
Hd-5423	Ver-699	10	6	79	–	25	6	79	286 ± 8	–8.93
Hd-5441	Ver-701	25	6	79	–	15	7	79	310 ± 5	–8.49
Hd-5450	Ver-703	15	7	79	–	6	8	79	277 ± 5	–7.83
Hd-5451	Ver-705	6	8	79	–	25	8	79	312 ± 5	–7.74
Hd-5520	Ver-707	25	8	79	–	5	9	79	293 ± 4	–7.68
Hd-5531	Ver-708	5	9	79	–	16	9	79	278 ± 7	–7.99
Hd-5548	Ver-709	16	9	79	–	25	9	79	282 ± 6	–7.76
Hd-5550	Ver-710	25	9	79	–	5	10	79	283 ± 9	–8.12
Hd-5714	Ver-711	5	10	79	–	15	10	79	294 ± 8	–8.36
Hd-5724	Ver-715	5	11	79	–	15	11	79	288 ± 5	–8.08
Hd-5772	Ver-716	15	11	79	–	6	12	79	280 ± 5	–8.40
Hd-5797	Ver-720	26	12	79	–	15	1	80	288 ± 5	–8.46

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$\Delta^{14}\text{C}$ Values Measured in Atmospheric CO_2 (continued)

Analysis no.	Sample no.	Sampling period ^a						$\Delta^{14}\text{C}$ (‰) ^b	$\delta^{13}\text{C}$ (‰) ^c	
		d	mo	yr	–	d	mo			yr
Hd-5812	Ver-723	25	1	80	–	15	2	80	268 ± 5	–8.52
Hd-6002	Ver-733	5	5	80	–	15	5	80	262 ± 4	–8.33
Hd-6043	Ver-735	25	5	80	–	15	6	80	259 ± 4	–8.90
Hd-6048	Ver-737	15	6	80	–	25	6	80	270 ± 4	–8.18
Hd-6049	Ver-739	5	7	80	–	25	7	80	280 ± 5	–8.15
Hd-6060	Ver-741	25	7	80	–	15	8	80	274 ± 5	–8.07
Hd-6061	Ver-743	15	8	80	–	6	9	80	254 ± 5	–8.28
Hd-6062	Ver-745	6	9	80	–	25	9	80	263 ± 5	–7.99
Hd-6046	Ver-747	25	9	80	–	5	10	80	251 ± 7	–8.64
Hd-6055	Ver-748	5	10	80	–	16	10	80	263 ± 7	–8.53
Hd-6303	Ver-749	16	10	80	–	5	11	80	263 ± 6	–9.38
Hd-6304	Ver-751	5	11	80	–	14	11	80	254 ± 5	–10.00
Hd-6337	Ver-752	14	11	80	–	26	11	80	260 ± 8	–8.47
Hd-6342	Ver-753	26	11	80	–	15	12	80	246 ± 4	–9.17
Hd-6355	Ver-755	15	12	80	–	25	12	80	240 ± 7	–8.95
Hd-6356	Ver-756	25	12	80	–	5	1	81	247 ± 6	–9.43
Hd-6362	Ver-757	5	1	81	–	15	1	81	251 ± 6	–8.99
Hd-6376	Ver-758	15	1	81	–	25	1	81	245 ± 4	–8.84
Hd-6377	Ver-759	25	1	81	–	5	2	81	245 ± 5	–9.04
Hd-6506	Ver-760	5	2	81	–	15	2	81	256 ± 5	–8.73
Hd-6507	Ver-761	15	2	81	–	25	2	81	260 ± 6	–9.25
Hd-6515	Ver-763	5	3	81	–	15	3	81	252 ± 4	–9.43
Hd-6522	Ver-764	15	3	81	–	25	3	81	250 ± 5	–8.82
Hd-6554	Ver-765	25	3	81	–	5	4	81	258 ± 5	–8.61
Hd-6556	Ver-766	5	4	81	–	15	4	81	255 ± 5	–8.93
Hd-6559	Ver-767	15	4	81	–	5	5	81	247 ± 5	–8.28
Hd-6564	Ver-769	5	5	81	–	16	5	81	256 ± 5	–8.12
Hd-6565	Ver-770	16	5	81	–	5	6	81	264 ± 6	–8.39
Hd-6566	Ver-772	27	5	80	–	16	6	81	259 ± 5	–7.99
Hd-6727	Ver-773	15	6	81	–	5	7	81	265 ± 7	–7.91
Hd-6729	Ver-775	5	7	81	–	25	7	81	271 ± 5	–8.29
Hd-6730	Ver-777	25	7	81	–	15	8	81	263 ± 4	–7.41
Hd-6805	Ver-774	24	8	81	–	15	9	81	261 ± 5	–8.08
Hd-6807	Ver-778	5	10	81	–	26	10	81	264 ± 4	–8.66
Hd-6892	Ver-779	7	11	81	–	25	11	81	244 ± 4	–8.66
Hd-6902	Ver-781	2	12	81	–	15	12	81	245 ± 5	–8.67
Hd-6907	Ver-783	15	12	81	–	5	1	82	252 ± 5	–8.83
Hd-6980	Ver-785	15	1	82	–	6	2	82	246 ± 2	–8.74
Hd-7012	Ver-788	6	2	82	–	15	2	82	245 ± 6	–8.57
Hd-7025	Ver-790	15	2	82	–	25	2	82	234 ± 7	–8.81
Hd-7321	Ver-791	25	2	82	–	6	3	82	221 ± 5	–8.93
Hd-7320	Ver-792	6	3	82	–	25	3	82	244 ± 5	–9.37
Hd-7322	Ver-794	25	3	82	–	5	4	82	243 ± 5	–8.87
Hd-7323	Ver-795	5	4	82	–	15	4	82	224 ± 6	–8.70
Hd-7308	Ver-796	15	4	82	–	25	4	82	237 ± 13	–8.00
Hd-7410	Ver-797	25	4	82	–	16	5	82	243 ± 4	–8.34
Hd-7415	Ver-799	16	5	82	–	25	5	82	240 ± 4	–8.26
Hd-7416	Ver-800	25	5	82	–	5	6	82	236 ± 5	–8.29
Hd-7417	Ver-801	5	6	82	–	15	6	82	225 ± 5	–7.96
Hd-7418	Ver-802	15	6	82	–	25	6	82	235 ± 5	–8.17
Hd-7546	Ver-803	25	6	82	–	7	7	82	242 ± 3	–7.69

$\Delta^{14}\text{CO}_2$ records from sites in Central Europe

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 $\Delta^{14}\text{C}$ Values Measured in Atmospheric CO_2 (continued)

Analysis no.	Sample no.	Sampling period ^a						$\Delta^{14}\text{C}$ (‰) ^b	$\delta^{13}\text{C}$ (‰) ^c	
		d	mo	yr	–	d	mo			yr
Hd-7559	Ver-805	17	7	82	–	5	8	82	240 ± 4	–7.91
Hd-7521	Ver-807	5	8	82	–	16	8	82	233 ± 4	–7.84
Hd-7560	Ver-808	16	8	82	–	5	9	82	246 ± 4	–7.83
Hd-7677	Ver-810	5	9	82	–	15	9	82	254 ± 10	–7.98
Hd-7669	Ver-811	15	9	82	–	25	9	82	235 ± 4	–8.22
Hd-7664	Ver-813	27	11	82	–	6	12	82	235 ± 3	–9.10
Hd-7678	Ver-814	6	12	82	–	15	12	82	232 ± 4	–8.39
Hd-7670	Ver-815	15	12	82	–	27	12	82	229 ± 3	–8.58
Hd-7821	Ver-816	27	12	82	–	15	1	83	230 ± 3	–8.52
Hd-7806	Ver-812	18	2	83	–	25	2	83	217 ± 4	–8.36
Hd-7822	Ver-822	25	2	83	–	15	3	83	239 ± 4	–8.25
Hd-7907	Ver-818	15	3	83	–	26	3	83	225 ± 4	–8.50
Hd-7908	Ver-819	26	3	83	–	5	4	83	225 ± 4	–8.48
Hd-7909	Ver-820	5	4	83	–	15	4	83	219 ± 3	–8.49
Hd-7910	Ver-824	15	4	83	–	25	4	83	227 ± 4	–8.85
Hd-7923	Ver-825	25	4	83	–	5	5	83	228 ± 4	–8.11
Hd-8066	Ver-826	5	5	83	–	14	5	83	230 ± 5	–8.29
Hd-8067	Ver-827	14	5	83	–	25	5	83	237 ± 6	–8.36
Hd-8068	Ver-828	25	5	83	–	6	6	83	213 ± 5	–8.15
Hd-8069	Ver-829	6	6	83	–	15	6	83	227 ± 3	–8.28

^aInclusive dates are given for the sampling period: d = day; mo = month; and yr = year.

^bAll $\Delta^{14}\text{C}$ data are referred to NBS oxalic acid corrected for decay (Stuiver and Polach 1977). The data were corrected for isotopic fractionation on the basis of ^{13}C analysis of the sample CO_2 .

^cThe $\delta^{13}\text{C}$ values are given relative to the V-PBD standard (Hut 1987).

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Introduction

ATMOSPHERIC METHANE

Methane (CH_4) is one of the most important radiatively active atmospheric trace gases, having the potential to affect climate significantly within the next century. A large body of evidence suggests that the concentration of CH_4 in the atmosphere has risen rapidly in recent times and that present levels are perhaps twice as high as those of even a few hundred years ago in the pre-industrial era (see figure on next page). Although our understanding of the global CH_4 budget is continually changing, the major methane sources are now known to include enteric fermentation in ruminant animals; anaerobic decay of organic matter in rice paddies, natural wetlands, and landfills; inadvertent release of trapped and adsorbed gas during coal mining, natural gas production and distribution, and oil exploration; and incomplete combustion during biomass burning. Knowledge of past and present atmospheric concentrations of CH_4 and other trace gases is needed in order to elucidate the complex relationship between climate and ambient levels of greenhouse gases. Past concentrations of atmospheric CH_4 have been determined through the analysis of air bubbles trapped in ice cores taken from Greenland and Antarctica (see figure on page 227). For the modern record, most measurements have been made in the troposphere by means of gas chromatography with flame ionization detection. Modern measurements have also been made through the use of an infrared absorption technique that assesses the average atmospheric abundance of CH_4 along the entire vertical column of atmosphere traversed by the incoming solar beam. From the beginning of the modern CH_4 record in 1978 until the early to middle 1980s, systematic investigations found that global atmospheric CH_4 concentrations were increasing by 0.8 to 2% per year. Recently, however, researchers have reported that the globally averaged CH_4 growth rate decreased substantially over the last decade.

The following pages provide historical and modern CH_4 records, including data on CH_4 concentrations from ice cores drilled at 8 different sites, global monthly averages derived from 2 different globally distributed monitoring networks, and monthly atmospheric CH_4 concentration records from 52 globally distributed sites, which include 38 land-based and 14 shipboard sites (see figure on page 227). Data from the shipboard sites and from 34 of the land-based sites were collected as part of the monitoring program of the National Oceanic and Atmospheric Administration Climate Monitoring and Diagnostics Laboratory (NOAA/CMDL).

Readers may note that two apparently different systems of units have been used in presenting the atmospheric CH_4 data in this chapter. For data from ice cores and for some modern atmospheric records, CH_4 levels are presented as *concentrations* in parts per billion (1×10^9) by volume (ppbv). For much of the modern data, values are given as *mixing ratios*, in parts per billion or parts per billion by volume. These differences in unit designations reflect the preferences of the researchers who have contributed their respective data sets for inclusion in *Trends '93*. In the context of atmospheric CH_4 , *concentration* in parts per billion by volume refers to the number of volumes of CH_4 per billion volumes of sample. In this same context, *mixing ratio* in parts per billion is derived by dividing the number of moles of CH_4 by the total number of moles in the sample, and then multiplying the quotient by 1 billion. Assuming that the volume of a gas is proportional to the number of moles

Atmospheric CH₄ concentrations during the past 160,000 years. These data are derived from (1) ice cores drilled at Vostok (Chappellaz et al.), Dye 3 (Stauffer et al.), Byrd Station (Byrd 1: Stauffer et al.; Byrd 2: Rasmussen and Khalil), Camp Century (Rasmussen and Khalil), Summit (Blunier et al.), Crête (Rasmussen and Khalil), Siple Station (Stauffer et al.), and Law Dome (Etheridge et al.); and (2) a modern record of global monthly averages derived from data from a globally distributed network of land-based and shipboard ocean sites (Dlugokencky et al.).

*Siple
Station,
Antarctica*

Location of the sites for which methane data are presented in this chapter.

INTRODUCTION

contained within the volume (this assumption should be valid for CH₄ in air under the conditions that atmospheric measurements are routinely carried out), we can expect that CH₄ concentrations should be equivalent to CH₄ mixing ratios. For all practical applications, therefore, users of *Trends '93* should consider the terms *concentration* and *mixing ratio* to be interchangeable.

Readers should credit the principal investigators and their organizations listed at the beginning of each set of data records when referring to the data in *Trends '93*. To facilitate correct referencing, each set of records provides a full citation by which contributions in the section should be referenced. In addition, readers are encouraged to contact CDIAC before applying the data in specific model exercises or research exercises. Some of the data are preliminary and may be subject to change. All of the data presented here are available in digitized form from CDIAC at no cost.

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Period of Record

157,000–2600 years BP

Methods

A record of atmospheric CH₄ concentrations for nearly 160,000 years was obtained by analyzing the air in bubbles trapped within a 2083-m-long ice core recovered by the Soviet Antarctic Expeditions at Vostok (East Antarctica). Ice samples (~40 g) from the center of the ice core were placed in a sealed glass vacuum apparatus. After the ambient air surrounding the core sample was removed, the ice was melted. Through a slow refreezing of the meltwater from the bottom, the dissolved air (derived from bubbles trapped within the ice) was pushed out at the water-ice interface (extraction efficiency ~99%). The extruded air was then passed through an extraction line and analyzed for CH₄ through the use of a gas chromatograph (GC) equipped with a flame ionization detector. The GC was calibrated with a standard containing CH₄ in a mixture of N₂, O₂, and CO₂. Three successive analyses were performed on each extracted air sample, and the overall accuracy (excluding the uncertainty due to the standard gas) was estimated at 40 parts per billion by volume (ppbv). The effect of the extraction and analysis procedures on the ice core gas samples was tested by analyzing samples containing standard gas and artificial bubble-free ice. The results showed that the analytical system had introduced a CH₄ contamination of 37 ± 25 ppbv; therefore, the measured concentrations in the samples were corrected for this effect.

For further details concerning the sampling and analytical procedures, see Chappellaz et al. (1990), Raynaud et al. (1988), and Lorius et al. (1985).

Vostok
Antarctica
78°28' S, 106°48' E

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Historical CH₄ record from the Vostok ice core

J. Chappellaz, J.M. Barnola, D. Raynaud, Y.S. Korotkevich, and C. Lorius (continued)

VOSTOK

Trends

The CH₄ record from the Vostok ice core covers the climatic period from the Holocene (as recent as 2569 years BP) and extends back through the last glaciation and the previous interglacial period to the end of the preceding (penultimate) glaciation. The most striking changes in the record occur at the two glacial-interglacial transitions, the first at 150,000–133,000 years BP and the other at 18,000–9000 years BP. During each transition, CH₄ concentrations rise from the very lowest (<350 ppbv) to the very highest values (>650 ppbv) measured from the ice core. In each case, the transitions between minimal and maximal CH₄ levels take place over several thousand years. For the most recent glacial-interglacial transition, however, the record shows an additional large oscillation in CH₄ concentrations at the end of the period, ca. 13,000–9000 years BP. During this oscillation, CH₄ values increase from ~450 to ~650 ppbv, then decrease by ~170 ppbv, and finally increase to ~650 ppbv again.

During the interval between the two major transitions, there are four strong peaks centered at 106,000, 82,000, 52,000, and 32,000 years BP. At these peaks, CH₄ concentrations reach values (550–600 ppbv) that are well above the intervening mean level of 400 to 450 ppbv and only slightly less than the values observed at the two interglacial CH₄ maxima.

The general features presented here for the Vostok ice core are in good agreement with those from other ice cores presented in *Trends '93* that have overlapping periods of record, namely the Byrd, Antarctica, and Dye 3, Greenland ice cores (see Stauffer et al. 1988). For example, the latter two ice core records both show CH₄ minima at ca. 20,000 years BP and high CH₄ levels for the Holocene period, 9000–0 years BP. In addition, despite the poorer time resolution, the record from Dye 3 corroborates the oscillation seen in the Vostok record for the period ca. 13,000–9000 years BP. Note that the present-day mean CH₄ level at the South Pole, ~1650 ppbv (Dlugokencky et al. 1994), is roughly 2.5 times higher than the maximum value in the Vostok ice core record.

Concentrations of atmospheric CH₄ from the Vostok ice core.

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Historical CH₄ record from the Vostok ice core

J. Chappellaz, J.M. Barnola, D. Raynaud, Y.S. Korotkevich, and C. Lorius (continued)

VOSTOK

Concentrations of CH₄ from the Vostok Ice Core^a

Ice core depth (m)	Mean age of gas (yr BP)	Mean CH ₄ concentration ($\pm 2 \sigma$) ^b (ppbv)	Ice core depth (m)	Mean age of gas (yr BP)	Mean CH ₄ concentration ($\pm 2 \sigma$) ^b (ppbv)	Ice core depth (m)	Mean age of gas (yr BP)	Mean CH ₄ concentration ($\pm 2 \sigma$) ^b (ppbv)
149.2	2,569	668 (46)	788.2	43,330	466 (20)	1542.1	107,164	437 (26)
173.1	3,525	636 (50)	812.0	47,123	504 (40)	1557.4	108,705	451 (33)
177.4	3,701	595 (44)	834.8	48,833	480 (43)	1582.8	111,253	468 (24)
228.7	5,864	588 (38)	860.6	50,755	514 (38)	1614.8	114,251	448 (41)
236.4	6,197	574 (52)	885.3	52,587	528 (20)	1627.7	115,400	443 (39)
266.0	7,496	616 (50)	911.4	54,574	442 (44)	1637.7	116,272	489 (36)
303.8	9,195	667 (39)	937.3	56,620	411 (35)	1669.5	118,938	515 (34)
321.2	10,018	621 (47)	962.4	58,665	414 (38)	1694.0	120,891	544 (38)
331.7	10,537	477 (24)	986.3	60,672	415 (28)	1716.0	122,577	557 (41)
342.1	11,070	501 (20)	1011.3	62,858	434 (26)	1736.8	124,117	562 (37)
356.0	11,827	662 (31)	1037.5	65,215	424 (34)	1770.0	126,486	584 (44)
365.6	12,350	610 (35)	1062.2	67,396	458 (33)	1789.2	127,842	586 (19)
366.2	12,385	642 (30)	1087.2	69,558	430 (37)	1834.7	131,120	620 (26)
381.7	13,289	445 (39)	1112.6	71,714	462 (38)	1852.3	132,411	650 (27)
426.3	16,242	395 (45)	1137.7	73,809	402 (35)	1857.4	132,788	637 (44)
443.5	17,546	363 (22)	1162.1	75,815	438 (39)	1869.4	133,679	694 (24)
458.3	18,752	349 (46)	1186.5	77,774	497 (43)	1875.5	134,136	688 (43)
471.0	19,816	379 (40)	1209.7	79,642	545 (39)	1883.3	134,722	536 (29)
491.3	21,532	348 (34)	1237.2	81,805	594 (22)	1903.6	136,302	526 (35)
506.4	22,810	406 (26)	1261.2	83,680	529 (33)	1932.1	138,798	453 (25)
534.3	25,172	384 (33)	1289.2	85,881	425 (38)	1954.6	141,040	431 (33)
544.7	26,059	398 (35)	1309.2	87,460	417 (27)	1969.9	142,740	399 (36)
554.2	26,870	415 (38)	1338.2	89,766	454 (32)	1980.2	143,980	352 (27)
585.8	29,540	423 (52)	1363.7	91,806	443 (45)	1987.4	144,897	357 (26)
602.2	30,902	432 (60)	1387.2	93,698	406 (43)	1994.7	145,869	374 (19)
617.6	32,152	543 (29)	1413.0	95,792	407 (29)	1998.0	146,339	377 (33)
625.6	32,796	522 (45)	1442.8	98,232	476 (37)	2005.9	147,485	348 (39)
642.1	34,115	470 (38)	1451.4	98,943	480 (37)	2009.4	148,024	339 (29)
664.6	35,892	484 (45)	1463.3	99,941	521 (22)	2016.4	149,130	318 (24)
694.6	38,222	424 (49)	1476.1	101,037	493 (34)	2030.9	151,600	319 (30)
724.8	40,525	441 (45)	1505.0	103,619	559 (33)	2042.5	153,613	345 (23)
748.3	42,309	419 (40)	1526.2	105,611	591 (30)	2063.7	157,290	355 (17)
765.3	43,598	402 (51)	1532.0	106,173	564 (38)			

^aThese atmospheric CH₄ concentrations derived from the Vostok ice core were presented graphically in Chappellaz et al. (1990) and are available at no cost in electronic form from CDIAC.

^bThe symbol σ signifies standard deviation.

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Historical CH₄ record from the Vostok ice core

J. Chappellaz, J.M. Barnola, D. Raynaud, Y.S. Korotkevich, and C. Lorius (continued)

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B. Stauffer, E. Lochbronner, H. Oeschger, J. Schwander, A. Neftel

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Period of Record

51,000–550 years BP (Byrd Station); 100,000–3400 years BP (Dye 3)

Methods

The 2184-m ice core from Byrd Station, Antarctica, was drilled in 1967–68 by the U.S. Cold Regions Research and Engineering Laboratory. The 2037-m core from the Dye 3 site in Greenland was drilled during the summer months of 1979–81 as part of an international collaboration (the Greenland Ice Sheet Program) between the United States, Denmark, and Switzerland.

Air was extracted from 10 ice samples taken from the Byrd Station ice core and from 14 ice samples taken from the ice core at Dye 3. Investigators used a melt extraction method, by which air is released as the ice is melted. The ages for the ice samples from Byrd Station were estimated by Hammer et al. (1985). Their dating relies on a continuous measurement of the acidity along the whole core. Schwander and Stauffer (1984) reported a mean difference of 240 years between the age of the ice core from Byrd Station and the age of the air trapped in its bubbles. For the Dye 3 ice core, the ages are those provided by Dansgaard et al. (1982). Schwander and Stauffer (1984) determined that the mean difference between the age of the ice from Dye 3 and the age of the air trapped in its bubbles was 90 years.

For the extraction, a 500-g to 800-g ice sample was placed in a glass cylinder. The cylinder was evacuated for 20 min to further clean the sample surface, and the ice sample was subsequently melted over 30 to 40 min. The air released was dried and collected continuously by condensation at a temperature of 15 to 20 K. The collected air was then analyzed for CH₄ concentration through the use of a Hewlett-Packard 5880A gas chromatograph equipped with a flame ionization detector. Methane determinations were made by using standard gas mixtures of 980 ± 30 parts per billion by volume (ppbv) CH₄ in N₂, O₂, and CO₂. Each air sample was measured five times. Sample and standard gases were measured alternately. Stauffer et al. (1988) reported that the precision of these analyses,

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Historical CH₄ record from ice cores at Byrd Station and Dye 3

B. Stauffer, E. Lochbronner, H. Oeschger, J. Schwander, and A. Neftel (continued)

including extraction, was within ± 25 ppbv. They also noted that the accuracy was further limited by the standard gases, which raised the uncertainty of the CH₄ concentrations by an additional 3%. For further details on the sampling methods, see Stauffer et al. (1988).

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BYRD STATION AND DYE 3

Trends

On the basis of analyses of the ice cores from Dye 3 and Byrd Station, Stauffer et al. (1988) reported a decline in the CH₄ concentration from ~500 parts per billion by volume (ppbv) ca. 60,000 years BP to ~350 ppbv ca. 20,000 years BP. Stauffer et al. (1988) also reported that, according to measurements on ice samples, the atmospheric CH₄ concentration was stable at a level of ~650 ppbv for several millenia before the obviously anthropogenically induced increase began about 200 years ago.

Concentrations of atmospheric CH₄ from the Byrd Station and Dye 3 ice cores.

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Historical CH₄ record from ice cores at Byrd Station and Dye 3

B. Stauffer, E. Lochbronner, H. Oeschger, J. Schwander, and A. Neftel (continued)

BYRD STATION AND DYE 3

Concentrations of CH₄ from the Byrd Station and Dye 3 Ice Cores^a

Ice core depth (m)	Age of enclosed air (year BP)	CH ₄ concentration in extracted air (ppbv) ^b
Byrd Station		
147.22	550	667 ± 25
153.82	600	647 ± 25
750.04	7,100	615 ± 25
999.63	10,600	638 ± 25
1200.68	14,300	460 ± 25
1395.97	22,400	341 ± 27
1501.30	27,900	360 ± 25
1601.13	33,500	385 ± 25
1795.76	46,600	457 ± 27
1853.36	51,100	505 ± 31
Dye 3		
1185.03	3,400	627 ± 25
1670.91	7,700	663 ± 30
1675.26	7,800	680 ± 27
1681.40	7,900	645 ± 37
1789.00	10,800	477 ± 25
1808.39	14,000	650 ± 32
1818.90	16,000	389 ± 32
1828.90	19,000	327 ± 30
1836.81	21,000	358 ± 41
1896.83	39,800	561 ± 31
1898.33	40,500	411 ± 32
1899.33	41,000	427 ± 33
1951.77	73,000	468 ± 25
1990.22	100,000	468 ± 25

^aThese atmospheric CH₄ concentrations derived from ice cores were published in Stauffer et al. (1988). The data are available at no cost in electronic form from CDIAC.

^bFor a 500-g sample, the CH₄ concentration rose 40 ± 10 ppbv because of CH₄ contamination (Stauffer et al. 1988). These results have been corrected accordingly. The precision of these analyses, including extraction, is within ± 25 ppbv; the accuracy is further limited by the standard gas, which gives an additional uncertainty of 3% in the CH₄ concentration.

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Atmospheric Methane
Historical CH₄ record from ice cores
at Crête, Camp Century, and Byrd Station

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Period of Record

3140–170 years BP

Methods

Polar ice core samples were obtained from the National Science Foundation ice core facility at the State University of New York at Buffalo. Ice samples from the cores were sealed in stainless steel, internally electropolished (SUMMA®) cylinders. The cylinders were flushed ten times with nitrogen-free helium and pressurized to 1000 torr. The sealed containers were placed in warm water baths to melt the ice core sample. Melting caused the air from the bubbles trapped in the core to mix with the helium present in the headspace of the cylinders. Samples of air were withdrawn from the headspace, and concentrations of CH₄, N₂, O₂, and CCl₃F (CFC-11) were measured.

The gas concentrations were measured by established gas-chromatographic techniques. Methane was measured on a Carle 211-MS gas chromatograph fitted with a flame ionization detector. A Hewlett Packard 3390 was used to integrate the chromatographic peaks. A direct analysis of 3–5 mL of air provided a detection limit of 5 parts per billion by volume (ppbv) and a precision of approximately 5%. Calibrations of the CH₄ concentrations were based on three National Institute of Standards and Technology standards at 992 ppbv. The standards were checked weekly, and no drifts or significant changes were observed. For further details concerning the ice cores and analytical methods, see Rasmussen and Khalil (1984).

Crête
Greenland
71°07' N, 37°19' W

Camp Century
Greenland
77°11' N, 61°09' W

Byrd Station
Antarctica
79°59' S, 120°01' W

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CRÊTE, CAMP CENTURY, AND BYRD STATION

Trends

After analyzing 80 ice core samples from the polar regions, Rasmussen and Khalil (1984) found that the concentration of methane 250 years ago and earlier was only 700 (± 30) parts per billion by volume and that a rapid and significant increase of atmospheric methane started about 150 years ago. In addition, Rasmussen and Khalil (1984) reported that the concentration of CH₄ in the atmosphere 250 years ago and earlier, when CH₄ was not increasing, was 10% ($\pm 4\%$) higher in the Arctic than in the Antarctic.

CITE AS: Rasmussen, R.A., and M.A.K. Khalil. 1994. Historical CH₄ record from ice cores at Crête, Camp Century, and Byrd Station. pp. 239–243. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Historical CH₄ record from ice cores at Crête, Camp Century, and Byrd Station

R.A. Rasmussen and M.A.K. Khalil (continued)

CRÊTE, CAMP CENTURY, AND BYRD STATION

Concentrations of atmospheric CH₄ from ice cores drilled at Crête and Camp Century (Greenland) and at Byrd Station (Antarctica).

CITE AS: Rasmussen, R.A., and M.A.K. Khalil. 1994. Historical CH₄ record from ice cores at Crête, Camp Century, and Byrd Station. pp. 239-243. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Historical CH₄ record from ice cores at Crête, Camp Century, and Byrd Station

R.A. Rasmussen and M.A.K. Khalil (continued)

CRÊTE, CAMP CENTURY, AND BYRD STATION

Concentrations of CH₄ from Polar Ice Cores^a

Ice core depth (m)	Age of ice (yr BP)	Age of air ^b (yr BP)	CH ₄ concentration (ppbv)	Ice core depth (m)	Age of ice (yr BP)	Age of air ^b (yr BP)	CH ₄ concentration (ppbv)
Crête, 1974 ^c				Byrd, 1968 ^c			
97.65–97.97	280	190	840	89.84	600	510	600
119.14–119.53	350	260	710	97.52–97.71	650	560	660
139.56–139.85	420	330	640	105.3	720	630	690
149.69–150.13	450	360	670	109.84	750	660	800
168.96–169.29	510	420	650	114.69–114.89	790	700	680
190.28–190.56	600	510	630	121.11–124.91	880	790	690
Camp Century, 1961 ^c				130.75	930	840	670
83.95	280	190	1070	135.29–135.49	960	870	630
89.81	290	200	890	159.31	1190	1100	690
97.96	320	230	790	166.37–166.57	1240	1150	690
101.00	335	245	730	170.84	1270	1180	650
118.57	380	290	850	175.63–175.83	1300	1210	690
123.02	390	300	830	186.39–186.59	1370	1280	620
129.72	400	310	770	186.24	1370	1280	650
144.74	350	360	680	189.2	1390	1300	630
Camp Century, 1962 ^c				195.44–195.65	1430	1340	650
75.99–76.29	260	170	1130	200.68	1470	1380	620
83.45–83.62	280	190	880	201.0–201.2	1470	1380	680
92.11–92.33	295	205	870	220.95–221.15	1630	1540	600
100.39–100.59	320	230	780	221.8	1640	1550	640
117.26–117.46	370	280	820	230.94–231.14	1720	1630	660
125.14–125.34	390	300	770	241.37–241.57	1810	1720	640
131.50–131.63	410	320	790	252.13–252.33	1910	1820	640
141.24–141.44	440	350	750	260.87	1970	1880	620
149.13–149.37	465	375	740	261.13–261.33	1970	1880	640
Camp Century, 1963–66 ^c				271.08–271.28	2050	1960	630
77.91–78.10	260	170	970	281.03–281.23	2140	2050	650
86.59–86.70	280	190	920	319.14	2470	2380	570
98.05–98.22	325	235	930	370.46	2990	2900	630
106.98–107.15	350	260	770	381.96	3090	3000	520
116.94–117.14	370	280	780	400.24	3230	3140	590
128.42–128.62	395	305	710	Byrd, 1971 ^c			
138.2	425	335	690	76.52	510	420	650
147.24–147.41	460	370	730	90.55	600	510	700
157.42–157.59	500	410	750	105.79	720	630	660
167.07–169.22	540	450	720	119.82	820	730	640
176.82–176.99	590	500	750	141.37	1020	930	700
187.20–187.38	640	550	720	159.54	1200	1110	700
197.9–198.05	690	600	730	173.84	1290	1200	700
217.7–217.92	760	670	760	190.85	1400	1310	800
226.85–227.04	790	700	890	204.57	1500	1410	670
248.2–248.4	870	780	920	223.7	1740	1650	680
287.27–287.44	1110	1020	680	265.21	2010	1920	820
297.48–297.68	1200	1110	770				

^aThese atmospheric methane concentrations derived from ice cores were published in Rasmussen and Khalil (1984) and are available at no cost in electronic form from CDIAC.

^bThe age of the air as noted in Khalil and Rasmussen (1988).

^cYear that the ice core was drilled.

CITE AS: Rasmussen, R.A., and M.A.K. Khalil. 1994. Historical CH₄ record from ice cores at Crête, Camp Century, and Byrd Station. pp. 239–243. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Historical CH₄ record from ice cores
at Crête, Camp Century, and Byrd Station

R.A. Rasmussen and M.A.K. Khalil (continued)

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Period of Record

970–1900

Methods

In the framework of the Eurocore project, in 1989 an ice core of 304 m was drilled electromechanically in a dry borehole at Summit in Central Greenland (72°35' N, 37°38' W; mean annual temperature: -32°C; mean accumulation rate: 209 kg/m²/yr). The core was dated with an accuracy of ± 2 years by combining seasonal variations of δD δ(²H) and δ¹⁸O with electrical conductivity measurements and chemical data. Acid layers of volcanic eruptions were used as time markers for cross-checking. The age difference between the ice and the mean age of the enclosed air is -210 years. Due to the diffusive mixing in the firn (granular packed snow), the air in the bubbles does not have a discrete age but an age distribution with a standard deviation of ~7 years (Schwander et al. 1993).

The measurements presented were carried out in two laboratories. At Grenoble (France), a melt extraction technique was used. At Bern (Switzerland), the gas was extracted through the use of a dry extraction method.

For the melt extraction method, an ice sample of ~40 g was placed in a glass vessel sealed with vacuum grease. The air surrounding the sample was evacuated; then the ice was melted. Afterwards, the meltwater was slowly refrozen from the bottom. The efficiency of the extraction method was close to 100%. After refreezing, the extracted gas was expanded

*Summit
Greenland
72°35' N, 37°38' W*

CITE AS: Blunier, T, J.A. Chappellaz, J. Schwander, J.M. Barnola, T. Despert, B. Stauffer, and D. Raynaud. 1994. Historical CH₄ record from the Eurocore ice core at Summit, Greenland. pp. 244–249. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Historical CH₄ record from the Eurocore ice core at Summit, Greenland

T. Blunier, J.A. Chappellaz, J. Schwander, J.M. Barnola, T. Desperets,
B. Stauffer, and D. Raynaud (continued)

in an extraction line and injected into a Varian 3300 gas chromatograph (GC) equipped with a flame ionization detector (FID). The extracted air was used for three injections. The measured CH₄ concentrations needed to be corrected because of contamination in the extraction chamber. The correction was determined by calibration with standard gas added to gas-free ice. The overall accuracy estimated from calibration analyses (95% confidence interval, excluding the uncertainty due to the standard gas) was ± 40 parts per billion by volume (ppbv) (Raynaud et al. 1988). The system was calibrated by using an air standard (Air Liquide) containing 1200 ± 100 ppbv CH₄.

The dry extractions were performed with a newly developed milling device (Fuchs et al. 1993). For the dry method, 10–15 g of ice was sealed in the extraction chamber, which was continuously flushed with helium. When the air in the chamber was entirely replaced by helium, the ice was milled with a rotary cutter. The helium carried the gases escaping from the opened bubbles to a cryofocusing device (Porapak Q column, cooled to below -170°C by liquid nitrogen), where they were stored until the injection into the GC (Hewlett Packard 5880 A, equipped with an FID) through thermal desorption. For calibration, a standard gas with 980 ± 30 ppbv (Messer Griessheim) of CH₄ was used. To estimate the analytical accuracy, a calibration series was performed by introducing standard gas into the mill in order to approximate a real extraction. From this series, the 95% confidence interval for an analysis was ± 28 ppbv (excluding the uncertainty due to the standard gas).

A comparison between the two laboratories was carried out by measurements at the same depth levels and by intercalibrating the standard gases. Measurements at the same depth levels demonstrated that the equipment at Bern and Grenoble led to the same results within the statistical variability. The intercalibration of the standard gases used by the two laboratories revealed an agreement better than ± 5 ppbv. Therefore, it was assumed that the absolute uncertainty of the standard gases used at Bern and at Grenoble corresponds to the lower uncertainty indicated by the two suppliers, that is, ± 30 ppbv. For further details, see Blunier et al. (1993).

CITE AS: Blunier, T, J.A. Chappellaz, J. Schwander, J.M. Barnola, T. Desperets, B. Stauffer, and D. Raynaud. 1994. Historical CH₄ record from the Eurocore ice core at Summit, Greenland. pp. 244–249. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Historical CH₄ record from the Eurocore ice core at Summit, Greenland

T. Blunier, J.A. Chappellaz, J. Schwander, J.M. Barnola, T. Despert, B. Stauffer, and D. Raynaud (continued)

SUMMIT

Trends

Investigations of the atmospheric CH₄ changes during the last 1000 years from the Summit ice core confirm that the mean pre-industrial level was ~700 ppbv and that a recent anthropogenic increase has occurred. In addition, pre-industrial concentration variability appeared to be in the range of 70 ppbv.

Concentrations of atmospheric CH₄ from the Summit ice core.

CITE AS: Blunier, T, J.A. Chappellaz, J. Schwander, J.M. Barnola, T. Despert, B. Stauffer, and D. Raynaud. 1994. Historical CH₄ record from the Eurocore ice core at Summit, Greenland. pp. 244-249. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Historical CH₄ record from the Eurocore ice core at Summit, Greenland

T. Blunier, J.A. Chappellaz, J. Schwander, J.M. Barnola, T. Despertis,
B. Stauffer, and D. Raynaud (continued)

SUMMIT

Concentrations of CH₄ from the Summit Ice Core^a

Ice core depth (m) ^b	Year of air encapsulation (A.D.)	Sample CH ₄ concentration (ppbv), analysis at Bern ^c		Sample CH ₄ concentration (ppbv), analysis at Grenoble ^d	
292.6	974	714	695		
283	1025	722	717		
272.3	1075	711	725		
263	1114	738	727		
252.4	1165	763	756		
251.9	1168			811	752
242.9	1210	743	729		
243	1210			710	774
233.7	1253			693	656
233.5	1254	694	703		
222.7	1304			703	733
219.2	1320			714	749
216.1	1335	692	678		
211.5	1357			700	688
188.4	1466	690	710		
188.2	1467			724	727
178.6	1508			740	728
178.2	1510	761	726		
168.8	1555	763	760		
168.4	1557			760	781
158.8	1603			690	722
158.4	1605	730	743		
148.8	1651	740	766		
148.6	1652			714	750
139	1690			770	774
138.7	1691	738	773		
129	1733			729	726
128.8	1734	753	763		
119.2	1774			755	765
118.9	1775	803	796		
110.5	1815			764	754
110.1	1817	808	798		
104.5	1842			812	818
99.3	1864	870	862		

Historical CH₄ record from the Eurocore ice core at Summit, Greenland

T. Blunier, J.A. Chappellaz, J. Schwander, J.M. Barnola, T. Despert, B. Stauffer, and D. Raynaud (continued)

SUMMIT

Concentrations of CH₄ from the Summit Ice Core (continued)^a

Ice core depth (m) ^b	Year of air encapsulation (A.D.)	Sample CH ₄ concentration (ppbv), analysis at Bern ^c			Sample CH ₄ concentration (ppbv), analysis at Grenoble ^d	
99.1	1865				859	896
89.6	1905				1030	968
89.2	1907	996	991	980		

^aThese atmospheric CH₄ concentrations derived from the Eurocore ice core at Summit, Greenland, were published in Blunier et al. (1993) and are available at no cost in electronic form from CDIAC.

^bDepth is given as meters below the surface level as of 1989.

^cSamples were analyzed at the Physics Institute, University of Bern, Bern, Switzerland. Each set of two or three values consists of results from neighboring samples. Each value represents results from a single gas chromatographic analysis.

^dSamples were analyzed at the CNRS Laboratoire de Glaciologie, St Martin d'Hères (Grenoble), France. Each set of two values consists of results from neighboring samples. Each value represents an average from three gas chromatographic analyses.

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Historical CH₄ record from the Eurocore ice core at Summit, Greenland

T. Blunier, J.A. Chappellaz, J. Schwander, J.M. Barnola, T. Despert, B. Stauffer, and D. Raynaud (continued)

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Period of Record

1771–1956

Methods

The 200-m ice core from Siple Station, Antarctica, was drilled during the austral summer of 1983–84 by the Polar Ice Coring Office (Nebraska, U.S.A.) and the Physics Institute at the University of Bern. Researchers dated the ice core to a depth of 144 m by counting seasonal variations of the electrical conductivity. Schwander and Stauffer (1984) reported a mean difference of 95 years between the age of the ice and the age of the air trapped in its bubbles. Measurements of CH₄ in air from bubbles within the ice core were carried out through the use of two air extraction techniques. In one technique, vacuum melt extraction, ice samples (400 g) were melted in an evacuated glass container, and the escaping gas was then pumped into a small glass bulb continuously during the melting process. In the second technique, dry extraction, ice samples (600 g) were ground with a milling cutter in an evacuated steel container in order to mechanically release the ice core air from the opened bubbles. The escaping air was then collected in a small steel cylinder by condensation at 14 K.

For both extraction methods, CH₄ measurements of the ice core air were made through the use of a Hewlett-Packard 5880A gas chromatograph fitted with a flame ionization detector. A total of 23 ice samples from the Siple core were measured, 11 by vacuum melt extraction and 12 by dry extraction. Two analyses were performed for each sample obtained by the melt extraction method, and three to four analyses were performed for each sample obtained by the dry extraction method. Two gas mixtures composed of N₂, O₂, Ar, CO₂, and CH₄ were used as calibration standards for the analyses. Helium was used as a carrier gas. For further details on the extraction methods, ice dating, and standard gases, see Stauffer et al. (1985).

Siple Station
Antarctica
75°55' S, 83°55' W

CITE AS: Stauffer, B., A. Neftel, G. Fischer, and H. Oeschger. 1994. Historical CH₄ record from the Siple ice core. pp. 251–254. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Historical CH₄ record from the Siple ice core

B. Stauffer, A. Neftel, G. Fischer, and H. Oeschger (continued)

SIPLE STATION

Trends

The Siple Station site in western Antarctica is well suited for recording recent changes in atmospheric composition because its high rate of snow accumulation results in an excellent ice-core time resolution (Stauffer et al. 1985). Measurements of the CH₄ concentrations in air extracted by two different methods from ice samples from Siple Station have allowed investigators to reconstruct the history of the increase of atmospheric CH₄ during the past 200 years. The CH₄ concentrations in the 12 ice samples as measured by dry extraction show increases from 780 ± 90 parts per billion by volume (ppbv) in 1771 to 1300 ± 70 ppbv in 1955. The CH₄ concentrations in the 11 ice samples measured by vacuum melt extraction show increases from 800 ± 60 ppbv in 1771 to 1340 ± 80 ppbv in 1956.

Concentrations of atmospheric CH₄ from the Siple ice core.

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Historical CH₄ record from the Siple ice core

B. Stauffer, A. Neftel, G. Fischer, and H. Oeschger (continued)

SIPLE STATION

Concentrations of CH₄ from the Siple Ice Core^a

Ice core depth (m)	Mean date of air enclosure (year A.D.)	CH ₄ concentration in extracted air (ppbv) ^b
Dry extraction		
78.6	1955	1300 ± 70
82.6	1950	1180 ± 70
88.0	1940	1110 ± 70
96.4	1925	1020 ± 60
100	1919	1000 ± 70
113	1893	870 ± 70
119	1882	900 ± 80
130	1861	830 ± 70
136	1849	890 ± 80
144	1834	860 ± 70
160	1804	730 ± 80
177	1771	780 ± 90
Vacuum melt extraction		
78.0	1956	1340 ± 80
80.0	1954	1260 ± 80
83.0	1949	1160 ± 80
96.0	1927	1100 ± 70
101	1917	990 ± 60
107	1907	990 ± 60
120	1880	950 ± 60
132	1857	900 ± 60
147	1827	830 ± 60
160	1804	840 ± 60
177	1771	800 ± 60

^aThese atmospheric CH₄ concentrations derived from the Siple ice core were published in Stauffer et al. (1985). The data are available at no cost in electronic form from CDIAC.

^bThe error limits are the estimated precisions of the measurements. The estimates include the uncertainty of the contamination correction as well as the standard error of the chromatographic analyses. A possible inaccuracy (~3%) of the standard gas is not included.

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Period of Record

1841–1978

Methods

The 234-m-long ice core designated "DE08" was drilled in 1987 on the east side of Law Dome, Antarctica, by the Australian Antarctic Division. Core samples were collected with essentially no contamination because of a large (200-mm) core diameter, minimal cracking and snow-surface melting, and a drilling technique that avoided the use of hydrocarbon fluids in the borehole. Air bubbles trapped at various times in the past in ice below the air-occlusion zone (~72 m in the DE08 core) were used to sample the concentrations of atmospheric CH₄. Segments of the core representing about 15% of a year's accumulation were trimmed of their outer surfaces, placed in a stainless steel vacuum apparatus, and milled into small chips to release the entrapped air. Air samples were then dried, collected in a liquid helium cold finger apparatus, and analyzed for CH₄ through the use of a gas chromatograph equipped with a flame-ionization detector. The modification of the air samples during the extraction and analysis procedures was minimal because of methodological improvements, particularly in the vacuum line assembly and in the procedure of mixing air in the cold finger, instituted since the analysis of the ice core designated "BHD" at Law Dome (see Etheridge et al. 1988).

The researchers dated the ice by counting the seasonal cycles (which reflect either temperature- or light-dependent processes) observed in the oxygen isotope ratio ($\delta^{18}\text{O}$), hydrogen peroxide (H₂O₂) concentration, and solid electroconductivity in the ice. The mean age of the ice core air was calculated to be 35 ± 3 (2 σ) years younger than the surrounding ice, with an age resolution of 14 years (i.e., 80% of the air in a given sample has an age

Law Dome
Antarctica
66°43' S, 113°12' E
1250 m above MSL

CITE AS: Etheridge, D.M., G.I. Pearman, and P.J. Fraser. 1994. Historical CH₄ record from the "DE08" ice core at Law Dome. pp. 256–260. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Historical CH₄ record from the "DE08" ice core at Law Dome

D.M. Etheridge, G.I. Pearman, and P.J. Fraser (continued)

within a 14-year interval). This was based on the mean depth at which firn (i.e., granular packed snow) becomes sealed to air mixing and on the rate of diffuse mixing of CH₄.

Calibration gases were obtained from stainless steel tanks filled cryogenically with uncontaminated maritime air at the Australian Maritime Observatory at Cape Grim. These calibration gases were taken from the tanks used for analyzing atmospheric CH₄ from flask air samples from Cape Grim, Tasmania, Australia.

Further details on the methods of sampling and analysis are given in Etheridge et al. (1992).

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D.M. Etheridge, G.I. Pearman, and P.J. Fraser (continued)

LAW DOME (EAST SIDE, "DE08" SITE)

Trends

The site of the DE08 ice core, on the east side of Law Dome, Antarctica, is unique in having an extremely high rate of snow accumulation (about 1.16 m/year water equivalent) that encloses air into bubbles over a short time span, thus allowing a very fine air-age resolution for the ice core CH₄ measurements. This fine resolution permits analysis of the atmospheric CH₄ record back to 1841 at a level of detail not previously available. In addition, because the upper portion of the core contains air entrapped as recently as 1978, researchers for the first time can make direct comparisons between CH₄ concentrations from ice core records and those from modern atmospheric measurements. The precision of the atmospheric CH₄ concentrations from the DE08 ice core reported here is estimated at 22 parts per billion by volume (ppbv) (Etheridge et al. 1992), and the mean sampling interval corresponds to a spacing of ~3 years, with no gaps in the record longer than 10 years.

The atmospheric CH₄ concentrations in the DE08 ice core increased from 823 ppbv in 1841 to 1481 ppbv in 1978. Analysis of the corresponding CH₄ growth rate ($d\text{CH}_4/dt$) data shows that the observed growth rate generally increased throughout the period of record, from <1 ppbv/year in the 1850s to ~14 ppbv/year in the 1970s, except for the period ca. 1920–45, when the growth rate stabilized at ~5 ppbv/year. The DE08 ice core CH₄ concentrations, particularly the smoothing-spline values (Etheridge et al. 1992; Enting 1987), are in agreement with temporally overlapping results from a number of other atmospheric CH₄ measurements obtained by a variety of techniques. These include the 1978 CH₄ annual mean obtained from the Cape Grim flask air sampling program (Fraser et al. 1986) and earlier ice core measurements from Law Dome (Etheridge et al. 1988) and Siple Station (Stauffer et al. 1985).

Concentrations of atmospheric CH₄ from the Law Dome DE08 ice core.

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Historical CH₄ record from the "DE08" ice core at Law Dome

D.M. Etheridge, G.I. Pearman, and P.J. Fraser (continued)

LAW DOME (EAST SIDE, "DE08" SITE)

Concentrations of CH₄ from the Law Dome DE08 Ice Core^a

Year of air enclosure (A.D.)	CH ₄ concentration, sample value (ppbv)	CH ₄ concentration, smoothing-spline value (ppbv) ^b	Year of air enclosure (A.D.)	CH ₄ concentration, sample value (ppbv)	CH ₄ concentration, smoothing-spline value (ppbv) ^b
1841	806	823	1935	1111	1060
1841	823		1940	1094	1085
1841	825		1940	1120	
1841	829		1940	1090	
1841	837		1941	1067	1091
1842	814	823	1943	1095	1101
1842	825		1943	1127	
1843	825	824	1944	1114	1106
1846	835	826	1944	1116	
1854	819	831	1947	1107	1124
1861	848	836	1949	1168	1136
1862	823	837	1950	1114	1143
1862	841		1951	1120	1150
1862	830		1952	1161	1158
1867	833	843	1953	1159	1166
1867	848		1955	1155	1183
1872	876	848	1955	1160	
1875	842	851	1958	1171	1212
1881	874	858	1959	1220	1223
1882	866	859	1959	1205	
1883	857	860	1960	1238	1234
1885	854	863	1960	1221	
1891	866	872	1960	1225	
1898	889	887	1964	1277	1283
1903	922	902	1964	1284	
1903	873		1967	1306	1324
1903	892		1968	1354	1337
1913	919	942	1968	1337	
1916	960	956	1970	1370	1366
1918	967	967	1971	1364	1380
1921	1026	983	1972	1430	1394
1923	982	994	1972	1411	
1923	955		1972	1403	
1923	984		1972	1446	
1923	968		1973	1408	1409
1927	1047	1016	1973	1418	
1927	1017		1974	1427	1423
1927	1033		1974	1392	
1927	1023		1974	1395	
1929	1015	1027	1974	1408	
1929	1019		1974	1449	
1929	1056		1975	1438	1438
1933	1036	1049	1978	1504	1481

^aThese atmospheric CH₄ concentrations derived from the Law Dome DE08 ice core were published in Etheridge et al. (1992) and are available at no cost in electronic form from CDIAC.

^bSmoothing-spline values were calculated by fitting a spline curve with a period of 50% attenuation of 50 years. These parameters were chosen to generate a spline curve that dampens variations in the data with periods less than about twice the air-age resolution (80% distribution width) of 14 years. For further details, see Etheridge et al. (1992) and Enting (1987).

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Period of Record

1983–92

Methods

This globally and monthly averaged atmospheric CH₄ data set is derived from >10,000 air samples collected between May 1983 and December 1991 through the NOAA/CMDL global cooperative air sampling network. The number of sites that contributed air samples varied over the course of the record. At the end of 1991, data from 23 fixed sites and 14 shipboard Pacific Ocean latitudes (shown in the figure below) were used to generate the globally and monthly averaged data set. The shipboard samples were collected by officers of the Blue Star Line, Ltd., merchant vessels *Southland Star* and *Wellington Star* at intervals of 5° latitude between 45° N and 35° S. All data from each 5° latitude collection were considered part of a single site, regardless of the longitude of the cruise track. Fixed sites were usually sampled weekly, and shipboard samples were collected about every 1.5 weeks at a given latitude. The sampling locations of the NOAA/CMDL network are representative of a large volume

NOAA/CMDL sites from which data were used to generate the globally and monthly averaged data set.

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Global CH₄ record from the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

of the marine boundary layer and are generally remote from large sources of atmospheric CH₄.

Whole air samples were collected by using flasks of a number of different designs (see Komhyr et al. 1985; Lang et al. 1990a,b). Flasks were typically pressurized to ~1.5 atm except for shipboard sites and at Christmas Island, where samples were collected in single stopcock flasks evacuated to <0.01 mb prior to shipment from Boulder, Colorado. Whenever possible, samples were collected under preferred conditions of wind speed and direction. Methane mixing ratios [in parts per billion (dry air)] were determined by gas chromatography with flame ionization detection through the use of five different GC systems. All samples were referenced against an internally consistent methane standard scale consisting of natural air contained in stainless steel or aluminum cylinders. Further details of the sampling and measurement procedures can be found in Steele et al. (1987), Lang et al. (1990a,b), and Dlugokencky et al. (1994a,b).

For each sampling site, a function that approximates the average long-term trend, average seasonal cycle, and interannual variations in each was fitted to the data (Thoning et al. 1989). Biweekly values were extracted from these smooth curves and synchronized in time for all sites. A smooth curve, as a function of latitude, was fitted through each set of biweekly values (one value for each site) in the network at that time step. High-altitude sites and sites with sparse data or gaps in their records were excluded. Globally averaged CH₄ values at 14-day intervals were generated by a surface-area weighting of the spatially and temporally smoothed CH₄ distribution. This globally averaged, biweekly CH₄ data set was used to derive the monthly data presented here in *Trends* '93.

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GLOBAL

Trends

The globally averaged atmospheric CH₄ annual means derived from the NOAA/CMDL air sampling network increased from a value of 1625.6 parts per billion (ppb) in 1984 to 1714.1 ppb in 1992. Over the period 1983–92, the mixing ratio grew at an average rate of 11.1 ± 0.2 ppb/year (Dlugokencky et al. 1994b). This growth rate is somewhat lower than the rate of 12.9 ppb/year previously reported by Ehhalt et al. (1990) for the NOAA/CMDL data over the period 1983–87. Steele et al. (1992), however, reported that the global CH₄ growth rate decreased in recent years, from 13.3 ppb/year in 1983 to 9.5 ppb/year in 1990. An analysis by Steele et al. (1992) also suggested that the global growth rate showed significant interannual variation during the period 1988–90. The growth rate fluctuations found in the NOAA/CMDL globally averaged CH₄ data are smaller than those reported in other global CH₄ data sets (see, for example, Khalil and Rasmussen 1990), possibly in part because of the relatively large number of sampling sites used to derive the NOAA/CMDL record.

Global monthly mean mixing ratios of atmospheric CH₄.

CITE AS: Dlugokencky, E.J., P.M. Lang, K.A. Masarie, and L.P. Steele. 1994. Global CH₄ record from the NOAA/CMDL air sampling network. pp. 262–266. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Global CH₄ record from the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

GLOBAL

Mixing Ratios of Atmospheric CH₄Globally averaged CH₄ mixing ratios^a (ppb)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1983					1607.94	1607.22	1605.10	1608.08	1618.59	1624.57	1622.60	1619.50	
1984	1618.40	1618.41	1621.09	1624.24	1623.45	1620.38	1618.13	1622.05	1631.25	1635.43	1634.14	1637.46	1625.6
1985	1636.36	1632.71	1636.02	1639.45	1636.53	1629.52	1626.54	1632.58	1642.94	1648.68	1648.10	1646.51	1638.0
1986	1646.45	1647.13	1649.70	1651.50	1649.55	1645.26	1642.51	1645.45	1653.92	1660.14	1659.84	1659.41	1651.0
1987	1659.34	1658.65	1659.82	1661.89	1662.42	1659.53	1655.75	1656.79	1664.11	1670.37	1670.88	1670.74	1662.8
1988	1671.97	1672.12	1671.22	1670.63	1669.10	1666.25	1665.35	1668.31	1674.89	1680.88	1682.04	1681.33	1673.0
1989	1680.46	1680.71	1681.80	1682.83	1682.58	1679.50	1678.11	1681.27	1686.66	1690.65	1692.37	1692.26	1684.3
1990	1691.60	1692.26	1692.88	1691.39	1689.42	1687.16	1685.70	1689.18	1696.40	1701.40	1702.43	1702.40	1693.7
1991	1700.58	1699.51	1700.45	1701.30	1701.22	1698.27	1694.92	1697.04	1705.29	1711.75	1715.11	1717.74	1703.6
1992	1717.97	1715.95	1714.94	1715.21	1713.43	1709.93	1707.18	1708.09	1713.31	1716.64	1717.54	1718.37	1714.1

^aMethane mixing ratios are expressed in parts per billion (10⁹) (ppb). Values represent global averages derived from atmospheric air samples collected at sites in the NOAA/CMDL global cooperative air sampling network. Annual averages are based on the monthly means.

These data are available at no cost in electronic form from CDIAC. The monthly mean CH₄ mixing ratios from the individual NOAA/CMDL monitoring sites can be found elsewhere in *Trends '93* (pp. 274–350) and in NDP-038 (Steele and Lang 1991). Data from individual flask measurements taken at sites in the NOAA/CMDL global cooperative air sampling network may be obtained electronically from P.M. Lang or E.J. Dlugokencky at NOAA/CMDL.

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Period of Record

1980–91

Methods

These data represent monthly global averages derived from measurements of atmospheric CH₄ taken at six globally distributed locations spanning the polar, middle, and tropical latitudes of both hemispheres: Alaska, U.S.A. (Barrow, 72° N); Oregon, U.S.A. (Cape Meares, 45° N); Hawaii, U.S.A. (Cape Kumukahi and Mauna Loa, both 19° N); Samoa, U.S. Territory (Cape Matatula, 14° S); Tasmania, Australia (Cape Grim, 42° S); and Antarctica (primarily the South Pole, 90° S, with some data from Mawson, 67° S). Measurements were derived from flask samples collected in triplicate every week. At Cape Meares, flask measurements were combined with more than 100,000 automated (continuously sampled) measurements. Because of the high elevation of the Mauna Loa sampling location (often above the planetary boundary layer), it was necessary to adjust all Mauna Loa measurements upward by 0.9% in order to obtain equivalent ground-level concentrations for Hawaii. In addition, whenever measurements were available for both Cape Kumukahi and Mauna Loa, the average of the Cape Kumukahi and the adjusted Mauna Loa concentrations served as the representative CH₄ value for Hawaii.

Methane concentrations were usually measured within 2 weeks of collection, except for some Antarctic samples. Flask samples from all sites except Cape Grim were sent to the Oregon Graduate Institute (OGI) for analysis. For these samples, air was pumped by a metal bellows pump into 0.8-L stainless steel cans at pressures of up to 40 psi. At Cape Grim, large-volume air samples were collected cryogenically and analyzed at the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Division of Atmospheric Research, in Australia. For measurements made by continuous sampling at Cape Meares, air samples were pumped into an automated sampling apparatus, dried, and injected directly into a gas chromatograph. In all cases (flask samples analyzed at OGI and CSIRO; continuous

Barrow
Alaska, U.S.A.

Cape Grim
Tasmania, Australia

Samoa (Cape Matatula)
U.S. Territory

Cape Meares
Oregon, U.S.A.

Mauna Loa and
Cape Kumukahi
Hawaii, U.S.A.

South Pole and Mawson
Antarctica

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Global CH₄ record derived from six globally distributed locations

M.A.K. Khalil and R.A. Rasmussen (continued)

monitoring at Cape Meares), analyses were performed through the use of Carle 211-MS gas chromatographs equipped with flame ionization detectors. Measurements at all sites were referenced against a single primary calibration standard. The accuracy of the measurements was estimated to be $\pm 5\%$, based on analyses of commercially prepared primary standards and on interlaboratory comparisons. For further details concerning the methodology of obtaining samples and measuring CH₄ concentrations, the reader should refer to Khalil and Rasmussen (1983, 1990)

At each of the six representative sites, weekly measurements were averaged to generate monthly values. Each site was then assigned a latitudinal band for which the CH₄ concentrations measured at that site were considered representative. The monthly global averages were then obtained by calculating a weighted average of the concentrations from the six sites as follows:

$$C_{global} = \Sigma A_i C_i / \Sigma A_i ,$$

where C_i is the CH₄ concentration and A_i is the area of the associated latitudinal band for a particular site i . The summation, ΣA_i , is the total area of the earth's surface. In order to clearly show the long-term trends in the data, the seasonal cycles were removed (see Khalil and Rasmussen 1990; Khalil et al. 1993). Further details on the derivation of the globally averaged CH₄ concentrations are given in Khalil and Rasmussen (1990, 1993).

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GLOBAL

Trends

The globally averaged atmospheric CH₄ concentrations increased from a minimum of 1557.2 parts per billion by volume (ppbv) in December 1980 to a maximum of 1737.1 ppbv in December 1991. For the period 1980–88, Khalil and Rasmussen (1990) estimated the rate of increase to be 16.6 ± 0.4 ppbv/year. Khalil and Rasmussen (1993) also reported that the global rate of increase of CH₄ slowed from a mean value of 19.8 ± 0.8 ppbv/year for the period 1981–85 to a mean of 12.0 ± 0.5 ppbv/year for the period 1989–92. This represents an average deceleration in global CH₄ growth rate of about 1 ppbv/yr². These data show a greater decline in the global trend of CH₄ than do those reported by Steele et al. (1992), which were generated from measurements taken by the NOAA/CMDL flask sampling network. (The NOAA/CMDL global averages were derived from a much larger number of monitoring sites, but span a shorter time.)

Global monthly concentrations of atmospheric CH₄.

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Global CH₄ record derived from six globally distributed locations

M.A.K. Khalil and R.A. Rasmussen (continued)

GLOBAL

Concentrations of Atmospheric CH₄Globally averaged CH₄ concentrations^a (ppbv)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1980									1562.1	1566.5	1560.0	1557.2	
1981	1563.5	1563.9	1564.0	1572.1	1571.2	1570.2	1569.8	1578.5	1581.7	1579.0	1580.9	1584.9	1573.3
1982	1586.1	1583.3	1588.8	1590.5	1591.4	1594.5	1595.6	1594.7	1595.8	1598.9	1597.3	1597.6	1592.9
1983	1601.5	1604.4	1607.1	1611.6	1614.9	1620.6	1629.9	1621.9	1623.3	1619.3	1624.9	1622.2	1616.8
1984	1626.8	1631.7	1629.4	1624.8	1627.2	1631.1	1631.8	1632.9	1633.2	1635.4	1637.1	1641.3	1631.9
1985	1641.7	1639.7	1642.6	1641.2	1646.3	1644.6	1647.2	1645.0	1646.7	1651.7	1649.8	1651.2	1645.6
1986	1647.7	1647.5	1653.0	1657.2	1657.5	1660.3	1658.6	1659.0	1661.1	1665.2	1662.9	1668.3	1658.2
1987	1669.2	1669.3	1671.4	1674.4	1675.0	1676.9	1676.8	1675.6	1681.4	1683.1	1686.7	1687.5	1677.3
1988	1690.1	1690.0	1687.3	1690.9	1690.4	1689.8	1692.7	1693.0	1690.4	1693.9	1698.1	1701.1	1692.3
1989	1698.0	1700.2	1705.3	1703.1	1701.5	1701.5	1704.6	1708.5	1705.5	1709.9	1707.2	1710.3	1704.6
1990	1714.4	1714.6	1711.4	1710.1	1714.1	1716.6	1709.4	1720.6	1724.3	1720.1	1724.5	1718.0	1716.5
1991	1720.0	1727.5	1727.8	1725.9	1726.4	1724.4	1727.6	1730.2	1727.5	1730.3	1733.0	1737.1	1728.1

^aMethane concentrations are expressed in parts per billion by volume (ppbv). Values represent global averages derived from atmospheric CH₄ measurements taken at representative, globally distributed locations. The data have been adjusted to remove seasonal variations. Annual averages represent arithmetic means of the monthly values for years when data for all 12 months are available. These data are available at no cost in electronic form from CDIAC. Readers who wish to use these data in specific model exercises or research exercises should first refer to Khalil and Rasmussen (1990).

CITE AS: Khalil, M.A.K., and R.A. Rasmussen. 1994. Global CH₄ record derived from six globally distributed locations. pp. 268–272. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

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Atmospheric CH₄ records from sites in the NOAA/CMDL air sampling network

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Alert • Amsterdam Island • Ascension Island • Azores • Barbados • Barrow •
Bermuda (East) • Bermuda (West) • Cape Grim • Cape Kumukahi • Cape
Meares • Christmas Island • Cold Bay • Guam • Halley Bay • Izaña • Key
Biscayne • Mace Head • Mauna Loa • Midway Islands • Mould Bay • Niwot
Ridge • Olympic Peninsula • Pacific Ocean • Palmer Station • Qinghai
Province • Samoa • Seychelles • Shemya Island • South Georgia Island • South
Pole • Station "M" • Syowa Station • Tae-ahn Peninsula • Virgin Islands

Period of Record

Generally 1983–92 (varies by site)

Methods

Whole air samples are currently collected in 2.5-L cylindrical glass flasks equipped with two
Teflon O-ring sealed, glass piston stopcocks. Various other flask designs have been used
throughout the measurement program (see Komhyr et al. 1985; and Lang et al. 1990a,b).

Sites in the NOAA/CMDL air sampling network.

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Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

Two flasks are pressurized in series to approximately 1.5 atm through the use of a battery-powered portable pumping package. For shipboard sampling and at Christmas Island, samples are collected in single stopcock flasks evacuated to <0.01 mb before shipment from Boulder, Colorado. Sample collectors are instructed to collect samples under preferred conditions of wind speed and direction.

Methane mixing ratios are determined through the use of a gas chromatograph equipped with a flame ionization detector. Different gas chromatograph systems have been used over the sampling period, but the basic technique has remained essentially the same. All samples are referenced against an internally consistent methane standard scale consisting of natural air contained in stainless steel or aluminum cylinders. Methane mixing ratios in dry air parts per billion (10⁹) (ppb) are determined from peak height measurements. Throughout most of the period 1983–91, one flask of a pair collected simultaneously was analyzed for methane. Whenever the overpressure was sufficient, at least 2 aliquots were taken from each flask. Since October 1991, single aliquots from each member of a flask pair have been analyzed.

Further details of the sampling and measurement procedures can be found in Steele et al. (1987), Lang et al. (1990a,b), and Dlugokencky et al. (1994a,b).

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Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

ALERT

Trends

The monitoring site at Alert, Northwest Territories, Canada, is operated in cooperation with the Atmospheric Environment Service of Environment Canada. Annual mean atmospheric CH₄ mixing ratios at Alert rose from 1743.5 parts per billion (ppb) in 1986 to 1802.1 ppb in 1992. The average rate of increase over the period of record (June 1985–December 1992) was 10.3 ppb/year. The Alert CH₄ monthly record exhibits a seasonal cycle characteristic of the Northern Hemisphere: minimum mixing ratios occur during northern summer months (in this case, July).

Monthly mixing ratios of atmospheric CH₄ at Alert.

CITE AS: Dlugokencky, E.J., P.M. Lang, K.A. Masarie, and L.P. Steele. 1994. Atmospheric CH₄ records from sites in the NOAA/CMDL air sampling network. pp. 274–350. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

ALERT

Alert
Northwest Territories, Canada
Tundra
82°27' N, 62°31' W
210 m above MSL

Mixing Ratios of Atmospheric CH₄CH₄ mixing ratios^a at Alert (ppb)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1985						1708.01	1697.04	1695.06	1718.97	1740.22	1740.44	1750.43	
1986	1758.60	1760.79	1766.49	1758.44	1743.56	1724.55	1713.90	1717.69	1732.39	1753.64	1752.40	1741.30	1743.5
1987	1750.01	1756.47	1758.05	1756.38	1749.63	1735.42	1728.20	1735.56	1752.86	1765.93	1767.61	1768.28	1751.8
1988	1776.87	1777.17	1773.87	1774.39	1763.91	1747.69	1731.92	1734.30	1760.92	1780.94	1785.38	1783.60	1765.9
1989	1792.19	1798.65	1794.70	1782.75	1766.22	1756.94	1752.71	1755.34	1765.19	1772.18	1788.05	1806.61	1777.2
1990	1805.06	1800.22	1800.40	1792.55	1778.74	1764.89	1756.46	1755.05	1766.33	1787.96	1796.11	1801.93	1783.7
1991	1816.07	1813.05	1805.86	1799.93	1781.24	1765.19	1760.13	1772.69	1790.35	1797.96	1803.04	1822.71	1794.5
1992	1835.60	1831.20	1826.02	1814.04	1800.85	1788.50	1773.81	1772.75	1782.30	1791.72	1802.76	1818.13	1802.1

^aMethane mixing ratios are expressed in parts per billion (10⁹) (ppb). Monthly means are based only on those samples representative of background conditions. They were determined by first fitting a curve to the data [see Steele et al. (1992) for details of the curve fits]. To ensure that the data used in the curve fits were evenly spaced, the following guidelines were used. If a flask was analyzed more than once, all aliquots were averaged and the resulting mean was plotted as a single measurement. If both members of a flask pair were analyzed or if two pairs of flasks were sampled simultaneously and then analyzed, all aliquots from the flasks were averaged and their mean again plotted as a single measurement. Weekly values were extracted from the curve fits, and all values in each month were averaged to obtain the monthly means. Annual averages are based on the monthly means.

These data are available in electronic form from CDIAC and in NDP-038 (Steele and Lang 1991). Data from individual flask measurements may be obtained electronically from P.M. Lang or E.J. Dlugokencky at NOAA/CMDL.

CITE AS: Dlugokencky, E.J., P.M. Lang, K.A. Masarie, and L.P. Steele. 1994. Atmospheric CH₄ records from sites in the NOAA/CMDL air sampling network. pp. 274-350. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

AMSTERDAM ISLAND

Trends

The sampling site on Amsterdam Island was operated in cooperation with the French Centre des Faibles Radioactivities. The average rate of increase over the period of record (1983–90) at this site was 11.9 ppb/year. The seasonal pattern observed at Amsterdam Island was typical for sites of similar latitude in the Southern Hemisphere. After October 1990, atmospheric CH₄ monitoring at Amsterdam Island was discontinued.

Monthly mixing ratios of atmospheric CH₄ at Amsterdam Island.

CITE AS: Dlugokencky, E.J., P.M. Lang, K.A. Masarie, and L.P. Steele. 1994. Atmospheric CH₄ records from sites in the NOAA/CMDL air sampling network. pp. 274–350. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93. A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

AMSTERDAM ISLAND

Amsterdam Island
Indian Ocean
Island seashore
 37°57' S, 77°32' E
 150 m above MSL

Mixing Ratios of Atmospheric CH₄CH₄ mixing ratios^a at Amsterdam Island (ppb)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1983	1541.98	1540.52	1541.98	1548.19	1556.23	1563.77	1571.31	1575.35	1576.13	1578.40	1576.51	1567.73	
1984	1560.86	1560.29	1563.58	1570.31	1576.91	1582.13	1587.50	1589.53	1588.89	1589.15			
1985			1567.42	1576.52	1584.65	1587.99	1593.85	1604.45	1608.80	1602.90	1595.85	1591.13	
1986	1585.71	1582.95	1587.21	1593.06	1600.40	1606.41	1609.48	1614.50	1614.59	1612.05	1608.89	1602.94	1601.6
1987	1595.67	1589.45									1628.73	1614.85	
1988	1601.78	1600.72	1604.45	1613.70	1620.49	1621.88	1626.78	1633.38	1636.16	1635.67	1630.75	1624.94	1620.8
1989	1619.87	1614.62	1616.93	1627.55	1635.36	1640.58	1646.62	1649.57	1649.64	1648.22	1642.44	1632.61	1635.3
1990	1631.36	1631.41	1629.05	1633.30	1642.44	1650.55	1657.71	1662.00	1662.33	1662.28			

^aMethane mixing ratios are expressed in parts per billion (10⁹) (ppb). Monthly means are based only on those samples representative of background conditions. They were determined by first fitting a curve to the data [see Steele et al. (1992) for details of the curve fits]. To ensure that the data used in the curve fits were evenly spaced, the following guidelines were used. If a flask was analyzed more than once, all aliquots were averaged and the resulting mean was plotted as a single measurement. If both members of a flask pair were analyzed or if two pairs of flasks were sampled simultaneously and then analyzed, all aliquots from the flasks were averaged and their mean again plotted as a single measurement. Weekly values were extracted from the curve fits, and all values in each month were averaged to obtain the monthly means. Annual averages are based on the monthly means.

These data are available in electronic form from CDIAC and in NDP-038 (Steele and Lang 1991). Data from individual flask measurements may be obtained electronically from P.M. Lang or E.J. Dlugokencky at NOAA/CMDL.

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Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

ASCENSION ISLAND

Trends

The sampling site on Ascension Island is operated in cooperation with the U.S. Air Force and Pan American World Airways. The annual mean CH₄ mixing ratio at Ascension Island rose from 1588.7 parts per billion (ppb) in 1984 to 1677.2 ppb in 1992. The average rate of increase at this site over the period of record (1983–92) was 11.2 ppb/year. According to Steele et al. (1987), the CH₄ mixing ratio data from Ascension Island show a clear seasonal cycle, but the phase of the cycle is different from that observed at sites in middle and polar latitudes of the Southern Hemisphere. Steele et al. (1987) also report that this site does not appear to be influenced during any season by air originating north of the Intertropical Convergence Zone.

Monthly mixing ratios of atmospheric CH₄ at Ascension Island.

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Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

ASCENSION ISLAND

Ascension Island
U.K. Territory
South Atlantic Ocean
Island seashore
7°55' S, 14°25' W
54 m above MSL

Mixing Ratios of Atmospheric CH₄CH₄ mixing ratios^a at Ascension Island (ppb)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1983					1577.47	1584.54	1585.60	1583.99	1587.50	1585.66	1579.05	1575.88	
1984	1571.94	1569.40	1577.00	1585.50	1590.23	1594.94	1599.77	1601.33	1599.44	1594.20	1590.04	1591.02	1588.7
1985	1585.99	1583.71	1593.11	1600.49	1602.21	1607.55	1610.99	1615.06	1614.98	1607.85	1603.90	1600.65	1602.3
1986	1596.29	1596.49	1601.41	1610.94	1618.25	1618.24	1620.26	1620.44	1620.47	1628.15	1629.89	1620.43	1615.2
1987	1612.79	1611.46	1615.10	1625.73	1634.45	1635.96	1635.61	1637.58	1637.99	1633.07	1629.26	1624.23	1627.6
1988	1614.25	1617.47	1624.26	1626.55	1633.79	1638.42	1643.70	1647.58	1648.51	1647.57	1644.57	1637.72	1635.5
1989	1629.71	1630.45	1634.44	1640.21	1646.84	1651.36	1653.70	1655.08	1655.21	1657.17	1659.83	1653.35	1647.4
1990	1642.94	1641.64	1647.76	1652.31	1657.69	1662.13	1662.91	1664.22	1667.16	1666.60	1660.33	1660.05	1657.3
1991	1659.48	1653.77	1654.04	1660.21	1662.95	1665.07	1670.82	1677.29	1679.46	1680.66	1686.01	1685.46	1669.6
1992	1670.66	1663.97	1667.11	1674.78	1682.03	1682.16	1684.77	1685.62	1682.99	1679.48	1677.49	1673.55	1677.2

^aMethane mixing ratios are expressed in parts per billion (10⁹) (ppb). Monthly means are based only on those samples representative of background conditions. They were determined by first fitting a curve to the data [see Steele et al. (1992) for details of the curve fits]. To ensure that the data used in the curve fits were evenly spaced, the following guidelines were used. If a flask was analyzed more than once, all aliquots were averaged and the resulting mean was plotted as a single measurement. If both members of a flask pair were analyzed or if two pairs of flasks were sampled simultaneously and then analyzed, all aliquots from the flasks were averaged and their mean again plotted as a single measurement. Weekly values were extracted from the curve fits, and all values in each month were averaged to obtain the monthly means. Annual averages are based on the monthly means.

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Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

AZORES

Trends

The Azores sampling site on Terceira Island is operated in cooperation with the 7th Weather Wing of the U.S. Air Force. The annual mean CH₄ mixing ratio at Terceira Island rose from 1689.2 parts per billion (ppb) in 1984 to 1768.8 ppb in 1991. The average rate of increase over the period of record (May 1983–January 1992) at this site was 11.7 ppb/year. Steele et al. (1987) compared the CH₄ data from the Azores and Niwot Ridge sites (the two sites are at similar latitudes) and found that the long-term average CH₄ mixing ratio at the high-altitude site of Niwot Ridge was lower than that at the Azores.

Monthly mixing ratios of atmospheric CH₄ at the Azores.

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Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

AZORES

Azores (Terceira Island)
North Atlantic Ocean
Island seashore
38°45' N, 27°05' W
30 m above MSL

Mixing Ratios of Atmospheric CH₄CH₄ mixing ratios^a at the Azores (ppb)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1983					1680.13	1663.24	1652.92	1656.35	1667.13	1680.84	1678.01	1671.41	
1984	1686.43	1700.09	1697.10	1693.15	1687.80	1670.30	1661.91	1679.11	1687.94	1691.26	1711.11	1711.91	1689.2
1985	1698.33	1701.04	1705.28	1712.24	1716.67	1692.89	1687.00	1705.04	1704.11	1706.91	1705.86	1705.10	1703.3
1986	1719.47												1732.76
1987	1738.95	1730.62	1727.51	1734.77	1729.97	1716.98	1704.20	1701.09	1722.91	1742.57	1744.21	1745.69	1728.2
1988	1741.53	1729.79	1734.79	1751.73	1744.26	1718.23	1701.48	1700.75	1726.47	1753.05	1749.57	1739.94	1732.4
1989	1747.12	1746.30	1743.06	1752.72	1751.51	1738.50							
1990						1746.30	1745.09	1738.34	1751.17	1780.13	1774.16	1770.23	
1991	1789.54	1782.92	1773.78	1776.85	1763.93	1737.75	1743.42	1758.30	1753.20	1769.32	1789.53	1784.90	1768.8
1992	1779.12												

^aMethane mixing ratios are expressed in parts per billion (10⁹) (ppb). Monthly means are based only on those samples representative of background conditions. They were determined by first fitting a curve to the data [see Steele et al. (1992) for details of the curve fits]. To ensure that the data used in the curve fits were evenly spaced, the following guidelines were used. If a flask was analyzed more than once, all aliquots were averaged and the resulting mean was plotted as a single measurement. If both members of a flask pair were analyzed or if two pairs of flasks were sampled simultaneously and then analyzed, all aliquots from the flasks were averaged and their mean again plotted as a single measurement. Weekly values were extracted from the curve fits, and all values in each month were averaged to obtain the monthly means. Annual averages are based on the monthly means.

These data are available in electronic form from CDIAC and in NDP-038 (Steele and Lang 1991). Data from individual flask measurements may be obtained electronically from P.M. Lang or E.J. Dlugokencky at NOAA/CMDL.

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BARBADOS

Trends

The sampling site at Ragged Point, Barbados, is operated in cooperation with the University of Bristol. The site is located on the east coast of Barbados and generally receives unpolluted oceanic air under the influence of predominantly easterly winds. The annual mean CH₄ mixing ratio at Ragged Point rose from 1693.9 parts per billion (ppb) in 1988 to 1729.2 ppb in 1992. The average rate of increase over the period of record (1987–92) at this site was 9.3 ppb/year.

Monthly mixing ratios of atmospheric CH₄ at Barbados.

CITE AS: Dlugokencky, E.J., P.M. Lang, K.A. Masarie, and L.P. Steele. 1994. Atmospheric CH₄ records from sites in the NOAA/CMDL air sampling network. pp. 274–350. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric Methane
Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

BARBADOS

Barbados (Ragged Point)
Atlantic Ocean
Island seashore
13°10' N, 59°26' W
3 m above MSL

Mixing Ratios of Atmospheric CH₄

CH₄ mixing ratios^a at Barbados (ppb)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1987											1683.60	1694.54	
1988	1707.70	1700.80	1689.41	1690.55	1690.63	1683.96	1681.00	1686.84	1688.47	1693.69	1705.24	1708.95	1693.9
1989	1708.73	1704.00	1701.92	1705.39	1699.16	1688.52	1690.04	1694.44	1694.16	1704.31	1713.69	1716.87	1702.1
1990	1727.10	1729.54	1723.58	1719.36	1716.25	1709.85	1703.03	1707.67	1704.52	1701.84	1719.46	1733.94	1716.3
1991	1729.76	1726.08	1734.62	1734.88	1721.62	1710.04	1709.14	1710.74	1713.53	1722.41	1734.73	1746.61	1724.7
1992	1748.69	1746.85	1740.00	1731.43	1725.85	1723.46	1723.12	1721.11	1711.80	1714.69	1730.72	1733.49	1729.2

^aMethane mixing ratios are expressed in parts per billion (10⁹) (ppb). Monthly means are based only on those samples representative of background conditions. They were determined by first fitting a curve to the data [see Steele et al. (1992) for details of the curve fits]. To ensure that the data used in the curve fits were evenly spaced, the following guidelines were used. If a flask was analyzed more than once, all aliquots were averaged and the resulting mean was plotted as a single measurement. If both members of a flask pair were analyzed or if two pairs of flasks were sampled simultaneously and then analyzed, all aliquots from the flasks were averaged and their mean again plotted as a single measurement. Weekly values were extracted from the curve fits, and all values in each month were averaged to obtain the monthly means. Annual averages are based on the monthly means.

These data are available in electronic form from CDIAC and in NDP-038 (Steele and Lang 1991). Data from individual flask measurements may be obtained electronically from P.M. Lang or E.J. Dlugokencky at NOAA/CMDL.

CITE AS: Dlugokencky, E.J., P.M. Lang, K.A. Masarie, and L.P. Steele. 1994. Atmospheric CH₄ records from sites in the NOAA/CMDL air sampling network. pp. 274–350. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

BARROW

Trends

The sampling site at Barrow, Alaska, U.S.A., was established as a NOAA/CMDL station in 1973 for the purpose of measuring atmospheric CO₂ mixing ratios. Analyses of air samples for CH₄ began in April 1983. The annual mean CH₄ mixing ratio at Barrow rose from 1724.1 parts per billion (ppb) in 1984 to 1806.5 ppb in 1992. The average rate of increase over the period of record at this site was 11.1 ppb/year. On the basis of data for 1983 and 1984, Steele et al. (1987) observed that all of the northernmost NOAA/CMDL sites (Barrow, Cape Meares, Cold Bay, Station "M," and Mould Bay) exhibited major seasonal minima during the northern summer (usually in July).

Monthly mixing ratios of atmospheric CH₄ at Barrow.

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Atmospheric Methane

Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

Barrow
Alaska, U.S.A.
Arctic coastal seashore
71°19' N, 156°36' W
11 m above MSL

BARROW

Mixing Ratios of Atmospheric CH₄

CH₄ mixing ratios^a at Barrow (ppb)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1983				1696.01	1685.82	1681.54	1679.44	1686.40	1706.90	1722.69	1713.95	1710.57	
1984	1738.93	1755.27	1734.19	1717.30	1709.52	1700.24	1699.56	1708.98	1727.73	1733.58	1727.34	1741.02	1724.1
1985	1744.99	1736.52	1743.72	1748.13	1732.70	1709.52	1699.45	1703.56	1729.82	1756.56	1752.43	1741.46	1733.3
1986	1748.71	1772.70	1779.16	1760.65	1737.18	1730.41	1724.36	1723.48	1758.47	1794.32	1779.84	1755.79	1755.1
1987	1757.75	1775.22	1776.77	1764.58	1746.76	1733.73	1738.31	1750.94	1758.48	1760.91	1766.64	1773.82	1758.7
1988	1793.22	1808.21	1795.96	1777.21	1760.41	1746.84	1740.09	1744.20	1764.23	1775.33	1782.50	1800.40	1773.8
1989	1802.85	1801.71	1804.49	1784.36	1766.40	1755.44	1779.49	1803.97	1783.64	1785.63	1798.85	1799.84	1788.7
1990	1807.31	1820.57	1818.10	1799.49	1787.68	1774.11	1764.05	1773.34	1785.88	1795.91	1812.65	1826.88	1797.0
1991	1825.27	1816.68	1818.18	1805.62	1782.93	1776.48	1782.92	1783.47	1789.67	1805.93	1816.09	1823.91	1802.1
1992	1834.86	1828.90	1815.99	1810.49	1799.99	1791.22	1788.65	1785.31	1788.76	1802.99	1813.69	1817.17	1806.5

^aMethane mixing ratios are expressed in parts per billion (10⁹) (ppb). Monthly means are based only on those samples representative of background conditions. They were determined by first fitting a curve to the data [see Steele et al. (1992) for details of the curve fits]. To ensure that the data used in the curve fits were evenly spaced, the following guidelines were used. If a flask was analyzed more than once, all aliquots were averaged and the resulting mean was plotted as a single measurement. If both members of a flask pair were analyzed or if two pairs of flasks were sampled simultaneously and then analyzed, all aliquots from the flasks were averaged and their mean again plotted as a single measurement. Weekly values were extracted from the curve fits, and all values in each month were averaged to obtain the monthly means. Annual averages are based on the monthly means.

These data are available in electronic form from CDIAC and in NDP-038 (Steele and Lang 1991). Data from individual flask measurements may be obtained electronically from P.M. Lang or E.J. Dlugokencky at NOAA/CMDL.

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Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

BERMUDA (EAST)

Trends

The NOAA/CMDL sampling site at St. David's Head, located on the eastern side of St. David's Island, Bermuda, is operated in cooperation with the Bermuda Biological Station. Air sampling for determining atmospheric CH₄ began at this site in February 1989. Over the short period of record (1989–92), the atmospheric CH₄ mixing ratio increased at an average rate of 8.3 parts per billion (ppb) per year.

Monthly mixing ratios of atmospheric CH₄ at Bermuda (East).

CITE AS: Dlugokencky, E.J., P.M. Lang, K.A. Masarie, and L.P. Steele. 1994. Atmospheric CH₄ records from sites in the NOAA/CMDL air sampling network. pp. 274–350. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

BERMUDA (EAST)*Bermuda (East, St. David's Head)*
U.K.*Rocky seashore*
32°22' N, 64°39' W
30 m above MSL**Mixing Ratios of Atmospheric CH₄**CH₄ mixing ratios^a at Bermuda (East) (ppb)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1989		1754.50	1755.65	1756.21	1740.52	1723.71	1703.91	1699.63	1730.70	1755.98	1760.44	1768.78	
1990	1767.12	1762.99	1760.67	1763.16	1758.78	1732.64	1723.52	1751.68	1774.97	1774.43	1759.76	1757.74	1757.3
1991	1767.38	1775.01	1785.55	1788.03	1770.83	1755.55	1726.09	1721.02	1754.93	1770.38	1767.43	1773.84	1762.8
1992	1808.57	1810.37	1787.26	1780.02	1759.82	1736.52	1725.89	1728.74	1757.19	1779.02	1783.98	1786.67	1769.8

^aMethane mixing ratios are expressed in parts per billion (10⁹) (ppb). Monthly means are based only on those samples representative of background conditions. They were determined by first fitting a curve to the data [see Steele et al. (1992) for details of the curve fits]. To ensure that the data used in the curve fits were evenly spaced, the following guidelines were used. If a flask was analyzed more than once, all aliquots were averaged and the resulting mean was plotted as a single measurement. If both members of a flask pair were analyzed or if two pairs of flasks were sampled simultaneously and then analyzed, all aliquots from the flasks were averaged and their mean again plotted as a single measurement. Weekly values were extracted from the curve fits, and all values in each month were averaged to obtain the monthly means. Annual averages are based on the monthly means.

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Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

BERMUDA (WEST)

Trends

The sampling site at Southhampton, the NOAA/CMDL monitoring site established on the western side of the island of Bermuda, is operated in cooperation with the Bermuda Biological Station. Air sampling for determining atmospheric CH₄ began at the Southhampton site in May 1989. Over the short period of record (1989–92), the CH₄ mixing ratio showed an average growth rate of 7.8 parts per billion (ppb) per year.

Monthly mixing ratios of atmospheric CH₄ at Bermuda (West).

CITE AS: Dlugokencky, E.J., P.M. Lang, K.A. Masarie, and L.P. Steele. 1994. Atmospheric CH₄ records from sites in the NOAA/CMDL air sampling network. pp. 274–350. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

BERMUDA (West)

Bermuda (West, Southhampton)
U.K.

Promontory seashore
32°16' N, 64°53' W
30 m above MSL

Mixing Ratios of Atmospheric CH₄CH₄ mixing ratios^a at Bermuda (West) (ppb)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1989					1747.40	1724.58	1713.05	1708.14	1716.43	1725.07	1742.83	1764.87	
1990	1755.23	1752.65	1777.12	1769.10	1734.03	1722.01	1714.02	1716.68	1742.12	1748.54	1749.13	1763.35	1745.2
1991	1774.65	1762.74	1771.88	1791.46	1768.81	1721.13	1706.81	1734.71	1768.66	1776.17	1768.55	1776.64	1760.5
1992	1787.33	1786.24	1788.68	1778.19	1750.95	1725.26	1710.92	1724.71	1755.08	1769.14	1769.16	1783.95	1760.9

^aMethane mixing ratios are expressed in parts per billion (10⁹) (ppb). Monthly means are based only on those samples representative of background conditions. They were determined by first fitting a curve to the data [see Steele et al. (1992) for details of the curve fits]. To ensure that the data used in the curve fits were evenly spaced, the following guidelines were used. If a flask was analyzed more than once, all aliquots were averaged and the resulting mean was plotted as a single measurement. If both members of a flask pair were analyzed or if two pairs of flasks were sampled simultaneously and then analyzed, all aliquots from the flasks were averaged and their mean again plotted as a single measurement. Weekly values were extracted from the curve fits, and all values in each month were averaged to obtain the monthly means. Annual averages are based on the monthly means.

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Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

CAPE GRIM

Trends

The sampling site at Cape Grim, Tasmania, Australia, is operated in cooperation with the Commonwealth Scientific and Industrial Research Organisation (CSIRO), which has been making CH₄ measurements at Cape Grim since 1978. The NOAA/CMDL monitoring program has been collecting air samples at Cape Grim since April 1984. The NOAA/CMDL data show that the annual mean CH₄ mixing ratio at Cape Grim rose from 1588.5 parts per billion (ppb) in 1985 to 1666.2 ppb in 1992. The average CH₄ growth rate at Cape Grim over the period of record was 11.0 ppb/year.

The CH₄ record from Cape Grim is comparable to records from other Southern Hemisphere sites. Fraser et al. (1984) found no significant difference in either the seasonal cycle or the long-term trend when they compared CH₄ measurements taken from air samples collected by CSIRO at Cape Grim and at Mawson, Antarctica, during the period 1980–84.

Monthly mixing ratios of atmospheric CH₄ at Cape Grim.

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Atmospheric CH₄ records from sites in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

CAPE GRIM

Cape Grim
Tasmania, Australia
Promontory seashore
40°41' S, 144°41' E
94 m above MSL

Mixing Ratios of Atmospheric CH₄

CH₄ mixing ratios^a at Cape Grim (ppb)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1984				1566.03	1571.10	1578.89	1586.95	1591.38	1591.75	1592.08	1588.09	1581.15	
1985	1574.09	1569.38	1570.70	1575.73	1583.39	1590.40	1595.82	1601.59	1604.09	1603.57	1599.27	1592.02	1588.5
1986	1585.27	1581.29	1581.95	1585.80	1593.46	1601.46	1608.46	1614.11	1614.82	1613.16	1611.19	1606.06	1599.8
1987	1597.06	1592.73	1595.39	1601.79	1608.96	1613.98	1619.65	1624.82	1627.80	1627.65	1622.20	1615.34	1612.3
1988	1607.95	1601.66	1599.03	1604.29	1615.78	1622.91	1630.06	1636.05	1637.53	1636.26	1633.89	1627.19	1621.3
1989	1615.28	1614.89	1620.49	1624.15	1631.44	1639.21	1645.98	1650.56	1650.04	1648.67	1647.47	1640.11	1635.8
1990	1631.17	1627.07	1626.81	1630.16	1636.86	1648.92	1655.67	1655.31	1656.77	1658.60	1654.72	1644.38	1644.1
1991	1634.95	1631.81	1634.81	1640.32	1647.11	1653.67	1658.56	1662.95	1666.70	1667.91	1665.46	1659.55	1652.0
1992	1653.20	1649.62	1650.47	1655.38	1662.17	1669.10	1675.12	1678.80	1680.10	1677.77	1673.22	1668.58	1666.2

^aMethane mixing ratios are expressed in parts per billion (10⁹) (ppb). Monthly means are based only on those samples representative of background conditions. They were determined by first fitting a curve to the data [see Steele et al. (1992) for details of the curve fits]. To ensure that the data used in the curve fits were evenly spaced, the following guidelines were used. If a flask was analyzed more than once, all aliquots were averaged and the resulting mean was plotted as a single measurement. If both members of a flask pair were analyzed or if two pairs of flasks were sampled simultaneously and then analyzed, all aliquots from the flasks were averaged and their mean again plotted as a single measurement. Weekly values were extracted from the curve fits, and all values in each month were averaged to obtain the monthly means. Annual averages are based on the monthly means.

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Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

CAPE KUMUKAHI

Trends

Cape Kumukahi, located on the eastern extremity of the island of Hawaii, U.S.A., has served as a NOAA/CMDL monitoring site for atmospheric CH₄ since April 1983. The annual mean CH₄ mixing ratio at Cape Kumukahi rose from 1654.7 parts per billion (ppb) in 1984 to 1741.5 ppb in 1992. The mixing ratio increased at an average rate of 10.6 ppb/year over the period of record. Steele et al. (1987) compared the CH₄ data from Cape Kumukahi with those from Mauna Loa (also located on the island of Hawaii) and found a significant vertical gradient in CH₄ mixing ratio: the long-term average mixing ratios at Mauna Loa (3397 m above MSL) were ~1.5% lower than those at Cape Kumukahi (3 m above MSL). Using fitted cubic spline functions, Steele et al. (1987) also showed that both sites exhibited two minima and two maxima each year at times consistent with those reported by Khalil and Rasmussen (1983).

Monthly mixing ratios of atmospheric CH₄ at Cape Kumukahi.

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Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

CAPE KUMUKAHI

Cape Kumukahi
Hawaii, U.S.A.
Island seashore
19°31' N, 154°49' W
3 m above MSL

Mixing Ratios of Atmospheric CH₄CH₄ mixing ratios^a at Cape Kumukahi (ppb)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1983				1638.88	1646.97	1640.08	1623.29	1630.70	1665.62	1671.36	1658.70	1654.09	
1984	1651.66	1657.86	1663.21	1667.48	1658.71	1642.36	1633.52	1637.44	1653.93	1665.89	1660.05	1667.41	1654.7
1985	1677.39	1670.73	1673.93	1683.06	1683.49	1661.73	1644.22	1647.00	1665.47	1682.65	1681.14	1675.55	1670.6
1986	1673.08	1668.25	1676.34	1685.69	1677.72	1670.64	1660.69	1657.37	1667.70	1687.22	1698.25	1704.88	1677.8
1987	1708.09	1697.12	1693.29	1694.66	1694.13	1698.09	1684.82	1669.08	1677.73	1694.59	1710.47	1714.15	1694.5
1988	1699.05	1697.07	1708.55	1712.88	1706.24	1691.01	1676.33	1680.05	1692.39	1699.18	1705.66	1708.28	1697.9
1989	1704.20	1695.10	1700.99	1721.58	1720.52	1699.65	1690.34	1692.39	1699.87	1705.37	1715.42	1722.96	1705.4
1990	1725.20	1732.10	1730.59	1725.59	1725.56	1719.49	1700.20	1694.64	1719.33	1730.82	1736.43	1742.02	1723.4
1991	1731.17	1734.76	1746.09	1747.19	1747.69	1732.10	1709.76	1709.53	1721.06	1726.39	1738.01	1746.30	1732.2
1992	1753.51	1752.49	1752.23	1748.22	1739.92	1745.75	1728.26	1716.18	1732.61	1736.59	1741.76	1749.89	1741.5

^aMethane mixing ratios are expressed in parts per billion (10⁹) (ppb). Monthly means are based only on those samples representative of background conditions. They were determined by first fitting a curve to the data [see Steele et al. (1992) for details of the curve fits]. To ensure that the data used in the curve fits were evenly spaced, the following guidelines were used. If a flask was analyzed more than once, all aliquots were averaged and the resulting mean was plotted as a single measurement. If both members of a flask pair were analyzed or if two pairs of flasks were sampled simultaneously and then analyzed, all aliquots from the flasks were averaged and their mean again plotted as a single measurement. Weekly values were extracted from the curve fits, and all values in each month were averaged to obtain the monthly means. Annual averages are based on the monthly means.

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Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

CAPE MEARES

Trends

The sampling site at Cape Meares, Oregon, U.S.A., is operated in cooperation with the Oregon Graduate Institute of Science and Technology. The annual mean CH₄ mixing ratio at Cape Meares rose from 1698.4 parts per billion (ppb) in 1984 to 1776.5 ppb in 1992. The associated average growth rate over the period of record (May 1983–December 1992) was 10.9 ppb/year. Khalil and Rasmussen (1983), on the basis of in situ measurements of CH₄ over a 3-year period at Cape Meares, found that each annual cycle exhibited two minima and two maxima; the major minimum occurred during the northern summer, and the maxima occurred in spring and fall. Steele et al. (1987) reported that, on the basis of data for 1983 and 1984, all five of the northernmost NOAA/CMDL sites (Cape Meares, Cold Bay, Station "M," Barrow, and Mould Bay) exhibited major seasonal minima during the northern summer.

Monthly mixing ratios of atmospheric CH₄ at Cape Meares.

CITE AS: Dlugokencky, E.J., P.M. Lang, K.A. Masarie, and L.P. Steele. 1994. Atmospheric CH₄ records from sites in the NOAA/CMDL air sampling network. pp. 274–350. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric Methane

Atmospheric CH₄ records from sites in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

CAPE MEARES

Cape Meares
Oregon, U.S.A.
Promontory seashore
45°29' N, 123°58' W
30 m above MSL

Mixing Ratios of Atmospheric CH₄

CH₄ mixing ratios^a at Cape Meares (ppb)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1983					1669.92	1660.39	1660.55	1656.24	1673.97	1692.08	1694.97	1696.62	
1984	1678.55	1681.01	1703.25	1707.60	1695.74	1685.94	1671.78	1669.26	1710.84	1731.16	1717.62	1723.56	1698.4
1985	1715.53	1697.52	1718.45	1729.29	1708.63	1686.62	1670.18	1681.86	1715.76	1722.37	1717.89	1722.42	1707.5
1986	1720.04	1708.40	1715.72	1732.55	1725.69	1711.27	1688.56	1681.97	1723.18	1743.42	1732.19	1734.69	1717.5
1987	1735.36	1732.86	1740.34	1739.59	1737.22	1730.13	1710.38	1703.91	1728.46	1748.49	1746.01	1751.37	1733.5
1988	1758.38	1755.62	1758.62	1757.82	1746.54	1739.09	1731.42	1726.59	1741.85	1750.96	1747.85	1751.87	1747.1
1989	1764.83	1764.06	1751.60	1751.27	1757.22	1750.56	1735.51	1741.27	1759.98	1759.98	1764.77	1771.90	1756.0
1990	1760.38	1759.40	1766.60	1761.74	1759.02	1756.35	1737.03	1736.36	1762.68	1770.29	1771.71	1778.68	1760.2
1991	1768.03	1770.27	1779.39	1775.19	1774.24	1771.35	1759.11	1743.69	1741.02	1774.07	1786.25	1781.79	1768.4
1992	1785.89	1781.94	1781.25	1789.16	1786.43	1764.16	1753.10	1763.35	1777.47	1776.83	1776.89	1785.23	1776.5

^aMethane mixing ratios are expressed in parts per billion (10⁹) (ppb). Monthly means are based only on those samples representative of background conditions. They were determined by first fitting a curve to the data [see Steele et al. (1992) for details of the curve fits]. To ensure that the data used in the curve fits were evenly spaced, the following guidelines were used. If a flask was analyzed more than once, all aliquots were averaged and the resulting mean was plotted as a single measurement. If both members of a flask pair were analyzed or if two pairs of flasks were sampled simultaneously and then analyzed, all aliquots from the flasks were averaged and their mean again plotted as a single measurement. Weekly values were extracted from the curve fits, and all values in each month were averaged to obtain the monthly means. Annual averages are based on the monthly means.

These data are available in electronic form from CDIAC and in NDP-038 (Steele and Lang 1991). Data from individual flask measurements may be obtained electronically from P.M. Lang or E.J. Dlugokencky at NOAA/CMDL.

CITE AS: Dlugokencky, E.J., P.M. Lang, K.A. Masarie, and L.P. Steele. 1994. Atmospheric CH₄ records from sites in the NOAA/CMDL air sampling network. pp. 274–350. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

CHRISTMAS ISLAND

Trends

The trace gas monitoring site at Christmas Island, located in the Kiribati island group in the western Pacific Ocean, is operated in cooperation with Scripps Institution of Oceanography. The annual mean CH₄ mixing ratio at Christmas Island rose from 1616.0 parts per billion (ppb) in 1985 to 1692.4 ppb in 1992. Over the period of record at this site (1984–92), the average growth rate was 10.5 ppb/year. Because of the climatology of the convergence zone of surface winds in the central Pacific Ocean, atmospheric CH₄ mixing ratios from Christmas Island should be typical of those found in southern tropical latitudes.

Steele et al. (1987) reported that the CH₄ mixing ratios at Christmas Island during the austral winter and spring of 1984 agreed closely with measurements made at similar times at several locations in the Southern Hemisphere. The elevated mixing ratios during March and April 1984 were almost certainly caused by the influence of air from north of the Intertropical Convergence Zone (ITCZ), and the elevated mixing ratios in the first few months of 1985 may have been caused by the southward movement of the ITCZ or by an irregular intrusion of northern air (Steele et al. 1987).

Monthly mixing ratios of atmospheric CH₄ at Christmas Island.

CITE AS: Dlugokencky, E.J., P.M. Lang, K.A. Masarie, and L.P. Steele. 1994. Atmospheric CH₄ records from sites in the NOAA/CMDL air sampling network. pp. 274–350. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

CHRISTMAS ISLAND

Christmas Island
Kiribati
Pacific Ocean
Island seashore
1°42' N, 157° 10' W
3 m above MSL

Mixing Ratios of Atmospheric CH₄CH₄ mixing ratios^a at Christmas Island (ppb)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1984			1630.35	1633.35	1614.82	1594.85	1597.55	1598.36	1597.61	1598.79	1601.71	1619.58	
1985	1622.17	1620.31	1627.85	1622.78	1613.72	1610.91	1607.75	1608.29	1612.02	1612.79	1613.34	1622.22	1616.0
1986	1628.66	1628.10	1642.68	1649.28	1628.14	1619.08	1621.66	1622.56	1622.24	1618.35	1622.69	1632.40	1627.7
1987	1633.68	1635.66	1651.90	1657.06	1642.58	1635.38	1634.63	1631.94	1629.95	1635.50	1639.66	1641.03	1639.2
1988	1654.85	1664.92	1660.55	1646.24	1636.55	1635.71	1642.65	1646.95	1644.23	1646.58	1651.20	1656.27	1648.8
1989	1663.35	1674.15	1681.80	1673.92	1659.89	1653.34	1655.69	1656.72	1653.72	1655.77	1661.28	1661.10	1662.6
1990	1667.51	1683.70	1684.10	1662.95	1655.23	1659.73	1663.89	1666.22	1665.34	1663.14	1664.63	1672.86	1667.5
1991	1678.31	1678.92	1675.69	1672.30	1672.39	1671.62	1673.90	1679.83	1677.76	1676.71	1683.27	1692.62	1677.8
1992	1708.19	1709.51	1700.26	1701.32	1697.10	1683.41	1682.18	1686.67	1685.15	1685.93	1684.05	1682.26	1692.4

^aMethane mixing ratios are expressed in parts per billion (10⁹) (ppb). Monthly means are based only on those samples representative of background conditions. They were determined by first fitting a curve to the data [see Steele et al. (1992) for details of the curve fits]. To ensure that the data used in the curve fits were evenly spaced, the following guidelines were used. If a flask was analyzed more than once, all aliquots were averaged and the resulting mean was plotted as a single measurement. If both members of a flask pair were analyzed or if two pairs of flasks were sampled simultaneously and then analyzed, all aliquots from the flasks were averaged and their mean again plotted as a single measurement. Weekly values were extracted from the curve fits, and all values in each month were averaged to obtain the monthly means. Annual averages are based on the monthly means.

These data are available in electronic form from CDIAC and in NDP-038 (Steele and Lang 1991). Data from individual flask measurements may be obtained electronically from P.M. Lang or E.J. Dlugokencky at NOAA/CMDL.

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Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

COLD BAY

Trends

The sampling site at Cold Bay, lying near the tip of the Alaskan Peninsula, is operated in cooperation with the National Weather Service (U.S.A.). The annual mean CH₄ mixing ratio at Cold Bay rose from 1707.4 parts per billion (ppb) in 1984 to 1794.3 ppb in 1992. The associated average growth rate over the period of record (May 1983–December 1992) was 10.8 ppb/year. Steele et al. (1987) found that, on the basis of data for 1983 and 1984, the CH₄ records from the five northernmost NOAA/CMDL sites (Cold Bay, Cape Meares, Station "M," Barrow, and Mould Bay) exhibited major seasonal minima during the northern summer. Secondary minima were also apparent but not as well defined.

Monthly mixing ratios of atmospheric CH₄ at Cold Bay.

CITE AS: Dlugokencky, E.J., P.M. Lang, K.A. Masarie, and L.P. Steele. 1994. Atmospheric CH₄ records from sites in the NOAA/CMDL air sampling network. pp. 274–350. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

COLD BAY

Cold Bay
Alaska, U.S.A.
Treeless peninsula
55°12' N, 162°43' W
25 m above MSL

Mixing Ratios of Atmospheric CH₄CH₄ mixing ratios^a at Cold Bay (ppb)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1983					1683.63	1677.76	1666.46	1673.07	1702.97	1712.01	1702.91	1697.94	
1984	1706.42	1728.69	1724.75	1708.47	1703.23	1688.40	1676.07	1692.33	1711.26	1716.36	1719.24	1719.52	1707.4
1985	1717.26	1726.67	1735.65	1734.14	1728.29	1713.56	1694.91	1707.69	1729.54	1732.41	1725.45	1726.20	1722.5
1986	1740.45	1742.77	1738.86	1742.23	1739.83	1726.75	1708.88	1718.64	1750.98	1752.98	1735.88	1741.23	1736.5
1987	1746.78	1739.90	1745.32	1753.16	1748.78	1737.12	1720.02	1725.89	1755.95	1763.22	1757.07	1757.47	1746.1
1988	1758.04	1761.34	1764.58	1764.23	1758.30	1743.69	1742.07	1747.49	1752.70	1763.31	1765.40	1770.46	1757.7
1989	1774.44	1762.73	1763.31	1773.27	1768.06	1749.17	1733.66	1747.15	1770.33	1769.33	1771.73	1781.22	1763.9
1990	1786.72	1787.31	1779.46	1775.22	1774.95	1763.25	1752.94	1767.65	1786.81	1792.62	1795.43	1783.77	1779.0
1991	1779.77	1792.24	1794.12	1790.59	1785.86	1773.08	1764.83	1782.91	1797.23	1797.75	1801.11	1806.72	1788.4
1992	1804.62	1800.65	1803.12	1803.54	1797.90	1784.20	1770.78	1776.01	1792.97	1800.28	1800.71	1796.94	1794.3

^aMethane mixing ratios are expressed in parts per billion (10⁹) (ppb). Monthly means are based only on those samples representative of background conditions. They were determined by first fitting a curve to the data [see Steele et al. (1992) for details of the curve fits]. To ensure that the data used in the curve fits were evenly spaced, the following guidelines were used. If a flask was analyzed more than once, all aliquots were averaged and the resulting mean was plotted as a single measurement. If both members of a flask pair were analyzed or if two pairs of flasks were sampled simultaneously and then analyzed, all aliquots from the flasks were averaged and their mean again plotted as a single measurement. Weekly values were extracted from the curve fits, and all values in each month were averaged to obtain the monthly means. Annual averages are based on the monthly means.

These data are available in electronic form from CDIAC and in NDP-038 (Steele and Lang 1991). Data from individual flask measurements may be obtained electronically from P.M. Lang or E.J. Dlugokencky at NOAA/CMDL.

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Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

GUAM

Trends

The NOAA/CMDL sampling site at Guam, in the Mariana Islands, is operated in cooperation with the University of Guam. The annual mean atmospheric CH₄ mixing ratio at Guam rose from 1624.8 parts per billion (ppb) in 1984 to 1726.2 ppb in 1992. The mixing ratio at this site increased at an average rate of 12.1 ppb/year over the period of record (May 1983–December 1992). Steele et al. (1987) found a pronounced minimum in the CH₄ mixing ratios for Guam in the late northern summer, on the basis of data for 1983 and 1984, but found no evidence of a secondary minimum in either year.

Monthly mixing ratios of atmospheric CH₄ at Guam.

CITE AS: Dlugokencky, E.J., P.M. Lang, K.A. Masarie, and L.P. Steele. 1994. Atmospheric CH₄ records from sites in the NOAA/CMDL air sampling network. pp. 274–350. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

GUAM

Guam, Mariana Islands
U.S. Territory
Pacific Ocean
Island seashore
13°26' N, 144°47' E
2 m above MSL

Mixing Ratios of Atmospheric CH₄CH₄ mixing ratios^a at Guam (ppb)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1983					1623.19	1622.67	1603.44	1585.59	1608.41	1628.50	1631.70	1624.08	
1984	1626.92	1637.54	1632.08	1625.24	1621.65	1618.93	1609.35	1602.71	1616.27	1626.83	1633.26	1648.97	1624.8
1985	1649.73	1658.13	1663.04	1644.76	1632.90	1631.59	1627.74	1627.50	1639.90	1657.53	1670.42	1670.06	1648.0
1986	1673.14	1674.26	1672.42	1677.72	1664.47	1657.87	1658.27	1647.53	1648.62	1667.50	1683.44	1685.76	1667.6
1987	1687.98	1686.58	1685.67	1691.16	1691.24	1671.38	1655.42	1653.93	1665.36	1684.05	1688.42	1698.38	1680.0
1988	1699.73	1700.73	1694.15	1684.44	1681.19	1663.98	1655.37	1656.79	1654.57	1668.54	1697.77	1701.71	1680.1
1989	1701.77	1714.48	1715.41	1703.49	1680.16	1673.03	1665.87	1664.53	1681.65	1699.15	1710.16	1712.27	1694.2
1990	1714.15	1721.79	1721.45	1716.01	1708.10	1692.76	1681.16	1687.23	1699.11	1710.54	1729.09	1734.15	1709.3
1991	1738.28	1743.85	1730.38	1716.35	1713.75	1705.50	1691.08	1686.40	1695.47	1718.29	1738.07	1742.48	1718.1
1992	1733.77	1737.95	1743.60	1735.00	1731.78	1718.30	1701.47	1698.72	1705.45	1722.43	1740.51	1746.94	1726.2

^aMethane mixing ratios are expressed in parts per billion (10⁹) (ppb). Monthly means are based only on those samples representative of background conditions. They were determined by first fitting a curve to the data [see Steele et al. (1992) for details of the curve fits]. To ensure that the data used in the curve fits were evenly spaced, the following guidelines were used. If a flask was analyzed more than once, all aliquots were averaged and the resulting mean was plotted as a single measurement. If both members of a flask pair were analyzed or if two pairs of flasks were sampled simultaneously and then analyzed, all aliquots from the flasks were averaged and their mean again plotted as a single measurement. Weekly values were extracted from the curve fits, and all values in each month were averaged to obtain the monthly means. Annual averages are based on the monthly means.

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Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

HALLEY BAY

Trends

The monitoring site at Halley Bay, Antarctica, is operated in cooperation with the British Antarctic Survey. Over the period of record (1983–91), the CH₄ mixing ratio at Halley Bay showed an average growth rate of 11.9 parts per billion (ppb) per year. Steele et al. (1987) reported that the CH₄ record from Halley Bay was similar to records from the other NOAA/CMDL sites in the Southern Hemisphere. Furthermore, the CH₄ data from Halley Bay exhibited the same phase and seasonal cycle amplitude observed at the other Southern Hemisphere sites.

Monthly mixing ratios of atmospheric CH₄ at Halley Bay.

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Atmospheric Methane
Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

HALLEY BAY

*Halley Bay
Antarctica
Barren seashore
75°40' S, 25°30' W
10 m above MSL*

Mixing Ratios of Atmospheric CH₄

CH₄ mixing ratios^a at Halley Bay (ppb)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1983	1541.64	1536.87	1536.81	1541.35	1550.89	1563.02	1571.44	1574.84	1577.27	1578.27	1574.95	1569.13	
1984	1560.40	1556.63	1558.51					1589.84	1591.58	1591.98	1587.98	1581.05	
1985	1572.68	1570.64				1588.24	1593.77	1597.51	1603.62	1606.62	1602.56	1594.32	
1986	1581.12	1571.86	1573.29	1579.76	1584.32	1593.89	1606.60	1610.72	1612.51	1613.96	1611.32	1601.92	1595.5
1987	1589.82	1585.20	1589.33	1595.57	1601.37	1613.64	1621.52	1621.43					
1988	1610.21	1604.48	1605.85	1609.52	1615.51	1627.43	1636.10	1638.65	1641.87	1643.68	1640.20	1632.30	1625.7
1989	1623.27	1616.93	1617.04	1619.84	1625.03	1636.23	1644.12				1647.54	1640.03	
1990	1630.70	1624.76				1643.29	1651.39	1654.75	1658.84				
1991								1660.67	1664.25				

^aMethane mixing ratios are expressed in parts per billion (10⁹) (ppb). Monthly means are based only on those samples representative of background conditions. They were determined by first fitting a curve to the data [see Steele et al. (1992) for details of the curve fits]. To ensure that the data used in the curve fits were evenly spaced, the following guidelines were used. If a flask was analyzed more than once, all aliquots were averaged and the resulting mean was plotted as a single measurement. If both members of a flask pair were analyzed or if two pairs of flasks were sampled simultaneously and then analyzed, all aliquots from the flasks were averaged and their mean again plotted as a single measurement. Weekly values were extracted from the curve fits, and all values in each month were averaged to obtain the monthly means. Annual averages are based on the monthly means.

These data are available in electronic form from CDIAC and in NDP-038 (Steele and Lang 1991). Data from individual flask measurements may be obtained electronically from P.M. Lang or E.J. Dlugokencky at NOAA/CMDL.

CITE AS: Dlugokencky, E.J., P.M. Lang, K.A. Masarie, and L.P. Steele. 1994. Atmospheric CH₄ records from sites in the NOAA/CMDL air sampling network. pp. 274–350. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

IZAÑA

Trends

The NOAA/CMDL monitoring site on the Canary Islands is located at the Izaña Observatory at Tenerife and is operated in cooperation with the observatory. Air sampling for determining atmospheric CH₄ began at this site in November 1991, and the record contains only 14 months of data. Although the period is too short to show a trend, the values are consistent with those obtained at other Northern Hemisphere sites at this latitude.

Monthly mixing ratios of atmospheric CH₄ at Izaña.

CITE AS: Dlugokencky, E.J., P.M. Lang, K.A. Masarie, and L.P. Steele. 1994. Atmospheric CH₄ records from sites in the NOAA/CMDL air sampling network. pp. 274–350. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric Methane

Atmospheric CH₄ records from sites in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

IZAÑA

Izaña
Canary Islands, Spain
28°18' N, 16°29' W
2300 m above MSL

Mixing Ratios of Atmospheric CH₄

CH₄ mixing ratios^a at Izaña (ppb)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1991											1754.75	1757.13	
1992	1752.66	1748.50	1756.52	1751.20	1747.31	1746.85	1730.14	1730.31	1748.00	1752.36	1748.25	1752.20	1746.8

^aMethane mixing ratios are expressed in parts per billion (10⁹) (ppb). Monthly means are based only on those samples representative of background conditions. They were determined by first fitting a curve to the data [see Steele et al. (1992) for details of the curve fits]. To ensure that the data used in the curve fits were evenly spaced, the following guidelines were used. If a flask was analyzed more than once, all aliquots were averaged and the resulting mean was plotted as a single measurement. If both members of a flask pair were analyzed or if two pairs of flasks were sampled simultaneously and then analyzed, all aliquots from the flasks were averaged and their mean again plotted as a single measurement. Weekly values were extracted from the curve fits, and all values in each month were averaged to obtain the monthly means. Annual averages are based on the monthly means.

These data are available in electronic form from CDIAC and in NDP-038 (Steele and Lang 1991). Data from individual flask measurements may be obtained electronically from P.M. Lang or E.J. Dlugokencky at NOAA/CMDL.

CITE AS: Dlugokencky, E.J., P.M. Lang, K.A. Masarie, and L.P. Steele. 1994. Atmospheric CH₄ records from sites in the NOAA/CMDL air sampling network. pp. 274–350. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

KEY BISCAYNE

Trends

The annual mean CH₄ mixing ratio at Key Biscayne, Florida, U.S.A., rose from 1667.2 parts per billion (ppb) in 1984 to 1755.0 ppb in 1992. The associated average growth rate over the period of record (October 1983–December 1992) was 10.9 ppb/year. According to Steele et al. (1987), it is difficult to interpret the CH₄ data from Key Biscayne because of changes in sampling frequency, the proximity of the site to urban Miami, and the large degree of scatter shown by the Key Biscayne record. Nevertheless, the CH₄ data from Key Biscayne indicate a seasonal minimum during the summer months. In addition, the annual mean mixing ratios reported for this site are consistent with those from other northern NOAA/CMDL sites. However, because of difficulties and questions concerning the suitability of the site for monitoring background measurements, NOAA/CMDL complemented the southern Florida site by starting a sampling site at Midway Islands in 1985. The site at Midway Islands is at a comparable latitude (28° N) to the Key Biscayne site and is believed to be suitable for obtaining background measurements.

Monthly mixing ratios of atmospheric CH₄ at Key Biscayne.

CITE AS: Dlugokencky, E.J., P.M. Lang, K.A. Masarie, and L.P. Steele. 1994. Atmospheric CH₄ records from sites in the NOAA/CMDL air sampling network. pp. 274–350. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric Methane
Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

KEY BISCAYNE

Key Biscayne
Florida, U.S.A.
Coastal island
seashore
25°40' N, 80°12' W
3 m above MSL

Mixing Ratios of Atmospheric CH₄

CH₄ mixing ratios^a at Key Biscayne (ppb)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1983										1653.24	1668.44	1665.55	
1984	1682.11	1670.27	1650.62	1663.53	1667.11	1654.16	1642.75	1649.35	1672.49	1684.63	1683.46	1685.04	1667.2
1985	1698.83	1688.72	1681.64	1695.14	1688.88	1662.54	1645.16	1647.01	1666.33	1683.59	1691.75	1704.43	1679.5
1986	1707.00	1702.87	1715.08	1723.60	1698.43	1666.77	1659.40	1654.81	1671.83	1698.04	1696.09	1705.84	1691.6
1987	1716.43	1718.08	1722.34	1715.20	1691.25	1673.64	1675.10	1682.39	1709.83	1732.75	1716.89	1718.84	1706.6
1988	1733.71	1720.66	1714.68	1724.14	1717.77	1706.37	1694.95	1683.22	1711.98	1748.20	1745.93	1740.29	1719.8
1989	1727.89	1717.19	1718.51	1732.06	1732.85	1704.47	1691.05	1690.21	1707.52	1737.12	1751.76	1752.91	1721.9
1990	1744.81	1740.92	1745.48	1754.82	1743.97	1726.75	1725.23	1716.19	1721.94	1756.92	1773.96	1754.34	1742.0
1991	1746.99	1752.22	1754.79	1741.19	1723.33	1713.74	1705.16	1711.62	1731.67	1741.76	1758.93	1778.60	1738.2
1992	1779.54	1764.61	1761.88	1773.11	1761.08	1732.98	1719.57	1712.03	1743.09	1777.37	1771.21	1763.57	1755.0

^aMethane mixing ratios are expressed in parts per billion (10⁹) (ppb). Monthly means are based only on those samples representative of background conditions. They were determined by first fitting a curve to the data [see Steele et al. (1992) for details of the curve fits]. To ensure that the data used in the curve fits were evenly spaced, the following guidelines were used. If a flask was analyzed more than once, all aliquots were averaged and the resulting mean was plotted as a single measurement. If both members of a flask pair were analyzed or if two pairs of flasks were sampled simultaneously and then analyzed, all aliquots from the flasks were averaged and their mean again plotted as a single measurement. Weekly values were extracted from the curve fits, and all values in each month were averaged to obtain the monthly means. Annual averages are based on the monthly means.

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Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

MACE HEAD

Trends

The collection of flask air samples at Mace Head, Ireland, for the NOAA/CMDL program began in June 1991. The site at Mace Head is operated in cooperation with the University College Atmospheric Research Station. The record is as yet too short to determine a meaningful trend; however, the CH₄ mixing ratios thus far obtained are consistent with those obtained at other Northern Hemisphere sites at this latitude.

Monthly mixing ratios of atmospheric CH₄ at Mace Head.

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Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

MACE HEAD

Mace Head
County Galway, Ireland
53°20' N, 09°54' W
25 m above MSL

Mixing Ratios of Atmospheric CH₄CH₄ mixing ratios^a at Mace Head (ppb)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1991						1773.00	1765.25	1772.39	1772.90	1781.95	1792.70	1786.01	
1992	1781.32	1782.36	1779.95	1787.75	1788.66	1777.43	1772.15	1773.12	1777.87	1786.62	1791.19	1788.69	1782.2

^aMethane mixing ratios are expressed in parts per billion (10⁹) (ppb). Monthly means are based only on those samples representative of background conditions. They were determined by first fitting a curve to the data [see Steele et al. (1992) for details of the curve fits]. To ensure that the data used in the curve fits were evenly spaced, the following guidelines were used. If a flask was analyzed more than once, all aliquots were averaged and the resulting mean was plotted as a single measurement. If both members of a flask pair were analyzed or if two pairs of flasks were sampled simultaneously and then analyzed, all aliquots from the flasks were averaged and their mean again plotted as a single measurement. Weekly values were extracted from the curve fits, and all values in each month were averaged to obtain the monthly means. Annual averages are based on the monthly means.

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MAUNA LOA

Trends

The annual mean CH₄ mixing ratio at Mauna Loa Observatory in Hawaii, U.S.A., increased from 1635.6 parts per billion (ppb) in 1984 to 1724.0 ppb in 1992. Over the period of record (1983–92), the mixing ratio increased at an average rate of 11.4 ppb/year. Steele et al. (1987) compared the CH₄ data from Mauna Loa with those from Cape Kumukahi (also located on the island of Hawaii) and found a significant vertical gradient in CH₄ mixing ratio: the long-term average mixing ratios at Mauna Loa (3397 m above MSL) were ~1.5% lower than those at Cape Kumukahi (3 m above MSL). Using fitted cubic spline functions, Steele et al. (1987) also showed that both sites exhibited two minima and two maxima each year at times consistent with those reported by Khalil and Rasmussen (1983).

Monthly mixing ratios of atmospheric CH₄ at Mauna Loa.

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Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

MAUNA LOA

Mauna Loa
Hawaii, U.S.A.
Barren volcanic
mountain slope
19°32' N, 155°35' W
3397 m above MSL

Mixing Ratios of Atmospheric CH₄CH₄ mixing ratios^a at Mauna Loa (ppb)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1983					1617.02	1613.42	1613.30	1611.48	1628.50	1643.29	1637.82	1634.17	
1984	1638.62	1636.08	1635.57	1637.39	1628.76	1613.44	1609.86	1622.01	1641.73	1654.22	1656.74	1652.71	1635.6
1985	1643.73	1647.30	1658.99	1655.41	1647.81	1639.74	1633.69	1634.58	1648.72	1661.10	1659.93	1657.55	1649.0
1986	1655.93	1647.65	1651.59	1668.22	1665.03	1664.43	1661.57	1650.09	1660.66	1670.47	1671.66	1677.45	1661.9
1987	1671.63	1669.84	1674.39	1675.85	1674.73	1666.86	1660.61	1658.49	1661.53	1681.49	1695.63	1686.69	1673.0
1988	1677.35	1680.56	1685.43	1687.41	1685.02	1677.53	1666.86	1671.92	1680.35	1687.51	1699.62	1705.50	1683.4
1989	1700.59	1691.87	1694.25	1702.60	1703.45	1693.41	1680.31	1687.74	1700.54	1701.33	1705.65	1709.47	1697.7
1990	1706.47	1707.52	1712.44	1716.05	1712.61	1701.53	1692.07	1696.24	1711.82	1715.34	1719.44	1727.70	1710.1
1991	1712.16	1710.69	1725.88	1728.03	1726.19	1718.92	1708.80	1700.55	1712.66	1730.70	1728.83	1730.78	1719.7
1992	1734.38	1729.06	1730.75	1731.24	1723.07	1721.73	1715.32	1705.11	1709.47	1719.06	1733.32	1736.36	1724.0

^aMethane mixing ratios are expressed in parts per billion (10⁹) (ppb). Monthly means are based only on those samples representative of background conditions. They were determined by first fitting a curve to the data [see Steele et al. (1992) for details of the curve fits]. To ensure that the data used in the curve fits were evenly spaced, the following guidelines were used. If a flask was analyzed more than once, all aliquots were averaged and the resulting mean was plotted as a single measurement. If both members of a flask pair were analyzed or if two pairs of flasks were sampled simultaneously and then analyzed, all aliquots from the flasks were averaged and their mean again plotted as a single measurement. Weekly values were extracted from the curve fits, and all values in each month were averaged to obtain the monthly means. Annual averages are based on the monthly means.

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Atmospheric CH₄ records from sites in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

MIDWAY ISLANDS

Trends

The Midway Islands sampling site, located on Sand Island, is operated in cooperation with the U.S. Department of the Navy. Atmospheric trace gas monitoring at the site began in 1985 and was initially intended to complement the NOAA/CMDL monitoring program at Key Biscayne (Florida), which is located at about the same latitude as Sand Island. The annual mean atmospheric CH₄ mixing ratio at Midway Islands rose from 1700.5 parts per billion (ppb) in 1986 to 1756.5 ppb in 1992. The associated average rate of increase at this site was 10.2 ppb/year over the period of record (1985–92).

Monthly mixing ratios of atmospheric CH₄ at Midway Islands.

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Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

MIDWAY ISLANDS

Midway Islands (Sand Island)
Pacific Ocean
Island seashore
28°13' N, 177°22' W
4 m above MSL

Mixing Ratios of Atmospheric CH₄CH₄ mixing ratios^a at Midway Islands (ppb)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1985								1645.72	1670.90	1695.90	1699.58	1693.93	
1986	1703.41	1715.68	1703.93	1692.83	1703.72	1692.72	1670.24	1671.88	1700.62	1713.22	1714.80	1725.39	1700.5
1987	1729.08	1722.84	1725.66	1733.79	1727.71	1709.90	1689.93	1692.54	1716.21	1732.47	1727.49	1724.10	1719.4
1988	1733.25	1736.96	1724.10	1721.70	1715.30	1700.61	1690.45	1687.43	1713.45	1726.46	1726.59	1727.72	1717.0
1989	1724.65	1733.20	1745.98	1744.45	1729.49	1715.63	1696.80	1703.03	1731.06	1739.29	1739.40	1751.69	1729.7
1990	1755.17	1757.11	1761.49	1759.40	1744.27	1717.95	1707.00	1710.08	1722.01	1750.09	1764.66	1754.68	1741.8
1991	1757.95	1772.65	1770.50	1769.14	1764.14	1739.98	1718.01	1706.91	1730.37	1768.98	1774.01	1769.45	1753.1
1992	1774.26	1778.84	1778.40	1773.95	1762.08	1741.42	1726.56	1720.69	1736.86	1756.93	1761.27	1768.45	1756.5

^aMethane mixing ratios are expressed in parts per billion (10⁹) (ppb). Monthly means are based only on those samples representative of background conditions. They were determined by first fitting a curve to the data [see Steele et al. (1992) for details of the curve fits]. To ensure that the data used in the curve fits were evenly spaced, the following guidelines were used. If a flask was analyzed more than once, all aliquots were averaged and the resulting mean was plotted as a single measurement. If both members of a flask pair were analyzed or if two pairs of flasks were sampled simultaneously and then analyzed, all aliquots from the flasks were averaged and their mean again plotted as a single measurement. Weekly values were extracted from the curve fits, and all values in each month were averaged to obtain the monthly means. Annual averages are based on the monthly means.

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Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

MOULD BAY

Trends

The sampling site at Mould Bay, Northwest Territories, Canada, is operated in cooperation with the Canadian Atmospheric Environment Service of Environment Canada. The annual mean CH₄ mixing ratio at Mould Bay rose from 1714.7 parts per billion (ppb) in 1984 to 1802.8 ppb in 1992. Over the period of record (April 1983–December 1992), the mixing ratio increased at a rate of 11.7 ppb/year. Steele et al. (1987) reported that the five northernmost NOAA/CMDL sites (Mould Bay, Cape Meares, Cold Bay, Station "M," and Barrow) exhibited major seasonal minima during the northern summer months. Steele et al. (1987) also found that the degree of scatter for the CH₄ data from Mould Bay was much less than that from the other four northernmost sites and suggested that this reduced scatter may reflect the greater distances between the Mould Bay site and significant sources of CH₄.

Monthly mixing ratios of atmospheric CH₄ at Mould Bay.

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Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

MOULD BAY

*Mould Bay
Northwest Territories
Canada
Island seashore
76°15' N, 119°21' W
58 m above MSL*

Mixing Ratios of Atmospheric CH₄CH₄ mixing ratios^a at Mould Bay (ppb)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1983				1691.40	1670.42	1661.63	1663.73	1676.46	1699.07	1706.07	1710.39	1725.45	
1984	1736.95	1736.69	1728.40	1717.05	1704.89	1694.70	1687.95	1692.25	1707.49	1717.11	1720.54	1735.73	1714.7
1985	1742.98	1734.68	1739.58	1744.37	1728.83	1706.23	1698.81	1703.79	1723.34	1747.35	1750.16	1749.45	1730.7
1986	1754.15	1757.48	1761.04	1755.04	1737.47	1723.28	1717.16	1714.70	1731.96	1761.75	1758.56	1768.60	1745.7
1987	1782.43	1771.81	1770.48	1771.62	1755.33	1734.61	1729.28	1734.74	1750.40	1766.56	1769.90	1779.39	1759.6
1988	1788.74	1788.67	1789.70	1784.23	1763.65	1741.46	1733.59	1737.96	1755.86	1774.00	1785.71	1806.85	1770.3
1989	1808.40	1796.67	1795.66	1781.41	1764.98	1752.47	1747.37	1759.88	1770.73	1778.56	1792.80	1806.25	1779.3
1990	1809.44	1812.85	1812.43	1795.60	1782.55	1766.88	1758.13	1763.52	1775.30	1790.11	1798.40	1816.84	1790.1
1991	1838.44	1825.64	1810.56	1800.70	1785.02	1770.35	1771.28	1785.42	1792.52	1802.93	1812.11	1821.15	1801.5
1992	1827.84	1820.11	1812.87	1807.13	1798.96	1786.65	1778.25	1783.20	1788.32	1792.48	1805.61	1833.66	1802.8

^aMethane mixing ratios are expressed in parts per billion (10⁹) (ppb). Monthly means are based only on those samples representative of background conditions. They were determined by first fitting a curve to the data [see Steele et al. (1992) for details of the curve fits]. To ensure that the data used in the curve fits were evenly spaced, the following guidelines were used. If a flask was analyzed more than once, all aliquots were averaged and the resulting mean was plotted as a single measurement. If both members of a flask pair were analyzed or if two pairs of flasks were sampled simultaneously and then analyzed, all aliquots from the flasks were averaged and their mean again plotted as a single measurement. Weekly values were extracted from the curve fits, and all values in each month were averaged to obtain the monthly means. Annual averages are based on the monthly means.

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Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

NIWOT RIDGE

Trends

The NOAA/CMDL monitoring site at Niwot Ridge, located in the Front Range of the Rocky Mountains in north-central Colorado, U.S.A., is operated in cooperation with the University of Colorado's Institute of Arctic and Alpine Research. The annual mean CH₄ mixing ratio at Niwot Ridge rose from 1673.0 parts per billion (ppb) in 1984 to 1756.2 ppb in 1992. The rate of increase in the mixing ratio over the period of record (1983–92) was 10.8 ppb/year. Steele et al. (1987) compared the CH₄ data from Niwot Ridge with data from Azores (the two sites are at similar latitudes) and found that, for extended periods of time, the CH₄ mixing ratios at the high-altitude site of Niwot Ridge were lower than those at the Azores site.

Monthly mixing ratios of atmospheric CH₄ at Niwot Ridge.

CITE AS: Dlugokencky, E.J., P.M. Lang, K.A. Masarie, and L.P. Steele. 1994. Atmospheric CH₄ records from sites in the NOAA/CMDL air sampling network. pp. 274–350. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

NIWOT RIDGE

Niwot Ridge
Colorado, U.S.A.
Alpine mountain
40°03' N, 105°38' W
3475 m above MSL

Mixing Ratios of Atmospheric CH₄CH₄ mixing ratios^a at Niwot Ridge (ppb)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1983						1643.27	1636.30	1629.70	1653.05				
1984		1670.98	1682.35	1684.80	1680.46	1667.01	1660.34	1655.25	1666.70	1688.11	1684.10	1677.80	1673.0
1985	1685.84	1689.98	1682.43	1683.80	1686.80	1665.12	1651.50	1660.64	1680.07	1695.94	1706.21	1699.86	1682.2
1986	1686.76	1699.86	1699.78	1691.09	1701.72	1688.51	1665.60	1667.28	1674.53	1694.78	1703.43	1699.43	1689.2
1987	1700.19	1716.23	1723.70	1705.13	1698.57	1699.81	1692.54	1690.99	1698.86	1708.83	1720.82	1729.63	1707.1
1988	1728.52	1732.21	1730.52	1726.22	1722.05	1708.40	1699.60	1701.85	1713.03	1714.43	1726.31	1735.85	1720.1
1989	1730.30	1729.82	1721.03	1721.49	1729.28	1721.75	1716.10	1714.56	1718.45	1730.57	1743.13	1739.04	1726.2
1990	1734.33	1738.72	1737.10	1734.29	1725.89	1712.72	1715.60	1721.08	1733.05	1744.32	1749.41	1749.92	1733.1
1991	1749.49	1755.78	1754.60	1754.48	1749.75	1735.83	1731.14	1733.45	1746.37	1756.31	1765.80	1767.08	1749.8
1992	1764.46	1769.02	1771.60	1763.35	1755.36	1748.08	1735.81	1736.77	1743.90	1754.65	1767.07	1765.56	1756.2

^aMethane mixing ratios are expressed in parts per billion (10⁹) (ppb). Monthly means are based only on those samples representative of background conditions. They were determined by first fitting a curve to the data [see Steele et al. (1992) for details of the curve fits]. To ensure that the data used in the curve fits were evenly spaced, the following guidelines were used. If a flask was analyzed more than once, all aliquots were averaged and the resulting mean was plotted as a single measurement. If both members of a flask pair were analyzed or if two pairs of flasks were sampled simultaneously and then analyzed, all aliquots from the flasks were averaged and their mean again plotted as a single measurement. Weekly values were extracted from the curve fits, and all values in each month were averaged to obtain the monthly means. Annual averages are based on the monthly means.

These data are available in electronic form from CDIAC and in NDP-038 (Steele and Lang 1991). Data from individual flask measurements may be obtained electronically from P.M. Lang or E.J. Dlugokencky at NOAA/CMDL.

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Atmospheric CH₄ records from sites in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

OLYMPIC PENINSULA

Trends

The monitoring site on the northwestern tip of the Olympic Peninsula, Washington, U.S.A., operated from November 1984 to May 1990 in cooperation with the University of Washington. Because the record is incomplete, annual mean CH₄ mixing ratios are available for only two years, 1986 and 1989. However, it has been possible to calculate an average growth rate of 8.7 parts per billion (ppb) per year for the period of record. Despite the sparsity of the monthly data, the record for Olympic Peninsula exhibits seasonal patterns consistent with records at other Northern Hemisphere sites: yearly minimum mixing ratios occurred during northern summer months, and yearly maximum mixing ratios during winter or early spring months. Following May 1990, atmospheric CH₄ monitoring at the Olympic Peninsula site was discontinued.

Monthly mixing ratios of atmospheric CH₄ at Olympic Peninsula.

CITE AS: Dlugokencky, E.J., P.M. Lang, K.A. Masarie, and L.P. Steele. 1994. Atmospheric CH₄ records from sites in the NOAA/CMDL air sampling network. pp. 274-350. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93. A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric Methane
Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

OLYMPIC PENINSULA

*Olympic Peninsula
Washington, U.S.A.
48°15' N, 124°25' W
488 m above MSL*

Mixing Ratios of Atmospheric CH₄

CH₄ mixing ratios^a at Olympic Peninsula (ppb)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1985				1718.31	1723.67	1714.10	1694.12	1698.25	1722.63	1726.12	1709.11	1707.75	
1986	1713.89	1712.93	1718.01	1734.07	1733.79	1718.65	1696.06	1686.62	1716.25	1739.47	1728.55	1726.57	1719.1
1987	1729.95	1732.07	1738.18	1742.85	1737.68	1724.92	1702.67	1693.78	1735.28				
1988	1755.01	1757.93	1763.06				1712.41	1710.92	1740.04	1759.78	1755.75	1756.64	
1989	1766.54	1763.14	1753.28	1757.42	1757.49	1740.80	1717.60	1724.28	1751.17	1759.32	1756.86	1753.35	1749.6
1990	1762.49	1771.47	1765.87	1761.35	1759.99								

^aMethane mixing ratios are expressed in parts per billion (10⁹) (ppb). Monthly means are based only on those samples representative of background conditions. They were determined by first fitting a curve to the data [see Steele et al. (1992) for details of the curve fits]. To ensure that the data used in the curve fits were evenly spaced, the following guidelines were used. If a flask was analyzed more than once, all aliquots were averaged and the resulting mean was plotted as a single measurement. If both members of a flask pair were analyzed or if two pairs of flasks were sampled simultaneously and then analyzed, all aliquots from the flasks were averaged and their mean again plotted as a single measurement. Weekly values were extracted from the curve fits, and all values in each month were averaged to obtain the monthly means. Annual averages are based on the monthly means.

These data are available in electronic form from CDIAC and in NDP-038 (Steele and Lang 1991). Data from individual flask measurements may be obtained electronically from P.M. Lang or E.J. Dlugokencky at NOAA/CMDL.

CITE AS: Dlugokencky, E.J., P.M. Lang, K.A. Masarie, and L.P. Steele. 1994. Atmospheric CH₄ records from sites in the NOAA/CMDL air sampling network. pp. 274-350. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

PACIFIC OCEAN

Trends

Air sampling for the NOAA/CMDL program has been carried out since December 1986 by the merchant vessel *Southland Star*, operated by Blue Star Line, Ltd. Beginning in May 1990, air sampling has also been carried out by the merchant vessel, *Wellington Star* (also operated by Blue Star Line, Ltd.). Each ship usually sails southward from Los Angeles, passing near Christmas Island, American Samoa, and Fiji en route to its destination in Auckland, New Zealand. Air samples are collected at a latitude of 30° N, and then at every 5° latitude until 35° S. The northward return voyage uses a different track, passing Hawaii en route to Seattle. Air samples are collected at 35° S and then at every 5° latitude northward to 30° N (samples are sometimes also collected at 35° N, 40° N, and 45° N, but data at these latitudes were too sparse to calculate averages). Thus, samples are collected at a minimum of two longitudes for a given latitude. Because the longitudinal variations in CH₄ mixing ratios are considered negligible compared with the latitudinal variations, all samples collected within a given latitudinal band, defined as the center latitude (e.g., 30° N, 0°, 35° S) $\pm$ 2.5°, are considered representative of a single latitude "site." The frequency of sampling on average is ~3 weeks per latitude per ship. Since May 1990, when the Pacific Ocean air sampling program was augmented by the contribution of the *Wellington Star*, the overall frequency of sampling has increased because of the somewhat staggered cruise schedules of the two ships.

The CH₄ mixing ratios at Pacific Ocean shipboard sites exhibit both a temporal trend and a latitudinal gradient. The annual mean mixing ratios for 1987 ranged from 1612.4 parts per billion (ppb) at 25° S to 1714.2 ppb at 30° N. For 1992, the annual mean values ranged from 1668.7 ppb at 25° S to 1769.4 ppb at 30° N. At all latitudes, the mixing ratios increased with time over the period of record (December 1986–December 1992 for all sites except 10° N). For any given year, the annual mean mixing ratios generally decreased along a gradient from north to south. Accordingly, CH₄ levels were consistently highest at the northernmost latitude, 30° N, and they decreased to their minimum values at 25° S. Mixing ratios at latitudes further south (i.e., 30° S and 35° S) were comparable to those at 25° S. Overall, the shipboard CH₄ mixing ratios were consistent with those obtained at land-based sites located at similar latitudes. The shipboard data also exhibited seasonal cycles that were most evident at higher latitudes, particularly in the Southern Hemisphere. This observed seasonality was also in general agreement with results from land-based monitoring sites.

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Atmospheric Methane
Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

PACIFIC OCEAN

Monthly mixing ratios of atmospheric CH₄ at Pacific Ocean shipboard sites.

CITE AS: Dlugokencky, E.J., P.M. Lang, K.A. Masarie, and L.P. Steele. 1994. Atmospheric CH₄ records from sites in the NOAA/CMDL air sampling network. pp. 274-350. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

PACIFIC OCEAN

Monthly mixing ratios of atmospheric CH₄ at Pacific Ocean shipboard sites.

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Atmospheric Methane

Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

PACIFIC OCEAN

*Southland Star and Wellington
Star cruise tracks
Pacific Ocean
Sample collection at 5° latitude
increments from 30° N to 35° S.*

Mixing Ratios of Atmospheric CH₄

CH₄ mixing ratios^a at Pacific Ocean shipboard sites (ppb)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
30° N													
1986													1704.89
1987	1710.01	1710.90	1717.99	1726.12	1719.68	1712.00	1700.87	1696.81	1709.37	1710.60	1721.76	1742.97	1714.2
1988	1745.05	1725.65	1715.65	1719.22	1732.10	1738.16	1705.94	1697.01	1730.32	1740.69	1737.21	1741.58	1727.6
1989	1742.44	1740.31	1738.47	1733.08	1736.54	1739.45	1719.23	1710.57	1731.63	1740.84	1742.05	1742.51	1734.1
1990	1756.97	1759.91	1744.63	1742.74	1740.94	1732.80	1717.76	1712.44	1738.03	1752.42	1751.33	1757.21	1742.4
1991	1757.92	1766.86	1775.38	1769.04	1769.56	1757.69	1734.81	1738.31	1749.34	1763.09	1776.34	1785.27	1761.2
1992	1786.32	1776.17	1777.50	1781.46	1777.59	1767.89	1747.14	1738.70	1755.32	1770.26	1774.03	1785.23	1769.4
25° N													
1986													1696.59
1987	1703.75	1709.05	1702.24	1696.73	1702.55	1709.82	1704.03	1687.68	1693.25	1717.11	1715.78	1725.44	1705.7
1988	1729.61	1724.77	1730.72	1730.99	1726.02	1709.40	1698.75	1712.58	1732.63	1738.09	1733.97	1730.28	1724.8
1989	1712.98	1696.32	1709.74	1726.87	1736.31	1738.65	1711.64	1700.36	1725.41	1737.21	1734.11	1725.27	1721.9
1990	1713.67	1715.76	1733.35	1739.39	1732.11	1726.81	1710.47	1704.70	1731.05	1750.91	1755.28	1748.78	1729.7
1991	1736.02	1738.35	1744.26	1749.73	1763.00	1753.15	1727.47	1726.65	1741.06	1749.49	1753.44	1770.00	1746.2
1992	1782.31	1775.52	1775.27	1776.30	1765.20	1753.04	1741.55	1727.58	1737.15	1755.79	1760.11	1766.62	1759.4
20° N													
1986													1707.35
1987	1713.03	1702.20	1704.37	1704.83	1696.64	1697.39	1688.55	1670.35	1664.21	1672.16	1689.78	1716.63	1693.5
1988	1718.69	1716.14	1717.56	1718.44	1713.69	1700.44	1690.29	1692.62	1701.85	1701.17	1699.19	1702.00	1706.2
1989	1702.00	1699.98	1696.59	1700.81	1723.75	1732.65	1698.34	1678.04	1701.97	1711.66	1705.87	1721.55	1706.2
1990	1747.00	1736.47	1723.57	1733.72	1730.24	1726.25	1709.29	1698.53	1721.37	1738.67	1750.23	1754.92	1730.0
1991	1735.73	1730.11	1742.60	1748.76	1757.47	1746.67	1718.00	1713.77	1728.50	1733.08	1736.36	1759.34	1737.9
1992	1768.17	1759.61	1764.81	1769.10	1765.12	1755.05	1736.00	1721.42	1716.23	1726.52	1748.79	1765.29	1750.0
15° N													
1986													1690.84
1987	1694.57	1695.91	1707.22	1702.94	1682.79	1678.26	1678.15	1665.07	1667.14	1684.65	1690.87	1694.29	1686.9
1988	1700.70	1709.16	1706.85	1697.70	1698.29	1692.27	1679.99	1683.79	1697.26	1700.90	1699.02	1701.35	1697.0
1989	1708.97	1715.15	1703.83	1695.05	1707.76	1708.15	1694.96	1688.41	1697.83	1709.66	1701.14	1693.25	1702.0
1990	1702.15	1699.19	1707.35	1724.38	1726.74	1721.79	1700.52	1693.31	1718.80	1732.14	1730.01	1735.60	1716.2
1991	1729.28	1725.32	1736.98	1739.39	1736.18	1722.36	1702.42	1700.55	1719.92	1727.73	1719.33	1735.47	1724.3
1992	1755.98	1750.61	1747.17	1744.28	1744.09	1737.49	1722.01	1711.50	1707.25	1719.11	1737.63	1741.66	1735.2
10° N													
1987	1680.63	1681.26	1683.06	1675.90	1681.08	1676.15	1657.14	1651.65	1660.58	1672.05	1667.18	1676.17	1671.6
1988	1694.46	1701.82	1693.92	1690.05	1691.30	1675.08	1656.70	1651.69	1651.64	1661.50	1682.14	1697.00	1679.0
1989	1692.91	1691.62	1691.27	1683.64	1689.79	1685.78	1671.63	1669.00	1660.72	1675.51	1695.30	1695.08	1683.1
1990	1700.39	1702.97	1704.45	1703.65	1703.27	1693.63	1679.78	1676.53	1675.76	1675.23	1698.74	1728.30	1695.1
1991	1721.78	1713.63	1723.06	1728.63	1726.85	1714.77	1703.68	1695.12	1693.70	1714.32	1727.72	1735.42	1715.7
1992	1740.72	1738.19	1742.85	1733.16	1727.13	1724.43	1704.12	1690.70	1694.64	1711.53	1729.35	1733.75	1722.8

Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

PACIFIC OCEAN

Mixing Ratios of Atmospheric CH₄ (continued)

CH₄ mixing ratios^a at Pacific Ocean shipboard sites (ppb)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
5° N													
1986													1652.48
1987	1671.63	1670.52	1656.86	1652.46	1652.14	1645.57	1635.76	1634.75	1635.17	1631.68	1633.28	1643.60	1647.1
1988	1663.58	1688.64	1699.43	1676.96	1644.80	1638.88	1643.20	1643.83	1646.31	1651.23	1664.32	1670.81	1660.6
1989	1668.18	1681.14	1690.29	1681.18	1668.10	1658.73	1663.92	1665.54	1656.61	1658.68	1665.80	1667.04	1668.8
1990	1670.32	1687.68	1705.81	1702.88	1692.12	1675.09	1663.85	1672.16	1668.35	1665.33	1672.41	1676.62	1679.3
1991	1684.49	1687.28	1681.99	1687.11	1690.55	1686.88	1678.34	1677.07	1679.86	1682.13	1706.37	1725.17	1689.6
1992	1726.51	1728.68	1725.10	1715.72	1706.95	1695.53	1687.83	1687.08	1688.41	1688.80	1687.49	1687.94	1701.4
Equator													
1986													1640.43
1987	1644.25	1643.76	1645.53	1647.62	1641.91	1629.46	1623.34	1631.36	1635.69	1632.14	1633.80	1632.61	1636.8
1988	1641.67	1666.56	1665.55	1650.52	1646.55	1644.95	1642.93	1640.44	1642.26	1648.77	1662.62	1669.86	1651.4
1989	1675.28	1690.83	1692.83	1676.31	1659.06	1652.71	1661.75	1663.93	1653.80	1656.81	1664.24	1663.01	1667.6
1990	1670.08	1683.44	1688.21	1674.62	1663.08	1660.93	1658.59	1666.69	1669.39	1661.57	1662.89	1670.04	1668.9
1991	1676.34	1674.81	1671.59	1673.05	1670.31	1667.77	1669.58	1672.11	1675.37	1678.80	1691.52	1698.36	1676.6
1992	1696.77	1708.74	1714.47	1695.33	1677.72	1675.24	1680.57	1686.66	1687.33	1682.21	1684.02	1688.45	1689.3
5° S													
1986													1624.64
1987	1629.68	1643.07	1638.24	1627.69	1632.69	1624.53	1621.62	1630.09	1629.80	1631.86	1645.16	1646.84	1633.2
1988	1647.72	1661.18	1657.61	1647.95	1640.94	1639.13	1644.81	1644.94	1645.06	1647.58	1659.66	1666.69	1650.6
1989	1654.89	1666.60	1680.70	1662.83	1650.88	1648.78	1651.06	1654.13	1651.20	1651.49	1659.95	1665.66	1658.6
1990	1669.71	1677.43	1685.86	1671.80	1656.39	1658.32	1656.57	1660.29	1663.33	1658.51	1660.85	1672.96	1666.0
1991	1675.16	1672.69	1669.31	1663.73	1662.54	1666.19	1670.36	1672.50	1671.82	1675.42	1696.21	1700.98	1674.7
1992	1690.66	1694.51	1687.42	1677.44	1675.48	1673.56	1678.81	1682.84	1682.68	1679.72	1676.09	1678.40	1681.1
10° S													
1986													1625.30
1987	1644.03	1640.77	1620.33	1611.27	1609.84	1615.79	1619.97	1622.28	1624.25	1623.97	1623.41	1624.97	1622.2
1988	1632.90	1634.84	1627.50	1626.79	1625.18	1628.01	1640.72	1652.09	1659.14	1658.61	1653.92	1653.97	1641.3
1989	1659.70	1651.40	1641.39	1644.43	1646.26	1644.65	1653.88	1653.16	1647.10	1648.73	1651.09	1653.52	1649.6
1990	1659.81	1664.97	1664.99	1649.44	1643.19	1652.31	1652.03	1653.00	1654.72	1653.25	1654.12	1660.35	1655.1
1991	1665.48	1663.42	1659.76	1658.94	1657.68	1659.17	1668.03	1669.98	1668.68	1671.28	1671.47	1671.93	1665.4
1992	1673.85	1673.37	1668.78	1665.18	1665.63	1669.52	1676.50	1677.35	1675.72	1675.54	1672.34	1674.30	1672.5
15° S													
1986													1612.83
1987	1614.61	1613.92	1604.26	1600.82	1609.74	1617.15	1620.08	1625.80	1626.75	1620.21	1611.87	1609.05	1614.7
1988	1616.18	1617.48	1610.57	1610.88	1617.97	1625.83	1634.50	1636.87	1634.06	1633.48	1632.00	1628.90	1624.9
1989	1637.15	1642.81	1635.37	1641.82	1649.72	1645.35	1647.99	1649.62	1644.72	1645.97	1638.84	1635.68	1643.3
1990	1642.66	1640.08	1633.17	1634.15	1638.21	1644.00	1652.37	1655.20	1652.59	1652.67	1651.42	1649.54	1645.5
1991	1656.26	1662.27	1654.82	1647.34	1653.42	1657.36	1659.49	1668.67	1673.72	1668.65	1663.68	1657.35	1660.4
1992	1659.91	1670.14	1664.19	1660.15	1667.28	1671.76	1675.26	1678.43	1675.27	1671.86	1671.90	1669.09	1669.4
20° S													
1986													1607.94
1987	1603.26	1603.19	1613.68	1609.53	1608.81	1617.73	1620.86	1623.93	1625.30	1621.63	1616.05	1612.71	1614.7
1988	1614.69	1616.93	1613.08	1612.87	1618.79	1624.14	1630.58	1636.55	1638.44	1636.29	1630.60	1625.28	1624.9
1989	1632.99	1641.62	1630.65	1627.80	1641.13	1646.22	1645.39	1646.68	1649.10	1649.69	1641.61	1636.33	1640.6
1990	1641.01	1645.26	1642.64	1636.21	1638.90	1647.21	1652.87	1655.16	1658.54	1656.11	1648.02	1650.04	1647.9
1991	1648.15	1642.00	1646.90	1647.75	1649.03	1656.27	1662.71	1666.08	1669.39	1670.57	1667.65	1662.66	1657.4
1992	1655.88	1657.26	1663.18	1662.58	1665.64	1675.06	1678.30	1677.21	1676.55	1677.40	1672.43	1663.45	1669.0

Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

PACIFIC OCEAN

Mixing Ratios of Atmospheric CH₄ (continued)CH₄ mixing ratios^a at Pacific Ocean shipboard sites (ppb)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
25° S													
1986													1599.28
1987	1597.94	1595.38	1596.76	1606.43	1615.32	1617.18	1619.17	1624.10	1626.47	1624.29	1617.46	1609.46	1612.4
1988	1610.97	1614.65	1610.52	1610.82	1614.91	1620.08	1631.30	1635.63	1634.18	1632.83	1625.97	1617.39	1622.0
1989	1619.38	1622.66	1618.73	1626.72	1639.77	1643.05	1646.12	1650.89	1650.97	1647.05	1643.92	1637.84	1637.0
1990	1631.65	1635.31	1636.84	1635.27	1639.36	1644.16	1650.81	1656.39	1656.43	1655.45	1650.46	1642.32	1644.8
1991	1638.19	1639.84	1642.26	1643.66	1649.55	1655.32	1660.54	1666.91	1671.56	1671.22	1666.04	1660.45	1655.2
1992	1655.96	1653.19	1654.84	1661.28	1666.39	1671.78	1679.40	1679.92	1679.70	1678.69	1670.58	1663.36	1668.7
30° S													
1986													1602.14
1987	1597.11	1592.76	1594.78	1602.62	1614.09	1623.25	1624.86	1623.34	1625.42	1627.94	1625.52	1617.56	1614.1
1988	1608.50	1602.85	1599.72	1603.54	1614.61	1622.99	1631.44	1639.97	1640.19	1638.28	1633.71	1626.90	1622.5
1989	1619.66	1615.92	1618.12	1624.77	1634.48	1642.91	1648.19	1651.15	1650.54	1646.75	1645.55	1640.42	1636.4
1990	1631.76	1628.49	1629.37	1633.86	1637.99	1644.19	1655.33	1659.79	1656.74	1656.40	1650.79	1641.96	1644.3
1991	1637.07	1633.52	1633.25	1641.23	1651.57	1656.58	1661.08	1666.58	1668.99	1670.14	1669.96	1666.72	1654.6
1992	1657.78	1652.52	1654.36	1659.85	1667.40	1673.12	1679.06	1682.55	1682.10	1678.70	1671.31	1665.47	1669.3
35° S													
1986													1603.05
1987	1595.93	1593.66	1595.96	1602.96	1616.30	1623.55	1623.79	1627.28	1630.77	1631.06	1630.62	1622.93	1616.2
1988	1609.44	1603.09	1602.40	1605.09	1616.33	1622.81	1627.07	1636.99	1639.24	1637.86	1638.02	1629.49	1622.8
1989	1619.57	1620.22	1628.59	1634.87	1635.39	1638.01	1646.52	1649.90	1645.10	1644.83	1647.26	1639.58	1637.3
1990	1628.27	1624.12	1627.45	1632.81	1637.85	1645.82	1654.78	1658.91	1658.09	1659.89	1659.16	1646.59	1645.0
1991	1637.91	1638.20	1638.49	1643.12	1653.55	1661.01	1663.18	1668.11	1673.00	1671.64	1672.07	1669.63	1657.2
1992	1659.10	1655.86	1657.36	1659.01	1665.11	1671.74	1677.59	1684.68	1686.73	1683.65	1686.05	1681.30	1672.2

^aMethane mixing ratios are expressed in parts per billion (10⁹) (ppb). Monthly means are based only on those samples representative of background conditions. They were determined by first fitting a curve to the data [see Steele et al. (1992) for details of the curve fits]. To ensure that the data used in the curve fits were evenly spaced, the following guidelines were used. If a flask was analyzed more than once, all aliquots were averaged and the resulting mean was plotted as a single measurement. If both members of a flask pair were analyzed or if two pairs of flasks were sampled simultaneously and then analyzed, all aliquots from the flasks were averaged and their mean again plotted as a single measurement. Weekly values were extracted from the curve fits, and all values in each month were averaged to obtain the monthly means. Annual averages are based on the monthly means.

These data are available in electronic form from CDIAC and in NDP-038 (Steele and Lang 1991). Data from individual flask measurements may be obtained electronically from P.M. Lang or E.J. Dlugokencky at NOAA/CMDL.

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Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

PALMER STATION

Trends

Palmer Station is located on Anvers Island, lying off the western coast of the Antarctic Peninsula. The site is operated in cooperation with the National Science Foundation (U.S.A.). The annual mean CH₄ mixing ratio at Palmer Station increased from 1577.0 parts per billion (ppb) in 1984 to 1667.6 ppb in 1992. Over the period of record (January 1983–December 1992), the CH₄ mixing ratio at Palmer Station grew at an average rate of 11.6 ppb/year. Steele et al. (1987) made direct comparisons of the NOAA/CMDL CH₄ flask air data with the in situ measurements of CH₄ that Robinson et al. (1984) made at Palmer Station during 1982–83 and found that the 1983 data from both records exhibited seasonal cycles similar in phase and amplitude. However, the mixing ratios reported by Robinson et al. (1984) were ~30 ppb lower than those reported by Steele et al. (1987). Robinson et al. (1984) also reported no increasing trend in CH₄ at Palmer Station; this finding differs from the findings of Fraser et al. (1984) and Steele et al. (1987).

Monthly mixing ratios of atmospheric CH₄ at Palmer Station.

CITE AS: Dlugokencky, E.J., P.M. Lang, K.A. Masarie, and L.P. Steele. 1994. Atmospheric CH₄ records from sites in the NOAA/CMDL air sampling network. pp. 274–350. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

PALMER STATION

*Palmer Station
Anvers Island,
Antarctica
Barren island seashore
64°55' S, 64°00' W
10 m above MSL*

Mixing Ratios of Atmospheric CH₄CH₄ mixing ratios^a at Palmer Station (ppb)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1983	1536.65	1530.96	1536.24	1546.49	1552.13	1558.67	1566.33	1574.57	1577.89	1576.73	1574.59	1569.17	
1984	1563.43	1559.63	1560.80	1564.84	1570.23	1577.11	1583.84	1590.71	1591.96	1590.59	1587.92	1580.17	1577.0
1985	1571.95	1566.99	1567.48	1573.90	1580.90	1587.66	1593.10	1598.73	1604.54	1606.62	1604.82	1596.51	1587.9
1986	1587.11	1579.85	1578.41	1584.02	1589.64	1599.05	1607.66	1612.30	1615.70	1616.13	1613.22	1608.27	1599.4
1987	1599.25	1591.06	1592.26	1596.46	1603.01	1612.70	1617.73	1620.19	1624.27	1626.17	1623.26	1616.64	1610.2
1988	1609.71	1603.84	1601.29	1605.89	1614.95	1623.11	1628.55	1635.82	1642.11	1641.79	1635.33	1624.49	1622.4
1989	1614.45	1614.26	1619.26	1622.22	1627.31	1639.11				1653.39	1646.55	1639.88	
1990	1630.16	1624.21	1625.19	1628.58	1634.77	1641.27	1647.86	1653.63	1656.95	1655.77	1651.58	1646.44	1641.4
1991	1637.95	1630.69	1630.74	1637.38	1643.97	1650.79	1658.49	1664.12	1668.73	1670.22	1668.48	1663.52	1652.5
1992	1656.37	1652.83	1652.97	1655.36	1661.01	1669.48	1676.72	1680.72	1681.69	1679.76	1674.98	1669.07	1667.6

^aMethane mixing ratios are expressed in parts per billion (10⁹) (ppb). Monthly means are based only on those samples representative of background conditions. They were determined by first fitting a curve to the data [see Steele et al. (1992) for details of the curve fits]. To ensure that the data used in the curve fits were evenly spaced, the following guidelines were used. If a flask was analyzed more than once, all aliquots were averaged and the resulting mean was plotted as a single measurement. If both members of a flask pair were analyzed or if two pairs of flasks were sampled simultaneously and then analyzed, all aliquots from the flasks were averaged and their mean again plotted as a single measurement. Weekly values were extracted from the curve fits, and all values in each month were averaged to obtain the monthly means. Annual averages are based on the monthly means.

These data are available in electronic form from CDIAC and in NDP-038 (Steele and Lang 1991). Data from individual flask measurements may be obtained electronically from P.M. Lang or E.J. Dlugokencky at NOAA/CMDL.

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Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

QINGHAI PROVINCE

Trends

In May 1991, the collection of air samples for the NOAA/CMDL program began at a site in Qinghai Province, located in a mountainous area in the west-central region of the Peoples Republic of China. The site is operated in cooperation with the Chinese Academy of Meteorological Sciences. Although the record is currently too short to determine a meaningful trend, the CH₄ mixing ratios measured at this site are generally consistent with those measured at other locations lying at similar latitudes.

Monthly mixing ratios of atmospheric CH₄ at Qinghai Province.

CITE AS: Dlugokencky, E.J., P.M. Lang, K.A. Masarie, and L.P. Steele. 1994. Atmospheric CH₄ records from sites in the NOAA/CMDL air sampling network. pp. 274-350. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric Methane

Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

QINGHAI PROVINCE

Qinghai Province
Peoples Republic of China
36°16' N, 100°55' E
3810 m above MSL

Mixing Ratios of Atmospheric CH₄

CH₄ mixing ratios^a at Qinghai Province (ppb)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1991					1775.18	1774.56	1759.38	1752.17	1762.28	1766.93	1764.47	1750.86	
1992	1751.51	1770.21	1771.06	1768.19	1771.55	1776.78	1771.01	1761.29	1767.77	1766.85	1757.94	1755.03	1765.8

^aMethane mixing ratios are expressed in parts per billion (10⁹) (ppb). Monthly means are based only on those samples representative of background conditions. They were determined by first fitting a curve to the data [see Steele et al. (1992) for details of the curve fits]. To ensure that the data used in the curve fits were evenly spaced, the following guidelines were used. If a flask was analyzed more than once, all aliquots were averaged and the resulting mean was plotted as a single measurement. If both members of a flask pair were analyzed or if two pairs of flasks were sampled simultaneously and then analyzed, all aliquots from the flasks were averaged and their mean again plotted as a single measurement. Weekly values were extracted from the curve fits, and all values in each month were averaged to obtain the monthly means. Annual averages are based on the monthly means.

These data are available in electronic form from CDIAC and in NDP-038 (Steele and Lang 1991). Data from individual flask measurements may be obtained electronically from P.M. Lang or E.J. Dlugokencky at NOAA/CMDL.

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Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

SAMOA

Trends

The NOAA/CMDL observatory in American Samoa is located at Cape Matatula on the island of Tutuila. The annual mean CH₄ mixing ratio at Samoa rose from 1585.2 parts per billion (ppb) in 1984 to 1668.7 ppb in 1992. The average rate of increase over the period of record (1983–92) was 10.4 ppb/year. Steele et al. (1987) reported that the CH₄ mixing ratios from American Samoa showed a long-term increase but no apparent seasonal variation. Steele et al. (1987) suggested that, because CH₄ mixing ratios north of the Intertropical Convergence Zone (ITCZ) are always higher than those in the Southern Hemisphere, intrusions of air reaching American Samoa from north of the ITCZ will always increase the CH₄ mixing ratio at American Samoa. The absence of any clear seasonal variation in the mixing ratio at American Samoa is probably due to the seasonal transport of CH₄-rich air from north of the ITCZ at about the same time as the normal seasonal minimum in atmospheric CH₄ in the Southern Hemisphere (Steele et al. 1987).

Monthly mixing ratios of atmospheric CH₄ at Samoa.

CITE AS: Dlugokencky, E.J., P.M. Lang, K.A. Masarie, and L.P. Steele. 1994. Atmospheric CH₄ records from sites in the NOAA/CMDL air sampling network. pp. 274–350. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric CH₄ records from sites in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

SAMOA

Samoa (Cape Matatula)
U.S. Territory
Pacific Ocean
Island rocky promontory
14°15' S, 170°34' W
42 m above MSL

Mixing Ratios of Atmospheric CH₄

CH₄ mixing ratios^a at Samoa (ppb)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1983				1546.56	1555.09	1568.34	1573.56	1573.50	1574.85	1578.66	1577.54	1578.81	
1984	1588.66	1582.69	1569.28	1572.93	1578.40	1585.67	1591.19	1589.65	1589.63	1589.84	1588.99	1595.73	1585.2
1985	1602.25	1603.63	1598.14	1593.15	1597.05	1597.96	1599.40	1603.48	1604.30	1602.28	1598.79	1596.62	1599.7
1986	1607.42	1619.79	1615.85	1605.78	1602.75	1605.25	1609.08	1611.80	1613.47	1611.56	1607.29	1603.88	1609.5
1987	1609.19	1620.43	1617.77	1605.35	1608.77	1617.88	1622.45	1624.09	1623.16	1623.10	1619.57	1616.36	1617.2
1988	1623.01	1628.16	1625.86	1625.03	1619.92	1621.26	1630.65	1636.12	1636.81	1638.10	1637.85	1638.25	1629.9
1989	1643.13	1641.54	1635.74	1637.67	1641.90	1642.48	1645.78	1649.03	1646.93	1643.81	1647.52	1644.85	1643.3
1990	1635.83	1636.04	1642.03	1642.95	1640.46	1645.90	1652.34	1654.04	1654.51	1651.91	1651.55	1656.02	1647.1
1991	1658.88	1662.83	1654.59	1646.79	1652.59	1656.02	1660.76	1665.36	1667.83	1666.23	1666.05	1665.98	1660.4
1992	1657.58	1662.90	1670.00	1660.72	1663.24	1672.32	1674.91	1676.21	1674.45	1672.70	1670.41	1665.39	1668.7

^aMethane mixing ratios are expressed in parts per billion (10⁹) (ppb). Monthly means are based only on those samples representative of background conditions. They were determined by first fitting a curve to the data [see Steele et al. (1992) for details of the curve fits]. To ensure that the data used in the curve fits were evenly spaced, the following guidelines were used. If a flask was analyzed more than once, all aliquots were averaged and the resulting mean was plotted as a single measurement. If both members of a flask pair were analyzed or if two pairs of flasks were sampled simultaneously and then analyzed, all aliquots from the flasks were averaged and their mean again plotted as a single measurement. Weekly values were extracted from the curve fits, and all values in each month were averaged to obtain the monthly means. Annual averages are based on the monthly means.

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Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

SEYCHELLES

Trends

The Seychelles monitoring site at Mahé Island is operated in cooperation with the Physical Science Laboratory of New Mexico State University. The annual mean CH₄ mixing ratio at the Seychelles site increased from 1601.6 parts per billion (ppb) in 1984 to 1689.0 ppb in 1992. Over the period of record (May 1983–December 1992), the average rate of CH₄ increase was 10.5 ppb/year. The Seychelles (and the corresponding CH₄ measurements) are influenced by monsoons and the seasonal migration of the surface wind convergence zone. Steele et al. (1987) reported that during the austral winter this convergence zone is normally found to the north of the Seychelles, bringing southeast monsoon winds and typically Southern Hemisphere CH₄ mixing ratios to the Mahé Island site. During the austral summer, however, the convergence zone migrates far south of the Seychelles, bringing Mahé Island under the predominant influence of the northwest monsoon winds and higher CH₄ mixing ratios (Steele et al. 1987).

Monthly mixing ratios of atmospheric CH₄ at the Seychelles.

CITE AS: Dlugokencky, E.J., P.M. Lang, K.A. Masarie, and L.P. Steele. 1994. Atmospheric CH₄ records from sites in the NOAA/CMDL air sampling network. pp. 274–350. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

Seychelles (Mahé Island)
Indian Ocean
Island seashore
4°40' S, 55°10' E
3 m above MSL

SEYCHELLES

Mixing Ratios of Atmospheric CH₄CH₄ mixing ratios^a at the Seychelles (ppb)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1983					1562.69	1573.76	1579.33	1573.50	1582.49	1601.75	1605.80	1616.53	
1984	1623.59						1591.94	1596.12	1602.97	1602.39	1610.59	1635.89	
1985	1651.22	1643.88	1609.21	1591.53	1597.02	1602.31	1604.33	1607.87	1606.58	1597.97	1597.25	1607.61	1609.2
1986	1629.79	1648.85	1636.59	1606.27	1595.78	1608.58	1619.24	1629.36	1631.68	1616.95	1621.41	1658.72	1624.7
1987	1679.57	1665.36	1654.15	1644.07						1621.17	1619.77	1646.12	
1988	1675.78	1674.42	1657.42	1630.20	1617.42						1662.47	1687.49	
1989	1701.97							1649.28	1653.63	1651.71	1652.41	1680.92	
1990	1704.34	1704.83	1695.89	1671.74	1656.45	1654.01	1659.07	1665.19	1666.49	1657.06	1647.75	1670.36	1671.1
1991	1707.20	1705.23	1667.52	1649.37	1652.59	1656.70	1663.19	1669.09	1673.37	1670.50	1676.53	1702.56	1674.0
1992	1723.77	1727.99	1710.42	1686.63	1673.22	1677.42	1681.06	1680.39	1681.00	1676.95	1668.66	1681.53	1689.0

^aMethane mixing ratios are expressed in parts per billion (10⁹) (ppb). Monthly means are based only on those samples representative of background conditions. They were determined by first fitting a curve to the data [see Steele et al. (1992) for details of the curve fits]. To ensure that the data used in the curve fits were evenly spaced, the following guidelines were used. If a flask was analyzed more than once, all aliquots were averaged and the resulting mean was plotted as a single measurement. If both members of a flask pair were analyzed or if two pairs of flasks were sampled simultaneously and then analyzed, all aliquots from the flasks were averaged and their mean again plotted as a single measurement. Weekly values were extracted from the curve fits, and all values in each month were averaged to obtain the monthly means. Annual averages are based on the monthly means.

These data are available in electronic form from CDIAC and in NDP-038 (Steele and Lang 1991). Data from individual flask measurements may be obtained electronically from P.M. Lang or E.J. Dlugokencky at NOAA/CMDL.

CITE AS: Dlugokencky, E.J., P.M. Lang, K.A. Masarie, and L.P. Steele. 1994. Atmospheric CH₄ records from sites in the NOAA/CMDL air sampling network. pp. 274-350. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

SHEMYA ISLAND

Trends

The monitoring site at Shemya Island, located in the western Aleutian Islands, Alaska, U.S.A., is operated in cooperation with the U.S. Air Force. The annual mean CH₄ mixing ratio at Shemya Island rose from 1739.9 parts per billion (ppb) in 1986 to 1795.0 ppb in 1992. The associated average rate of CH₄ increase over the period of record (September 1985–December 1992) was 10.0 ppb/year. The record also exhibits a strong seasonal cycle with a minimum in July and a maximum during the period December–February. These results are consistent with those obtained at other high-latitude Northern Hemisphere sites.

Monthly mixing ratios of atmospheric CH₄ at Shemya Island.

CITE AS: Dlugokencky, E.J., P.M. Lang, K.A. Masarie, and L.P. Steele. 1994. Atmospheric CH₄ records from sites in the NOAA/CMDL air sampling network. pp. 274–350. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

SHEMYA ISLAND

Shemya Island
Alaska, U.S.A.
Island seashore
52°43' N, 174°06' E
40 m above MSL

Mixing Ratios of Atmospheric CH₄CH₄ mixing ratios^a at Shemya Island (ppb)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1985									1734.73	1742.78	1736.30	1734.54	
1986	1731.16	1733.18	1742.92	1748.71	1742.17	1721.09	1714.05	1736.38	1754.28	1760.20	1751.24	1743.55	1739.9
1987	1754.24	1755.23	1745.83	1752.07	1754.61	1739.66	1722.54	1720.90	1741.24	1759.15	1766.58	1767.64	1748.1
1988	1764.79	1766.18	1771.11	1776.32	1766.17	1743.04	1733.04	1740.07	1758.01	1771.94	1773.38	1773.12	1761.4
1989	1779.30	1779.97	1776.92	1776.55	1765.04	1746.82	1746.24	1766.63	1781.90	1782.01	1778.25	1783.62	1771.6
1990	1794.49	1795.30	1786.20	1782.68	1776.71	1755.13	1753.37	1780.77	1793.68	1793.99	1793.30	1798.73	1783.7
1991	1802.13	1796.35	1796.61	1796.41	1791.62	1776.24	1762.80	1778.28	1794.62	1793.33	1799.42	1805.89	1791.2
1992	1805.32	1800.64	1801.65	1803.18	1792.34	1777.45	1775.25	1790.45	1795.87	1794.60	1803.42	1803.32	1795.0

^aMethane mixing ratios are expressed in parts per billion (10⁹) (ppb). Monthly means are based only on those samples representative of background conditions. They were determined by first fitting a curve to the data [see Steele et al. (1992) for details of the curve fits]. To ensure that the data used in the curve fits were evenly spaced, the following guidelines were used. If a flask was analyzed more than once, all aliquots were averaged and the resulting mean was plotted as a single measurement. If both members of a flask pair were analyzed or if two pairs of flasks were sampled simultaneously and then analyzed, all aliquots from the flasks were averaged and their mean again plotted as a single measurement. Weekly values were extracted from the curve fits, and all values in each month were averaged to obtain the monthly means. Annual averages are based on the monthly means.

These data are available in electronic form from CDIAC and in NDP-038 (Steele and Lang 1991). Data from individual flask measurements may be obtained electronically from P.M. Lang or E.J. Dlugokencky at NOAA/CMDL.

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Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

SOUTH GEORGIA ISLAND

Trends

The NOAA/CMDL sampling site on South Georgia Island in the Atlantic Ocean is operated in cooperation with the British Antarctic Survey. Despite the short period of record (February 1989–September 1991) and the presence of temporal gaps, the data from South Georgia Island show an increase in CH₄ mixing ratio at an average rate of 11.5 parts per billion (ppb) per year. In addition, the data show a seasonal oscillation similar to that at other high-latitude sites in the Southern Hemisphere.

Monthly mixing ratios of atmospheric CH₄ at South Georgia Island.

CITE AS: Dlugokencky, E.J., P.M. Lang, K.A. Masarie, and L.P. Steele. 1994. Atmospheric CH₄ records from sites in the NOAA/CMDL air sampling network. pp. 274–350. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

SOUTH GEORGIA ISLAND

South Georgia Island
Atlantic Ocean
 54°00' S, 38°03' W
 30 m above MSL

Mixing Ratios of Atmospheric CH₄CH₄ mixing ratios^a at South Georgia Island (ppb)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1989		1620.02	1616.14				1644.45	1651.02	1648.48				
1990	1637.15	1630.69	1626.04	1629.29	1636.68	1643.94	1652.89					1650.00	
1991	1642.83	1634.40	1631.27	1636.20	1644.51	1651.04	1660.28	1669.32	1670.06				

^aMethane mixing ratios are expressed in parts per billion (10⁹) (ppb). Monthly means are based only on those samples representative of background conditions. They were determined by first fitting a curve to the data [see Steele et al. (1992) for details of the curve fits]. To ensure that the data used in the curve fits were evenly spaced, the following guidelines were used. If a flask was analyzed more than once, all aliquots were averaged and the resulting mean was plotted as a single measurement. If both members of a flask pair were analyzed or if two pairs of flasks were sampled simultaneously and then analyzed, all aliquots from the flasks were averaged and their mean again plotted as a single measurement. Weekly values were extracted from the curve fits, and all values in each month were averaged to obtain the monthly means. Annual averages are based on the monthly means.

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Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

SOUTH POLE

Trends

The annual mean CH₄ mixing ratio at the NOAA/CMDL South Pole Observatory increased from 1576.0 parts per billion (ppb) in 1984 to 1666.9 ppb in 1992. Over the period of record (February 1983–December 1992), the average CH₄ growth rate was 11.5 ppb/year. Using data for 1983 and 1984, Steele et al. (1987) reported that, within the limits of the measurement precision, both the absolute mixing ratio and the phase and amplitude of the seasonal cycle were indistinguishable at the five southernmost sites in the NOAA/CMDL network (i.e., South Pole, Halley Bay, Palmer Station, Cape Grim, and Amsterdam Island).

Monthly mixing ratios of atmospheric CH₄ at the South Pole.

CITE AS: Dlugokencky, E.J., P.M. Lang, K.A. Masarie, and L.P. Steele. 1994. Atmospheric CH₄ records from sites in the NOAA/CMDL air sampling network. pp. 274–350. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

South Pole
Antarctica
Ice- and snow-
covered plateau
89°59' S, 24°48' W
2810 m above MSL

SOUTH POLE

Mixing Ratios of Atmospheric CH₄CH₄ mixing ratios^a at the South Pole (ppb)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1983		1535.85	1537.04	1542.84	1550.97	1558.63	1566.56	1572.81	1576.19	1577.60	1574.69	1568.31	
1984	1561.00	1557.03	1558.24	1563.60	1571.67	1577.73	1581.48	1585.30	1591.13	1591.88	1588.85	1583.36	1576.0
1985	1573.99	1569.57	1567.86	1571.20	1578.79	1584.97	1593.61	1600.51	1603.84	1604.29	1599.49	1590.63	1586.8
1986	1583.58	1579.85	1582.06	1587.95	1592.76	1599.14	1607.78	1612.90	1614.29	1614.83	1611.61	1604.72	1599.4
1987	1595.82	1590.92	1593.39	1598.58	1604.20	1611.40	1618.27	1622.63	1625.36	1625.45	1621.63	1615.09	1610.4
1988	1606.46	1600.81	1604.41	1609.43	1613.97	1621.78	1629.16	1634.62	1637.42	1640.15	1636.89	1628.12	1622.0
1989	1620.25	1614.63	1614.74	1619.01	1625.90	1635.97	1643.12	1648.35	1651.23	1649.28	1645.30	1639.60	1634.1
1990	1630.88	1626.25	1627.72	1630.70	1635.24	1641.75	1648.90	1654.28	1657.27	1656.55	1651.79	1644.96	1642.3
1991	1639.33	1638.44	1635.17	1635.97	1645.50	1652.57	1657.77	1663.59	1668.32	1670.36	1667.92	1661.35	1653.0
1992	1654.36	1651.17	1651.22	1655.73	1661.27	1668.79	1677.20	1681.11	1681.75	1679.13	1673.48	1667.22	1666.9

^aMethane mixing ratios are expressed in parts per billion (10⁹) (ppb). Monthly means are based only on those samples representative of background conditions. They were determined by first fitting a curve to the data [see Steele et al. (1992) for details of the curve fits]. To ensure that the data used in the curve fits were evenly spaced, the following guidelines were used. If a flask was analyzed more than once, all aliquots were averaged and the resulting mean was plotted as a single measurement. If both members of a flask pair were analyzed or if two pairs of flasks were sampled simultaneously and then analyzed, all aliquots from the flasks were averaged and their mean again plotted as a single measurement. Weekly values were extracted from the curve fits, and all values in each month were averaged to obtain the monthly means. Annual averages are based on the monthly means.

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Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

STATION "M"

Trends

The Station "M" monitoring site, located in the open North Atlantic Ocean west of Norway, is operated in cooperation with the Norway Meteorological Institute. The annual mean atmospheric CH₄ mixing ratio at Station "M" rose from 1708.5 parts per billion (ppb) in 1984 to 1793.8 ppb in 1992. The associated average growth rate over the period April 1983–December 1992 was 10.7 ppb/year. The monthly CH₄ record from the station exhibits a typical Northern Hemisphere seasonal cycle: major seasonal minimum mixing ratios occur during the northern summer months (invariably in July); primary and secondary seasonal maximum mixing ratios occur during the late winter and early spring months.

Monthly mixing ratios of atmospheric CH₄ at Station "M."

CITE AS: Dlugokencky, E.J., P.M. Lang, K.A. Masarie, and L.P. Steele. 1994. Atmospheric CH₄ records from sites in the NOAA/CMDL air sampling network. pp. 274–350. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93. A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

STATION "M"

Station "M"
North Atlantic Ocean
Open ocean
66°00' N, 2°00' E
4.5–9 m above MSL

Mixing Ratios of Atmospheric CH₄CH₄ mixing ratios^a at Station "M" (ppb)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1983				1684.20	1684.31	1685.92	1670.39	1671.36	1700.19	1706.29	1704.99	1710.67	
1984	1708.02	1702.86	1713.53	1713.86	1704.68	1694.53	1676.95	1683.70	1724.28	1734.13	1715.38	1724.04	1708.5
1985	1739.74	1733.65	1735.77	1741.43	1726.58	1708.84	1699.74	1705.25	1720.33	1726.38	1731.61	1743.93	1725.7
1986	1746.76	1743.47	1747.86	1749.34	1737.81	1718.39	1711.38	1725.06	1731.69	1729.78	1738.13	1738.75	1735.1
1987	1742.44	1766.30	1769.66	1751.71	1742.04	1735.23	1726.24	1729.05	1755.21	1773.47	1759.25	1757.06	1750.3
1988	1772.61	1777.11	1780.29	1777.26	1755.77	1741.18	1738.96	1750.09	1764.49	1769.04	1771.38	1772.49	1763.8
1989	1768.19	1771.17	1776.64	1772.48	1761.02	1750.03	1742.73	1751.23	1761.49	1764.02	1774.46	1786.62	1765.2
1990	1790.59	1794.15	1788.07	1776.88	1769.14	1759.61	1753.71	1761.78	1784.23	1797.49	1790.15	1789.14	1779.3
1991	1793.94	1799.01	1798.33	1787.05	1781.80	1771.43	1767.09	1777.93	1793.11	1797.66	1799.75	1804.14	1789.5
1992	1798.09	1798.09	1806.45	1803.34	1795.28	1783.71	1773.35	1780.17	1788.55	1792.83	1800.54	1805.74	1793.8

^aMethane mixing ratios are expressed in parts per billion (10⁹) (ppb). Monthly means are based only on those samples representative of background conditions. They were determined by first fitting a curve to the data [see Steele et al. (1992) for details of the curve fits]. To ensure that the data used in the curve fits were evenly spaced, the following guidelines were used. If a flask was analyzed more than once, all aliquots were averaged and the resulting mean was plotted as a single measurement. If both members of a flask pair were analyzed or if two pairs of flasks were sampled simultaneously and then analyzed, all aliquots from the flasks were averaged and their mean again plotted as a single measurement. Weekly values were extracted from the curve fits, and all values in each month were averaged to obtain the monthly means. Annual averages are based on the monthly means.

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Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

SYOWA STATION

Trends

The atmospheric trace gas monitoring site at Syowa Station, Antarctica, is operated in cooperation with the Upper Atmospheric and Space Laboratory at Tohoku University in Sendai, Japan. The annual mean CH₄ mixing ratio at Syowa increased from 1634.8 parts per billion (ppb) in 1989 (the first full year of monitoring) to 1667.6 ppb in 1992. Over the entire period for which measurements have been obtained (April 1986–December 1992), the CH₄ mixing ratio at Syowa increased at an average rate of 10.8 ppb/year. Both in the magnitudes of the monthly mean values and in the characteristic seasonal cycle, the data from Syowa Station agree closely with those from other high-latitude NOAA/CMDL sites in the Southern Hemisphere.

Monthly mixing ratios of atmospheric CH₄ at Syowa Station.

CITE AS: Dlugokencky, E.J., P.M. Lang, K.A. Masarie, and L.P. Steele. 1994. Atmospheric CH₄ records from sites in the NOAA/CMDL air sampling network. pp. 274–350. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

SYOWA STATION

Syowa Station
Antarctica
69°00' S, 39°35' E
11 m above MSL

Mixing Ratios of Atmospheric CH₄CH₄ mixing ratios^a at Syowa Station (ppb)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1986				1582.96	1591.96	1602.48	1611.03	1617.98	1619.18	1616.75	1612.10	1604.91	
1987													
1988		1606.69	1605.21	1608.36	1616.90	1624.16	1628.79	1633.59	1636.84	1637.07	1635.32	1631.02	
1989	1623.07	1616.76	1616.99	1620.81	1627.72	1636.60	1643.43	1648.98	1650.89	1648.74	1644.84	1637.42	1634.8
1990	1630.31	1626.43	1626.85	1631.20	1636.22	1642.95	1649.10	1653.03	1656.21	1657.43	1654.35	1646.35	1642.6
1991	1638.09	1633.89	1634.64	1638.40	1645.63	1652.48	1658.56	1664.80	1665.99	1667.59	1669.69	1664.20	1652.9
1992	1655.73	1651.38	1652.49	1656.24	1661.57	1669.50	1676.09	1679.57	1682.21	1681.68	1675.70	1668.62	1667.6

^aMethane mixing ratios are expressed in parts per billion (10⁹) (ppb). Monthly means are based only on those samples representative of background conditions. They were determined by first fitting a curve to the data [see Steele et al. (1992) for details of the curve fits]. To ensure that the data used in the curve fits were evenly spaced, the following guidelines were used. If a flask was analyzed more than once, all aliquots were averaged and the resulting mean was plotted as a single measurement. If both members of a flask pair were analyzed or if two pairs of flasks were sampled simultaneously and then analyzed, all aliquots from the flasks were averaged and their mean again plotted as a single measurement. Weekly values were extracted from the curve fits, and all values in each month were averaged to obtain the monthly means. Annual averages are based on the monthly means.

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Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

TAE-AHN PENINSULA

Trends

The monitoring site on the Tae-ahn Peninsula, located along the Yellow Sea in South Korea, is operated in cooperation with the Korea National University of Education. The collection of air samples at this site began in November 1990. The CH₄ mixing ratios obtained from this location are unusually high in comparison with values from other NOAA/CMDL sites at similar latitudes, presumably because Tae-ahn Peninsula is near the East Asian rice-growing region, a major source of atmospheric CH₄. Dlugokencky et al. (1993) have used the measurements from Tae-ahn Peninsula to constrain regional CH₄ sources in eastern Asia.

Monthly mixing ratios of atmospheric CH₄ at Tae-ahn Peninsula.

CITE AS: Dlugokencky, E.J., P.M. Lang, K.A. Masarie, and L.P. Steele. 1994. Atmospheric CH₄ records from sites in the NOAA/CMDL air sampling network. pp. 274-350. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

TAE-AHN PENINSULA

Tae-ahn Peninsula
South Korea
36°44' N, 126°08' E
20 m above MSL

Mixing Ratios of Atmospheric CH₄CH₄ mixing ratios^a at Tae-ahn Peninsula (ppb)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1991			1833.02	1799.66	1803.53	1803.42	1801.73	1880.96	1875.65	1805.19	1792.16	1816.77	1822.6
1992	1827.46	1829.08	1832.32	1833.13	1840.64	1844.03	1827.59	1820.94	1826.66	1817.79	1819.75	1835.81	1829.3

^aMethane mixing ratios are expressed in parts per billion (10⁹) (ppb). Monthly means are based only on those samples representative of background conditions. They were determined by first fitting a curve to the data [see Steele et al. (1992) for details of the curve fits]. To ensure that the data used in the curve fits were evenly spaced, the following guidelines were used. If a flask was analyzed more than once, all aliquots were averaged and the resulting mean was plotted as a single measurement. If both members of a flask pair were analyzed or if two pairs of flasks were sampled simultaneously and then analyzed, all aliquots from the flasks were averaged and their mean again plotted as a single measurement. Weekly values were extracted from the curve fits, and all values in each month were averaged to obtain the monthly means. Annual averages are based on the monthly means.

These data are available in electronic form from CDIAC and in NDP-038 (Steele and Lang 1991). Data from individual flask measurements may be obtained electronically from P.M. Lang or E.J. Dlugokencky at NOAA/CMDL.

CITE AS: Dlugokencky, E.J., P.M. Lang, K.A. Masarie, and L.P. Steele. 1994. Atmospheric CH₄ records from sites in the NOAA/CMDL air sampling network. pp. 274-350. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

VIRGIN ISLANDS

Trends

The NOAA/CMDL Virgin Islands sampling site, located on the island of St. Croix, U.S. Virgin Islands, was operated in cooperation with Fairleigh Dickinson University from 1993 to 1990. The annual mean CH₄ mixing ratio at the Virgin Islands site rose from 1650.4 parts per billion (ppb) in 1984 to 1704.0 ppb in 1989. Over the period of record (May 1983–August 1990), the CH₄ mixing ratio rose at an average rate of 10.7 ppb/year. In general, the results obtained at this site are consistent with those at other tropical locations in the Northern Hemisphere. After August 1990, atmospheric CH₄ monitoring at the Virgin Islands was discontinued.

Monthly mixing ratios of atmospheric CH₄ at the Virgin Islands.

CITE AS: Dlugokencky, E.J., P.M. Lang, K.A. Masarie, and L.P. Steele. 1994. Atmospheric CH₄ records from sites in the NOAA/CMDL air sampling network. pp. 274–350. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric Methane
Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

VIRGIN ISLANDS

Virgin Islands, U.S. (St. Croix)
Atlantic Ocean
Island seashore
17°45' N, 64°45' W
3 m above MSL

Mixing Ratios of Atmospheric CH₄

CH₄ mixing ratios^a at the Virgin Islands (ppb)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1983					1614.93	1626.01	1635.60	1639.66	1642.46	1646.02	1650.39	1651.58	
1984	1653.29	1653.32	1646.33	1648.94	1651.43	1639.97	1640.19	1647.62	1643.73	1642.20	1659.83	1679.49	1650.4
1985	1675.40	1665.70	1673.69	1676.65	1661.62	1653.84	1654.29	1653.03	1654.86	1670.66	1690.14	1692.69	1668.6
1986	1684.90	1684.65	1681.92	1672.44	1665.89	1665.93	1664.79	1659.67	1660.29	1670.23	1686.58	1697.98	1674.3
1987	1691.43	1689.80	1693.84	1683.78	1677.49	1677.88	1677.65	1678.92	1678.01	1680.88	1692.49	1704.63	1685.3
1988	1707.10	1706.40	1708.54	1699.34	1689.92	1685.36	1683.38	1688.04	1685.53	1687.74	1707.06	1714.86	1697.1
1989	1713.25	1713.35	1705.85	1700.67	1705.75	1702.41	1691.51	1691.48	1695.45	1702.27	1711.08	1717.57	1704.0
1990	1724.79	1726.75	1723.05	1726.66	1720.12	1706.21	1702.28	1707.77					

^aMethane mixing ratios are expressed in parts per billion (10⁹) (ppb). Monthly means are based only on those samples representative of background conditions. They were determined by first fitting a curve to the data [see Steele et al. (1992) for details of the curve fits]. To ensure that the data used in the curve fits were evenly spaced, the following guidelines were used. If a flask was analyzed more than once, all aliquots were averaged and the resulting mean was plotted as a single measurement. If both members of a flask pair were analyzed or if two pairs of flasks were sampled simultaneously and then analyzed, all aliquots from the flasks were averaged and their mean again plotted as a single measurement. Weekly values were extracted from the curve fits, and all values in each month were averaged to obtain the monthly means. Annual averages are based on the monthly means.

These data are available in electronic form from CDIAC and in NDP-038 (Steele and Lang 1991). Data from individual flask measurements may be obtained electronically from P.M. Lang or E.J. Dlugokencky at NOAA/CMDL.

CITE AS: Dlugokencky, E.J., P.M. Lang, K.A. Masarie, and L.P. Steele. 1994. Atmospheric CH₄ records from sites in the NOAA/CMDL air sampling network. pp. 274-350. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric CH₄ records from sites
in the NOAA/CMDL air sampling network

E.J. Dlugokencky, P.M. Lang, K.A. Masarie, and L.P. Steele (continued)

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Atmospheric CH₄ record from in situ measurements at Cape Point

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Period of Record

1983–91

Methods

Sample air was drawn through a 60-m-long stainless steel tube from the top of a 34-m-high radio mast. The air was passed through two consecutive cooling traps to remove water vapor. Methane mixing ratios were determined through the use of a gas chromatograph equipped with a flame ionization detector. Methane was separated on a 120-cm stainless steel column (6-mm outside diameter) packed with molecular sieve 13X (60–80 mesh). Three ambient samples and one calibration gas were analyzed per hour. The calibration gases used at the station consisted of cryogenically sampled natural air stored in high-pressure steel or aluminum cylinders. These working standards were all related to the primary CH₄ standard of the Fraunhofer Institute. Mixing ratios are reported in parts per billion by volume (ppbv). The mixing ratio assigned to the primary standard was based on absolute calibration by means of dynamic dilution of pure CH₄. Until July 1985, mixing ratios were calculated from chromatographic peak heights. Thereafter, peak areas reported by an integrator were used instead. From the individual results, hourly averages were calculated. Data selection with respect to background conditions was performed on the basis of the standard deviations of the simultaneously measured gases CH₄, CO, and CFC1₃.

From the hourly CH₄ data, monthly means were calculated. Results have been presented by Brunke et al. (1990) and Scheel et al. (1990). Recently, all hourly CH₄ data were carefully reprocessed and filtered anew by visual inspection. From the hourly values thus obtained, daily means were determined. Through the use of dynamic harmonic regression, the daily means were smoothed and interpolated where missing values occurred. Following this revision of the raw data, previously published CH₄ data for 1982 were found to be

Cape Point
South Africa
Cliff top seashore
34°21' S, 18°29' E
210 m above MSL

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Atmospheric CH₄ record from in situ measurements at Cape Point

E.G. Brunke, H.E. Scheel, and W. Seiler (continued)

unreliable and were discarded. In addition, a seemingly fast change of trend in 1985 was traced back to a calibration error. To correct this, all mixing ratios prior to July 1985 were lowered by 6 ppbv. Based on this corrected data set, new monthly means have been calculated; these revised means constitute the data set presented here in *Trends '93*.

Details on the analytical techniques and data selection procedure have been described by Brunke et al. (1990). For further information on the geographic and meteorological characteristics of Cape Point, see Brunke and Halliday (1983) and Seiler et al. (1984).

CITE AS: Brunke, E.G., H.E. Scheel, and W. Seiler. 1994. Atmospheric CH₄ record from in situ measurements at Cape Point. pp. 352–356. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.). *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

CAPE POINT

Trends

The station at Cape Point, South Africa, is operated jointly by the Council for Scientific and Industrial Research (CSIR), South Africa, and the Fraunhofer Institute for Atmospheric Environmental Research, Germany. The site is located at the southern tip of the Cape Peninsula, atop a cliff at an elevation of 210 m above sea level. The prevailing wind direction is southeast to southwest throughout the year.

The atmospheric mixing ratios of CH₄ increased from a minimum of 1543.0 parts per billion by volume (ppbv) in February 1983 to a maximum of 1668.7 ppbv in October 1991. This range of values is consistent with results from other Southern Hemisphere sites over the same time period. The data show an average CH₄ growth rate of 11.3 ppbv/year for the period January 1983–December 1991. Superimposed on the upward trend of the CH₄ mixing ratios is a seasonal oscillation with an average amplitude (peak to trough) of about 30 ppbv; minima occur in February or March, and maxima occur in August, September, or October.

Monthly mixing ratios of atmospheric CH₄ at Cape Point.

CITE AS: Brunke, E.G., H.E. Scheel, and W. Seiler. 1994. Atmospheric CH₄ record from in situ measurements at Cape Point. pp. 352–356. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.). *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric CH₄ record from in situ measurements at Cape Point

E.G. Brunke, H.E. Scheel, and W. Seiler (continued)

CAPE POINT

Mixing Ratios of Atmospheric CH₄CH₄ mixing ratios^a at Cape Point (ppbv)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann ^b
1983	1548.3	1543.0	1543.7	1552.6	1560.6	1567.8	1572.1	1576.7	1579.0	1578.6	1573.2	1569.0	1563.7
1984	1565.1	1554.2	1554.8	1566.0	1575.6	1582.1	1587.9	1591.9	1591.7	1589.3	1583.7	1575.5	1576.5
1985	1568.5	1566.9	1571.9	1578.9	1583.3	1586.1	1589.6	1596.8	1601.0	1600.0	1595.5	1588.1	1585.5
1986	1580.9	1577.7	1580.0	1587.6	1597.2	1604.1	1611.5	1615.1	1614.8	1612.9	1608.0	1600.1	1599.2
1987	1593.2	1591.1	1594.4	1600.6	1610.2	1619.2	1623.8	1624.3	1625.9	1625.7	1623.8	1618.3	1612.5
1988	1610.0	1605.2	1603.9	1611.5	1620.4	1626.4	1631.4	1635.7	1638.3	1637.7	1632.6	1623.9	1623.1
1989	1616.6	1612.8	1614.7	1622.7	1632.5	1640.0	1645.9	1647.4	1648.3	1647.4	1644.1	1637.1	1634.1
1990	1630.2	1625.6	1627.3	1632.4	1637.6	1644.4	1650.8	1654.8	1656.9	1655.3	1650.6	1643.1	1642.4
1991	1634.9	1629.8	1631.2		1648.1	1653.8	1657.7	1661.3	1665.9	1668.7	1665.3	1659.6	

^aThese atmospheric CH₄ mixing ratios represent monthly averages calculated from daily means based on individual (three-times-hourly) in situ measurements. The data are available at no cost in electronic form from CDIAC.

^bAnnual values were calculated by averaging monthly values when all 12 were available.

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Atmospheric CH₄ record from flask measurements at Lampedusa Island

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Period of Record

1992–93

Methods

Air samples were collected every 2 weeks in paired 2-L glass flasks. Flasks were evacuated at the ENEA Laboratory in Rome and then pressurized to 280–300 kPa with ambient air at the sampling site. After their return to the ENEA laboratory, the flask air samples were passed through a chemical water vapor trap and then analyzed for CH₄ by means of standard gas chromatography, using flame ionization detection (GC-FID). Analyses were carried out on a Carlo Erba model 4100 gas chromatograph fitted with a column packed with 100–200 mesh silica gel and molecular sieve 5A. Using a nitrogen carrier gas, chromatographic runs were performed either on flask air samples or on aliquots of a calibrating gas that consisted of a mixture of CH₄ [1700–1800 parts per billion by volume (ppbv)] and synthetic air. Each sample determination was calculated as the mean value from ten chromatographic runs, and the final CH₄ value reported was the average of the means obtained from each of the two flasks.

Lampedusa Island
Mediterranean Sea
Rocky island
35°31' N, 12°37' E
85 m above MSL

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LAMPEDUSA ISLAND

Trends

Lampedusa is a rocky island south of Sicily, in the middle of the Mediterranean Sea. The prevailing winds are north-northwest and south. The climate is temperate and dry, with maximum precipitation in the winter.

Atmospheric CH₄ measurements at Lampedusa began in May 1992. Over the period of record (May 1992–December 1993), monthly CH₄ concentrations ranged from 1773 to 1867 parts per billion by volume (ppbv). Because of the short duration of the record, it is not yet possible to ascertain a significant trend in the data from Lampedusa. However, the values appear to be relatively higher and more variable than those from other sites at similar latitudes that have been presented elsewhere in *Trends '93*.

Monthly concentrations of atmospheric CH₄ at Lampedusa Island.

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Atmospheric CH₄ record from flask measurements at Lampedusa Island

L. Ciattaglia and P. Chamard (continued)

LAMPEDUSA ISLAND

Concentrations of Atmospheric CH₄CH₄ concentrations^a at Lampedusa Island (ppbv)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann ^b
1992					1846	1832	1820	1817	1813	1800	1855	1812	
1993	1790	1834	1867	1809	1823	1812	1790	1773	1790	1814	1825	1839	1814

^aThese atmospheric CH₄ concentrations represent monthly averages calculated by CDIAC from determinations based on flask air samples collected every two weeks. All data, including bi-weekly sample determinations, monthly averages, and annual averages are available at no cost in electronic form from CDIAC.

^bAnnual values were calculated by averaging monthly values when all 12 were available.

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Atmospheric CH₄ record from in situ measurements at Cape Meares

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Period of Record

1979–91

Methods

Analysis of ambient air was carried out by means of an automated sampling and measurement system. At regular intervals, air samples were pumped into the apparatus, dried to a dew point of -30°C ($<1\%$ relative humidity) by a Nafion[®] dryer, and injected onto the column of a gas chromatograph equipped with a flame ionization detector. Chromatographic peak areas were determined by means of an electronic integrator. CH₄ concentrations in parts per billion by volume (ppbv) were then calculated from the integrated peak areas by comparison with peaks of a standard reference gas run before and after the ambient sample. At the beginning of the experiment (January 1979), 72 measurements of ambient air were taken per day. This frequency was reduced to 24 per day in 1984 and to 12 per day in 1986. Sufficient data were available to calculate monthly averages for all months over the period of record (1979–91). For most months, sampling was carried out on 80 to 90% of the days. During winter months, however, storms occasionally caused power outages and suspended station operation, sometimes for several weeks at a time.

The primary calibration standards consisted of precisely calibrated air stored in high-pressure stainless steel tanks. The continuous measurement procedure also employed secondary calibration standards at the monitoring site. During the course of the record, several primary and many secondary calibration tanks were used, but all can be linked to a single absolute calibration standard.

The overall precision of the measurements—including instrumental, atmospheric, and sampling variabilities—was estimated from the variability of the observed daily concentrations. The standard deviation of the individual measurements from a given day is, on average, ~ 10 ppbv, and 90% of the standard deviations are between 4 and 21 ppbv.

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CAPE MEARES

Trends

The atmospheric monitoring facility at Cape Meares, Oregon, U.S.A., is operated by the Oregon Graduate Institute of Science and Technology and was the first station in the world to carry out continuous automated measurements of CH₄. Measurements at this location (45°29' N, 123°58' W) are representative of CH₄ concentrations in the northern latitudes (from 30° N to 90° N). The site is isolated from populated areas by the presence of a coastal mountain range. Because westerly winds predominate, the site is influenced by largely unpolluted Pacific air masses. The data collected at Cape Meares represent nearly 120,000 individual CH₄ measurements carried out between 1979 and 1992.

Over the 13-year period of record, CH₄ concentrations at Cape Meares increased by ~190 parts per billion by volume (ppbv) and had an average value of 1698 ppbv. The rate of increase fell from $\sim 20 \pm 4$ ppbv/year in the first 2 years to $\sim 10 \pm 2$ ppbv/year in the last 2 years, suggesting a decline in the magnitude of the trend at this site. The data also show a prominent seasonal cycle. The average amplitude of the cycle is $\sim 30 \pm 7$ ppbv and appears to be increasing over the course of the record. This annual cycle begins with fairly constant CH₄ concentrations until May, followed by a drop to minimum levels in July and August and a rapid rise to nearly maximum levels by October. Using a mass balance calculation, Khalil et al. (1993) showed that, in order to explain the observed seasonality of atmospheric concentrations, CH₄ emissions from all sources must collectively reach peak levels in August and September.

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Atmospheric CH₄ record from in situ measurements at Cape Meares

M.A.K. Khalil and R.A. Rasmussen (continued)

CAPE MEARES

*Daily average concentrations of atmospheric CH₄ at Cape Meares.**

*The daily average CH₄ concentrations plotted here are derived from the same in situ measurements as the monthly averages presented in the accompanying table.

CITE AS: Khalil, M.A.K., and R.A. Rasmussen. 1994. Atmospheric CH₄ record from in situ measurements at Cape Meares. pp. 361–365. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric CH₄ record from in situ measurements at Cape Meares

M.A.K. Khalil and R.A. Rasmussen (continued)

CAPE MEARES

Concentrations of Atmospheric CH₄

CH₄ concentrations^a at Cape Meares (ppbv)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann ^b
1979		1589.5	1592.8	1600.1	1600.8	1595.2	1591.9	1599.2	1610.2	1620.4	1611.4	1609.1	
1980	1609.9	1594.2	1615.1	1623.7	1626.9	1606.4	1599.8	1617.3	1629.1	1640.7	1633.3	1630.2	1618.9
1981	1627.5	1636.8	1640.5	1640.9	1639.6	1623.3	1611.6	1614.5	1653.1	1659.1	1649.4	1647.9	1637.0
1982	1650.1	1647.5	1661.7	1666.3	1659.0	1639.6	1639.9	1638.0	1652.6	1658.5	1666.2	1664.5	1653.7
1983	1664.1	1671.6	1677.0	1683.4	1677.4	1667.2	1660.0	1671.9	1685.7	1697.1	1688.1	1695.6	1678.3
1984	1680.4	1691.5	1691.5	1699.6	1692.5	1680.8	1675.5	1675.4	1696.9	1705.7	1711.7	1715.2	1693.1
1985	1710.9	1712.7	1713.0	1716.1	1710.1	1696.9	1680.0	1695.4	1714.5	1719.1	1727.5	1723.5	1710.0
1986	1708.7	1708.4	1707.6	1729.2	1728.9	1711.0	1699.4	1690.0	1724.3	1729.2	1719.8	1733.3	1715.8
1987	1734.9	1727.0	1724.9	1738.8	1727.5	1723.4	1702.6	1702.9	1723.0	1741.8	1746.6	1754.5	1729.0
1988	1750.1	1745.0	1752.8	1752.2	1743.7	1731.3	1718.7	1722.5	1741.2	1744.9	1752.2	1759.1	1742.8
1989	1758.7	1760.7	1755.9	1763.6	1759.6	1747.2	1729.0	1730.7	1761.3	1764.0	1761.6	1757.6	1754.2
1990	1765.3	1767.2	1769.5	1766.2	1759.4	1754.1	1741.3	1733.7	1771.9	1791.7	1782.3	1791.8	1766.2
1991	1784.0	1781.6	1783.3	1786.1	1780.5	1766.4	1751.4	1754.0	1773.1	1779.6	1779.0	1782.9	1775.2

^aThese atmospheric CH₄ concentrations represent monthly averages calculated as arithmetic means of daily averages derived from in situ measurements taken 12–72 times per day. All data, including individual in situ measurements (~119,000), daily averages, and monthly averages are available at no cost in electronic form from CDIAC. Readers who wish to use these data in specific model exercises or research exercises should first refer to Khalil et al. (1993).

^bAnnual values were calculated by averaging monthly values when all 12 were available.

CITE AS: Khalil, M.A.K., and R.A. Rasmussen. 1994. Atmospheric CH₄ record from in situ measurements at Cape Meares. pp. 361–365. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

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D.E.J. Worthy, N.B.A. Trivett, M.K. Ernst

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Period of Record

1988–93

Methods

The automated quasi-continuous measurements of CH₄ at Alert, Northwest Territories, Canada, are made by using a Hewlett Packard (HP) 5890 gas chromatograph (GC) equipped with a flame ionization detector (FID) and an HP 5790 nickel catalyst to allow the measurement of CO₂ on the same sample run. The sampling module consist of a Valco oven (Model HVE-3) equipped with a thermostat and housing a 4-stream Valco selection valve and a 6-port Valco sampling valve equipped with appropriate electrical actuators and on/off flow control solenoid valves. An HP 3392A computing integrator acquires and processes the FID output and also controls the automated operation of the analysis procedure by means of programmed external timed events and appropriate connection to an HP 19405A Sampler/Event Control Module (S/ECM). A Campbell Scientific datalogger (Model CR21x) connected to the serial port of the integrator is used to acquire the report file generated by the integrator. The data are automatically transferred to a host computer for subsequent data reduction and analysis.

The automated sampling module is designed to draw in air from separate gas streams, which consist of either calibrated standard gases or ambient air. Standard gases are provided from pressurized cylinders equipped with high-purity, two-stage regulators. Ambient air is drawn in from a glass intake manifold (located on a tower 10 m above ground level) through a 7-micron stainless steel membrane filter and pressurized to 10 psi by a KNF N2202 pump. A glass trap submerged in a 80°C methanol bath is incorporated into the ambient air sample line to determine the ambient CH₄ mixing ratios on a "dry air" basis. Measurements were initially made by using sample aliquots of 1 cm³; however, in April 1993 the sample loop was increased to 3 cm³. The samples are equilibrated to atmospheric pressure before injection onto the chromatographic column (poropak QS) by means of a nitrogen carrier gas.

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Atmospheric CH₄ record from in situ measurements at Alert

D.E.J. Worthy, N.B.A. Trivett, and M.K. Ernst (continued)

The sampling protocol initially consisted of a five-injection cycle repeated every hour: standard, ambient air, standard, ambient air, and standard. This sampling cycle allowed for one injection of ambient air for each half-hour time period. In January 1990, the sampling protocol was changed to a three-injection protocol repeated every half hour: standard, ambient air, and ambient air. This sampling protocol doubled the number of ambient samples from 48 to 96 per day. The CH₄ mixing ratios were initially calculated on the basis of chromatographic peak areas by the HP 3392A integrator; however, on May 24, 1991, the integration procedure was changed to the peak-height method. The CH₄ values are referenced to the AES CH₄ calibration scale, which is propagated from a CH₄-in-air standard purchased from the U.S. National Institute of Standards and Technology SRM (Standard Reference Material) 1658a. The working standards are calibrated from three to five times against a secondary standard maintained at the Atmospheric Environment Service before they are deployed to Alert. The gases are then calibrated at least every 6 months at the station with a transfer standard and at least once after they have been returned.

For further details on the instrumentation and analytical techniques, see Trivett et al. (1989) and Worthy et al. (1994).

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Atmospheric CH₄ record from in situ measurements at Alert

D.E.J. Worthy, N.B.A. Trivett, and M.K. Ernst (continued)

ALERT

Trends

The Canadian baseline air chemistry observatory is located at 82°28' N, 62°30' W, on the northeastern tip of Ellesmere Island in the Canadian Arctic on a plateau 210 m above sea level (ASL). The terrain in the surrounding area is steeply rolling, approximately 100–150 m ASL, with many deep ravines and high cliffs. The land is snow covered for 10 months of the year and in summer has a sparse covering of polar desert vegetation, which has no diurnal effect on the CH₄ mixing ratios. The monitoring site is far removed from the major industrial areas of the Northern Hemisphere and is therefore representative of the tropospheric air over the Arctic basin. The primary function is to monitor the concentration levels of trace atmospheric constituents and their variability and to identify possible long-term trends. Besides the CH₄ program, the observatory at Alert operates continuous monitoring programs for CO₂, ozone, peroxyacetylnitrate, CFC-11, CFC-12, CFC-113, black carbon, condensation nuclei, polyaromatic hydrocarbons, CO, several additional toxic compounds, and other aerosol and meteorological variables. In addition, the operation includes numerous international flask sampling programs for CO₂, CH₄, light hydrocarbons, halocarbons, and stable and radiocarbon isotopes for both CO₂ and CH₄. The CH₄ measurements began officially in November 1987, but the data are available only from January 1988 on. Mixing ratios are reported in parts per billion by volume (ppbv).

During the period January 1988 to December 1991, the CH₄ mixing ratios at Alert increased at an average rate of ~10 ppbv/year. During 1992–93, however, the CH₄ mixing ratios did not increase but rather remained at 1991 levels. Toward the end of 1993, the growth rate increased again to approximately 10 ppbv/year. In addition, the data exhibit a seasonal oscillation with an average amplitude (peak to trough) of ~60 ppbv; maxima and minima usually occur in February and July, respectively. The in situ CH₄ values reported here have been compared with measurements reported from the NOAA/CMDL flask sampling site at Alert and found to generally agree within 5 ppbv after scale adjustments.

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Atmospheric CH₄ record from in situ measurements at Alert

D.E.J. Worthy, N.B.A. Trivett, and M.K. Ernst (continued)

ALERT

*Six-hourly average mixing ratios of atmospheric CH₄ at Alert.**

*The six-hourly average CH₄ mixing ratios plotted here are derived from the same in situ measurements as the monthly averages presented in the accompanying table.

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Atmospheric Methane

Atmospheric CH₄ record from in situ measurements at Alert

D.E.J. Worthy, N.B.A. Trivett, and M.K. Ernst (continued)

ALERT

Mixing Ratios of Atmospheric CH₄

CH₄ mixing ratios^a at Alert (ppbv)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann ^b
1988	1803.3	1805.9	1795.5		1786.9	1772.5	1755.9	1761.1	1790.8	1796.5	1806.4	1812.7	
1989	1807.1	1822.2	1820.6	1798.3	1783.4	1770.5	1764.4	1776.6	1791.7	1797.7	1815.9	1831.2	1798.3
1990	1829.3	1836.4	1821.7	1807.1	1805.1	1786.1	1780.9	1779.2	1791.3	1814.6	1821.7	1831.4	1808.7
1991	1846.3	1846.4	1820.7	1815.7	1806.5	1791.1	1788.4	1797.3	1816.7	1822.6	1834.7	1840.7	1818.9
1992	1864.3	1855.1	1859.9	1836.7	1829.4	1818.0	1798.0	1803.5	1805.5	1819.3	1832.4	1836.9	1829.9
1993	1835.6	1829.2	1833.0	1818.0	1816.1	1807.0	1795.9	1805.1	1823.1	1827.3	1838.2	1844.7	1822.8

^aThese atmospheric CH₄ mixing ratios represent monthly averages calculated as arithmetic means of daily medians derived from in situ measurements taken 48 times daily (before January 1990) or 96 times daily (since the beginning of January 1990). The data, including monthly and six-hourly averages, are available at no cost in electronic form from CDIAC.

^bAnnual values were calculated by averaging monthly values when all 12 were available.

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Atmospheric CH₄ record from in situ measurements at Alert

D.E.J. Worthy, N.B.A. Trivett, and M.K. Ernst (continued)

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Introduction

OTHER TRACE GASES AND ATMOSPHERIC AEROSOLS

Understanding the dynamics of global change requires an examination of trace gases other than CO₂ and CH₄ in the atmosphere and an analysis of the role played by aerosols suspended in the atmosphere.

Other Trace Gases

Although less abundant than either CO₂ or CH₄, a number of so-called minor atmospheric trace gases are also radiatively active; that is, they are able to perturb the radiative energy balance of the earth-atmosphere system. Thus, they are potentially important contributors to global climate change. As the release of chemicals into the atmosphere from anthropogenic sources has grown over the last 60 years, atmospheric concentrations of nearly all of the radiatively active gases ("greenhouse gases") have increased. Extrapolations of current trends in the atmospheric concentrations, along with estimates of their relative abilities to alter the global energy balance, suggest that the collective contribution of the minor trace gases to any future global warming may be significant. In addition, some trace gases—notably the chlorofluorocarbons (CFCs) and the halons—rise into the stratosphere and then decompose, releasing halogen atoms that cause chain-reaction destruction of ozone (O₃). Stratospheric O₃, through its absorption of high-energy ultraviolet radiation from the sun, provides a protective shielding for the living organisms (including man) that inhabit the Earth's biosphere. Not surprisingly, the unprecedented seasonal reductions of stratospheric O₃ in the Antarctic and more recently in the Arctic have captured the attention of the news media and the general public.

This chapter presents data for five man-made halocarbons: CCl₃F (CFC-11), a propellant in aerosol sprays and a blowing agent in flexible and rigid foam products; CCl₂F₂ (CFC-12), an aerosol propellant and a common cooling agent in refrigerators; CHClF₂ (HCFC-22), a refrigerant in home air-conditioners; and the halons CBrF₃ (H-1301) and CBrClF₂ (H-1211), the active agents in chemical fire extinguishers. In addition, data are presented for nitrous oxide (N₂O), a gas whose atmospheric origin is not fully understood but may result from a combination of human influences, including groundwater pollution, use of nitrogen fertilizers, combustion, and deforestation. These six gases were selected because they are radiatively important and they are potential depletors of stratospheric O₃. Furthermore, high-quality measurements of their atmospheric concentrations during several years are available from globally distributed sites. Readers familiar with *Trends '91* may note that the data on atmospheric trace gases have been substantially increased in *Trends '93*: additional species (HCFC-22, H-1301, and H-1211) are presented, and additional monitoring sites are included.

Some trace gases have not been included in this compilation although they are potentially important in terms of radiative activity and ability to deplete stratospheric O₃. Examples include CFC-113 (CCl₂FCClF₂), a cleaning solvent in the electronics industry; methylchloroform (CH₃CCl₃), an industrial solvent; and tropospheric O₃, which results from photochemical action on other pollutants such as the oxides of nitrogen (NO_x). At present, data on the atmospheric concentrations of these gases are limited, or the gases are thought to have less impact than those presented in this chapter.

INTRODUCTION

Atmospheric Aerosols

Efforts to accurately estimate human influence on the Earth's radiative energy balance must address the effects of atmospheric aerosols, very small solid particles (from $\sim 10^{-3}$ to $>10^2$ μm in radius) suspended in the troposphere or stratosphere. Aerosols are generated by natural processes, including volcanoes and windborne transit of soil or sea salt, and by human industrial activities. The latter consist primarily of fossil fuel combustion and metal smelting, which produce gases containing sulfur, carbon, and nitrogen. Chemical reactions in the atmosphere convert these gases to particulate matter, chiefly sulfate (SO_4^{2-}) compounds and elemental carbon. Atmospheric aerosols can absorb and scatter solar radiation, and they can act as condensation nuclei in cloud formation. Recent studies suggest that anthropogenic aerosols produce a cooling effect on the earth-atmosphere system of perhaps the same order of magnitude as the warming effect produced by anthropogenic greenhouse gases.

The presentation of atmospheric aerosol data in this chapter is a new addition to the *Trends* series. Data are presented for two variables—atmospheric solar transmission and aerosol optical depth—each of which is measured over a broad range of the solar spectrum. These variables were selected because they are indices of the overall loss of solar radiation at the Earth's surface due to absorption and scattering by atmospheric aerosols. Furthermore, data for these two variables are available in continuous records of long duration from one or more sites located relatively far from significant sources of pollution.

Researchers have also recorded high-quality measurements for other aerosol-related variables, including cloud condensation nuclei concentration, aerosol scattering extinction coefficients (measured at a number of discrete wavelengths), and lidar backscattering. At present, however, the data records for these variables are of limited duration or are of relatively specialized use, so they are not included in this report. It is our hope to be able to present some of these data in future editions of *Trends*.

Chapter Synopsis

The following pages provide data for N_2O concentrations found in ice cores; monthly averages for global and hemispheric concentrations of CFC-11 and CFC-12, as derived from a globally distributed monitoring network; monthly averages for atmospheric concentrations of several trace gases (selected from among the species CFC-11, CFC-12, HCFC-22, H-1301, H-1211, and N_2O), measured at a number of individual monitoring sites (see figure on top of the facing page); estimates of annual atmospheric releases of CFC-11 and CFC-12; atmospheric solar transmission measurements obtained at Mauna Loa (Hawaii, U.S.A.); and aerosol optical depth anomalies recorded at several globally distributed sites. The atmospheric concentration data were obtained from two sources: the Atmospheric Lifetime Experiment/Global Atmospheric Gases Experiment (ALE/GAGE) and the National Oceanic and Atmospheric Administration Climate Monitoring and Diagnostics Laboratory's (NOAA/CMDL's) Halocarbon Flask Sampling Program. The figure on the bottom of the facing page presents three representative N_2O records: the Byrd ice core, showing atmospheric concentrations during the period 3100–150 years BP; the Law Dome BHD ice core, showing atmospheric concentrations during the period 1520–1966; and the ALE/GAGE record from Barbados, a site with a continuous record that is representative of the trends observed at other monitoring sites. A comparison of these records reveals a significant increase in atmospheric N_2O concentrations during the past 100 years.

Location of sites for which trace gas concentration data or atmospheric aerosol data are presented in this chapter.

Atmospheric N_2O concentrations during the past 3100 years, according to analyses of the 1968 and 1971 Byrd ice cores (Rasmussen and Khalil), the Law Dome BHD ice core (Etheridge et al.), and the ALE/GAGE record from Barbados (Prinn et al.).

INTRODUCTION

Readers may note that two apparently different systems of units have been used in presenting the atmospheric trace gas data in this chapter. For most of the modern atmospheric trace gas data provided by NOAA/CMDL and ALE/GAGE, values are given as *mixing ratios* in parts per trillion (1×10^{12}); for N_2O , units are in parts per billion (1×10^9). For data on N_2O in ice cores, however, levels are presented as *concentrations* in parts per billion by volume. These differences in unit designations reflect the preferences of the researchers who have contributed their respective data sets for inclusion in *Trends '93*. In the context of atmospheric trace gases, *concentration* in parts per billion by volume refers to the number of volumes of trace gas per billion volumes of sample. In this same context, *mixing ratio* in parts per billion is derived by dividing the number of moles of trace gas by the total number of moles in the sample and then multiplying the quotient by 1 billion. Assuming that the volume of a gas is proportional to the number of moles contained within the volume (this assumption should be valid for trace gases in air under the conditions that atmospheric measurements are routinely carried out), we can expect that trace gas concentrations should be equivalent to trace gas mixing ratios. For all practical applications, therefore, users of *Trends '93* should consider the terms *concentration* and *mixing ratio* to be interchangeable.

Readers should credit the principal investigators and their organizations listed at the beginning of each set of data records when referring to the data in *Trends '93*. To facilitate correct referencing, each set of records provides a full citation by which contributions in the section should be referenced. In addition, readers are encouraged to contact CDIAC before applying the data in specific model exercises or research exercises. Some of the data are preliminary and may be subject to change. All of the data presented here are available in digitized form from CDIAC at no cost.

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Period of Record

43,000–680 years BP (Byrd Station); 1781–1947 A.D. (Dye 3)

Methods

Samples of air from bubbles trapped in ice cores from Byrd Station, Antarctica, and Dye 3 Station, South Greenland, were analyzed to obtain information about the composition of the Earth's atmosphere at various times in the past. The Byrd Station ice cores were drilled in 1968 (Ueda and Garfield 1969) and 1989 (Langway and Osada 1991). The Byrd ice samples are part of a collaboration between the University of Bern and the State University of New York at Buffalo. The Dye 3 ice core was drilled in 1988 by the University of Bern. Ice samples (~500 g) were ground in a dry extraction vacuum system with a milling cutter to open the bubbles and release the entrapped air (with an extraction efficiency of ~75–85%). Nitrous oxide (N₂O) and CO₂ were separated from the extracted air by freezing them out in a liquid nitrogen cold finger apparatus. The CO₂ concentration was determined volumetrically (the volume of N₂O was considered negligible because of its very small proportion in the mixture), and the N₂O:CO₂ ratio was determined by mass spectrometry. The N₂O:air mixing ratio was calculated by multiplying the N₂O:CO₂ ratio by the CO₂:air mixing ratio. The extraction procedure was checked by analyzing an air standard containing CO₂ and N₂O together with artificial bubble-free ice. This analysis revealed an enrichment in N₂O [$\sim 10 \pm 5$ parts per billion by volume (ppbv)], probably due to friction between the metal surfaces in the ice-milling apparatus. Consequently, all sample results were corrected for this effect. An additional standardization was performed by analyzing (both with and without processing through the ice-milling system) an artificial air sample from the Grenoble (France) ice core laboratory. The accuracy of the mass-spectrometric method of analysis was checked by measuring the N₂O content of air samples from Jungfraujoch, Switzerland, and comparing the results with those obtained through gas chromatography (the most common alternative method of analysis). The overall uncertainty of the N₂O concentration measurements was estimated to be ~10–12 ppbv for the ice core samples.

Byrd Station
Antarctica
79°59' S,
120°01' W

Dye 3
Greenland
65°11' N,
43°50' W

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Historical N₂O record from ice cores at Byrd Station and Dye 3

M. Leuenberger and U. Siegenthaler (continued)

The ages of the ice core samples from the Byrd cores were calculated through the use of a depth-age scale developed by C.U. Hammer of the University of Copenhagen. The age of the ice core air was then calculated as the age of the ice minus 220 years. The air in the trapped bubbles is not as old as the ice because the bubbles take years to seal during the transition from firn (i.e., granular packed snow) to ice (see Schwander and Stauffer 1984). The ages for the Dye 3 core were calculated by A. Sigg of the University of Bern from H₂O₂ measurements from another Dye 3 ice core drilled in 1986. For the Dye 3 samples, the age of the ice core air was calculated as the age of the ice minus 76 years.

Further details on the methods of sampling and analysis are given in Leuenberger and Siegenthaler (1992) and in Leuenberger et al. (1992).

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Historical N₂O record from ice cores at Byrd Station and Dye 3

M. Leuenberger and U. Siegenthaler (continued)

BYRD STATION AND DYE 3

Trends

The record from the Byrd 1968 ice core spans the period 43,000–800 years BP. In the early Holocene (ca. 10,000 years BP) the N₂O concentration averaged ~265 ppbv and remained at similar levels for the remainder of the period recorded for the Byrd 1968 core. During this period, the scatter of the data is on the order of the experimental error (~10–12 ppbv). Prior to the Holocene, the record shows a lowering of N₂O concentrations, which reached a minimum of ~190 ppbv during the Last Glacial Maximum (25,000–20,000 years BP). The pre-Holocene data also show a larger scatter than was observed for the Holocene. For the period 30,000–45,000 years BP, N₂O concentrations were ~200–250 ppbv, a range which is intermediate between the low values of the Last Glacial Maximum and the high values of the Holocene.

During the past 1000 years, N₂O concentrations decreased from ~280 ppbv during the 12th century (Byrd 1968 core, 830 and 890 years BP) to ~260 ppbv during the 18th and 19th centuries (Dye 3 core, 1781–1868), and an intermediate value of ~270 ppbv occurred ca. 1300 (Byrd 1989 core, 680 years BP). The higher values in the 20th century (Dye 3 core, 1908–47) may indicate an expected increase in N₂O resulting from the industrial revolution, whereas the high values for the years 1879 and 1898 may be outliers. The values reported here for pre-industrial N₂O (i.e., those for 1781–1868, excluding the 1788 and 1790 measurements) are lower than those from other ice cores presented in *Trends '93* (see pp. 385–389 and pp. 391–394.), namely those from Crête, Camp Century, and Byrd Station (Khalil and Rasmussen 1988) and from Law Dome (Etheridge et al. 1988).

Concentrations of atmospheric N₂O from the Byrd Station ice cores.

Concentrations of atmospheric N₂O from the Dye 3 ice core.

CITE AS: Leuenberger, M., and U. Siegenthaler. 1994. Historical N₂O record from ice cores at Byrd Station and Dye 3. pp. 380–384. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Historical N₂O record from ice cores at Byrd Station and Dye 3

M. Leuenberger and U. Siegenthaler (continued)

BYRD STATION AND DYE 3

Concentrations of N₂O from Ice Cores at Byrd Station and Dye 3^a

Ice core depth (m)	Mean age of air (yr BP)	Mean year of air enclosure (A.D.)	N ₂ O concentration (ppbv)	Ice core depth (m)	Mean age of air (yr BP)	Mean year of air enclosure (A.D.)	N ₂ O concentration (ppbv)
Byrd, 1989 ^b				Byrd, 1968 ^b (continued)			
133.6	680		270.9	1701.1	36,880		249.0
Byrd, 1968 ^b				1798.9	42,590		226.3
146.3	830		277.2	1803.8	42,890		210.9
152.7	890		274.9	Dye 3			
995.8	10,530		272.4	169.4		1781	260.0
1000.7	10,610		250.0	169.2		1782	259.4
1001.3	10,620		258.5	166.1		1788	270.1 ^c
1003.6	10,650		273.1	165.5		1790	267.1 ^c
1090.6	12,080		261.9	160.7		1799	259.9
1203.9	14,610		219.0	150.7		1817	258.2
1205.3	14,670		203.0	140.7		1839	258.1
1391.4	21,800		199.7	130.9		1858	264.8
1410.9	22,640		183.7	125.2		1868	258.4
1459.5	24,790		185.4	119.9		1879	287.4
1526.8	27,920		200.7	110.1		1898	296.1
1571.7	30,090		234.5	105.2		1908	269.9
1617.8	32,420		224.5	95.1		1928	273.8
1642.8	33,730		237.6	90.7		1936	270.9
1658.7	34,570		202.4	85.3		1947	274.0
1688.4	36,180		233.2				

^aThese atmospheric N₂O concentrations derived from ice cores were published in Leuenberger and Siegenthaler (1992) and are available at no cost in electronic form from CDIAC.

^bYear that the ice core was drilled.

^cTwo samples from the Dye 3 core were influenced by melt-layer formation (i.e., melting that occurred after ice core formation), as identified from enriched CO₂ concentration. These two measurements were therefore not included in the accompanying graph.

CITE AS: Leuenberger, M., and U. Siegenthaler. 1994. Historical N₂O record from ice cores at Byrd Station and Dye 3. pp. 380–384. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

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Other Trace Gases and Atmospheric Aerosols
Historical N₂O record from ice cores at Crête,
Camp Century, and Byrd Station

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Period of Record

3100–150 years BP

Methods

Samples from the Crête and Camp Century (Greenland) ice cores and from the Byrd Station (Antarctica) ice core were obtained from the National Science Foundation ice core facility at the State University of New York at Buffalo. Core samples were typically about 15 cm long and were kept frozen until analysis. The samples were prepared by scraping off the outer 1–3 cm to avoid contamination and cutting the samples into two or three pieces for replication of the measurements. Each replicate was sealed in an electropolished stainless steel cylinder, which was then flushed ten times with nitrogen-free helium and pressurized to 1000 torr. Afterwards the cylinders were placed in a warm water bath to melt the ice and release the trapped air bubbles. The air in the headspace of the cylinders was then sampled, and the concentrations of N₂O, CH₄, N₂, O₂, and CFCl₃ were measured.

The gas concentrations were measured by established gas-chromatographic techniques. Determinations of N₂O were made by electron capture gas chromatography (EC-GC) using a Perkin-Elmer 3920B instrument. Measurements of N₂ and O₂ were used to calculate the dilution ratio of ice core air in the helium-filled cylinders. The presence of CFCl₃ (CFC-11), an anthropogenic fluorocarbon not present before ca. 1930, was used as an index of contamination of the ice core air. For each ice core sample, the concentration of N₂O in the extracted air was calculated from the chromatographic measurement, the dilution ratio in the cylinder, and an estimate of the equilibrium partitioning of N₂O between the air and the meltwater. For further details, see Khalil and Rasmussen (1988) and Rasmussen and Khalil (1984).

Crête
Greenland
77°07' N, 37°19' W
Camp Century
Greenland
77°11' N, 61°09' W

Byrd Station
Antarctica
79°59' S, 120°01' W

CITE AS: Khalil, M.A.K., and R.A. Rasmussen. 1994. Historical N₂O record from ice cores at Crête, Camp Century, and Byrd Station. pp. 385–389. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Historical N₂O record from ice cores at Crête,
Camp Century, and Byrd Station

M.A.K. Khalil and R.A. Rasmussen (continued)

CRÊTE, CAMP CENTURY, AND BYRD STATION

Trends

Khalil and Rasmussen (1988) detected no systematic trends in the data spanning the period 3100–150 years BP. The data are highly variable, and each century is generally represented by only a few values. The average concentration of N₂O in the preindustrial era was estimated as 285 ± 1 (90% confidence limits) parts per billion by volume (ppbv). No significant difference was found between Arctic and Antarctic measurements. Fitting an exponential growth model to these ice core data and their recent atmospheric flask data, Khalil and Rasmussen (1988) found that N₂O levels were constant throughout the preindustrial era until ca. 1940–50, when levels began to increase significantly.

The ages of the ice cores were estimated by C.C. Chou of the Scripps Institution of Oceanography (San Diego, California). These age estimates were used to derive linear functions of sample age vs depth, from which the reported ages were calculated. The air in the trapped bubbles is not as old as the ice because the bubbles take years to seal during the transition from firn (i.e., granular packed snow) to ice (see Schwander and Stauffer 1984). On the basis of the estimated average length of time of this transition, the age of the air was calculated as the age of the ice minus 90 years.

CITE AS: Khalil, M.A.K., and R.A. Rasmussen. 1994. Historical N₂O record from ice cores at Crête, Camp Century, and Byrd Station. pp. 385–389. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Other Trace Gases and Atmospheric Aerosols
 Historical N₂O record from ice cores at Crête,
 Camp Century, and Byrd Station

M.A.K. Khalil and R.A. Rasmussen (continued)

CRÊTE, CAMP CENTURY, AND BYRD STATION

*Concentrations of atmospheric N₂O from ice cores drilled at Crête and
 Camp Century (Greenland) and at Byrd Station (Antarctica).*

CITE AS: Khalil, M.A.K., and R.A. Rasmussen. 1994. Historical N₂O record from ice cores at Crête, Camp Century, and Byrd Station. pp. 385-389. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Historical N₂O record from ice cores at Crête,
Camp Century, and Byrd Station

M.A.K. Khalil and R.A. Rasmussen (continued)

CRÊTE, CAMP CENTURY, AND BYRD STATION

Concentrations of N₂O from Polar Ice Cores^a

Ice core depth (m)	Age of air (yr BP)	N ₂ O concentration (ppbv)	Ice core depth (m)	Age of air (yr BP)	N ₂ O concentration (ppbv)
Crête, 1974^b			Byrd, 1968^b (continued)		
97.65–97.97	200	295	131.00–131.85	760	291
119.14–119.53	270	281	159.31–159.46	1000	283
139.56–139.85	340	278	171.14–171.29	1100	285
149.67–150.13	370	286	186.24–186.39	1230	279
168.96–169.29	430	287	189.60–189.80	1260	288
190.28–190.56	500	274	200.83–201.00	1360	278
Camp Century, 1961^b			221.92–222.06	1540	290
89.81–90.01	200	283	260.87–261.13	1880	284
97.96–98.18	230	289	270.83–270.98	1970	292
101.00–101.15	240	278	314.11–314.26	2340	280
118.57–118.77	300	283	319.14–319.34	2390	297
123.02–123.22	310	276	370.61–370.61	2830	282
130.52–130.72	330	291	381.96–382.11	2930	304
144.94–145.14	380	280	400.74–400.98	3090	283
Camp Century, 1962^b			Byrd, 1971^b		
75.99–76.29	160	280	61.28–61.58	150	290
83.45–83.62	180	287	76.52–76.80	280	280
92.11–92.33	210	278	90.55–90.75	400	286
100.39–100.59	240	284	105.20–105.40	530	297
108.92–109.14	260	282	106.19–106.39	540	279
117.26–117.46	290	290	114.69–114.89	610	283
125.14–125.34	310	286	119.82–120.04	660	282
131.50–131.63	330	280	124.39–124.62	700	289
141.24–141.44	360	293	135.29–135.49	790	280
149.14–149.37	390	290	141.49–141.64	840	292
Camp Century, 1963–66^b			159.54–159.70	1000	286
77.91–78.10	170	282	166.37–166.57	1060	278
86.59–86.70	190	299	173.84–173.99	1130	283
106.98–107.15	260	269	175.63–175.83	1140	284
116.94–117.14	290	274	186.39–186.59	1230	280
128.42–128.62	320	286	190.85–191.01	1270	281
138.10–138.30	360	288	195.44–195.65	1310	292
147.24–147.41	380	290	201.00–201.20	1360	291
157.42–157.59	420	270	204.57–204.72	1390	277
167.07–167.22	450	281	220.95–221.15	1530	281
176.82–176.99	480	287	225.36–225.53	1570	297
187.20–187.38	510	293	230.94–231.14	1620	284
197.90–198.02	540	292	233.70–233.85	1640	287
217.70–217.92	600	283	241.37–241.57	1710	287
237.52–237.72	670	294	252.13–252.33	1800	292
248.20–248.40	700	289	261.13–261.33	1880	282
287.27–287.44	820	280	265.21–265.36	1920	285
Byrd, 1968^b			271.08–271.28	1970	288
90.19–90.37	400	291	281.03–281.23	2050	292
109.84–109.99	570	287			

^aThese nitrous oxide concentrations derived from ice cores were published in Khalil and Rasmussen (1988) and are available at no cost in electronic form from CDIAC.

^bYear that the ice core was drilled.

CITE AS: Khalil, M.A.K., and R.A. Rasmussen. 1994. Historical N₂O record from ice cores at Crête, Camp Century, and Byrd Station. pp. 385–389. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

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Other Trace Gases and Atmospheric Aerosols

Historical N₂O record from the "BHD" ice core at Law Dome

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Period of Record

1520–1966

Methods

The 473-m-long ice core designated "BHD" was thermally drilled from the summit of Law Dome, Antarctica, by the 1977 Australian National Antarctic Research Expedition. Air bubbles from various times in the past were trapped in ice below the air-occlusion zone (~70 m for the BHD core). The atmospheric composition (CH₄, CO₂, and N₂O) of the trapped air in core samples has been analyzed. Segments of the core were selected carefully to ensure that the sample composition was not altered by either microfracturing or melting after the coring process. The core segments were placed in a stainless steel vacuum apparatus and milled into small chips to release the entrapped air. Air samples were then dried, collected in a liquid helium cold finger apparatus, and analyzed for N₂O through the use of a gas chromatograph equipped with an electron-capture detector. Two chlorofluorocarbons, CCl₃F and CCl₂F₂, were also measured, in order to check the quality of the ice core and the extraction process. In addition, air samples of known composition and comparative volume were used to test the effect of the extraction and analysis procedures on the ice core gas samples.

Calibration gases were obtained from stainless steel tanks filled cryogenically with uncontaminated maritime air at the Australian Maritime Observatory at Cape Grim. Concentrations of the calibration gases were determined by comparison with N₂O standards obtained from the Oregon Graduate Center.

Further details on the methods of sampling and analysis are given in Etheridge et al. (1988).

*Law Dome
Antarctica
66°43' S, 112°50' E
1375 m above MSL*

CITE AS: Etheridge, D.M., G.I. Pearman, and F. de Silva. 1994. Historical N₂O record from the "BHD" ice core at Law Dome. pp. 391–394. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

LAW DOME (SUMMIT, "BHD" SITE)

Trends

The Law Dome summit is a very favorable site for studying the composition of air entrapped in ice cores. Because the average annual rate of snow accumulation is high (0.65 m/year water equivalent), occluded air from as recent as 1966 may be analyzed with an age resolution of ~17 years (i.e., 80% of the air in a given sample has an age within the 17-year interval). The site has been separated from the main Antarctic ice sheet for a long time in relation to the interval represented by the ice core record, so the flow is essentially vertical. Thus, there is little distortion caused by lateral ice flow. In addition, the low mean annual temperature of -22°C precludes any interference by ice melt layers.

The data suggest that the atmospheric N₂O concentration has increased by ~18 parts per billion by volume (ppbv) over the past 300 years. The three high values recorded for 1520 A.D., 1520 A.D., and 1602 A.D. are anomalous and probably do not represent actual concentrations. The results presented here for the BHD ice core are similar to results for some other ice cores presented in *Trends '93* that have overlapping periods of record, namely from Camp Century and Byrd Station (pp. 385-389; see also Khalil and Rasmussen 1988); however, the values for the BHD ice core are somewhat higher than those from Dye 3 (pp. 380-384; see also Leuenberger and Siegenthaler 1992).

Concentrations of atmospheric N₂O from the Law Dome BHD ice core.

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Historical N₂O record from the "BHD" ice core at Law Dome

D.M. Etheridge, G.I. Pearman, and F. de Silva (continued)

LAW DOME (SUMMIT, "BHD" SITE)

Concentrations of N₂O from the Law Dome BHD Ice Core^a

Mean date of air enclosure (yr A.D.)	N ₂ O concentration (ppbv) ^b	Mean date of air enclosure (yr A.D.)	N ₂ O concentration (ppbv) ^b
1966	298.9	1796	299.4
1966	322.9	1735	281.7
1964	304.8	1735	296.6
1964	305.3	1735	302.6
1947	289.5	1730	302.8
1937	301.4	1729	272.2
1913	307.3	1718	289.9
1912	296.2	1718	281.8
1912	285.7	1714	284.4
1901	309.0	1712	296.7
1901	305.7	1712	299.9
1890	290.7	1702	283.9
1890	294.1	1686	290.6
1878	287.3	1662	284.1
1870	312.9	1610	282.3
1865	296.6	1606	284.5
1865	290.0	1606	283.5
1860	284.5	1602	329.8
1826	308.2	1520	328.3
1808	301.1	1520	303.2

^aThese atmospheric N₂O concentrations derived from the Law Dome BHD ice core were published in Etheridge et al. (1988) and are available at no cost in electronic form from CDIAC.

^bIn instances in which two or more values are presented for a single air age (e.g., two values are presented for the year 1966), the arithmetic mean was used for generating the graph. In addition, the data for years 1520 and 1602 were considered as outliers and not plotted.

CITE AS: Etheridge, D.M., G.I. Pearman, and F. de Silva. 1994. Historical N₂O record from the "BHD" ice core at Law Dome. pp. 391-394. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

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- Khalil, M.A.K., and R.A. Rasmussen. 1988. Nitrous oxide: Trends and global mass balance over the last 3000 years. *Annals of Glaciology* 10:73–79.
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Other Trace Gases and Atmospheric Aerosols

Atmospheric CFC-11 (CCl_3F), CFC-12 (CCl_2F_2), and N_2O from the ALE/GAGE network

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Adrigole • Barbados • Cape Grim • Cape Meares • Mace Head • Samoa

Period of Record

(see record for individual site)

Methods

The Atmospheric Lifetime Experiment (ALE) included measurements of CFC-11 (CCl_3F), CFC-12 (CCl_2F_2), and nitrous oxide (N_2O) at five globally distributed sites beginning in July 1978 (Prinn et al. 1983). The experiment was designed to accurately determine the atmospheric concentrations and long-term trends of several important trace gases so that their global circulation rates and globally averaged atmospheric lifetimes could be calculated. Beginning in late 1981 at Cape Grim (Tasmania) and later at other sites, additional measurements were collected using a new instrument as part of the Global Atmospheric Gases Experiment (GAGE). By mid-1986, ALE had ended and was succeeded

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Other Trace Gases and Atmospheric Aerosols
Atmospheric CFC-11 (CCl₃F), CFC-12 (CCl₂F₂), and N₂O
from the ALE/GAGE network

R.G. Prinn, R.F. Weiss, F.N. Alyea, D.M. Cunnold, P.J. Fraser, P.G. Simmonds,
A.J. Crawford, R.A. Rasmussen, and R.D. Rosen (continued)

by GAGE at all sites except the Adrigole (Ireland) station, which closed in December 1983 and was replaced by the GAGE station at Mace Head in January 1987.

Air samples, collected 4 times daily for ALE and 12 times daily for GAGE, were drawn in through an air intake located 2–15 m above the instrument building and were moved along a stainless steel line by a noncontaminating metal bellows pump. The air was then filtered and dried to roughly 700 parts per million by volume (ppmv) of H₂O. Halocarbon measurements were made by means of Hewlett Packard HP5840A (ALE) or HP5880A (GAGE) electron capture gas chromatographs fitted with two columns. Measurements of CFC-11, CFC-12, and N₂O were made from a 2- or 3-mL air sample by using a 1.8-m × 6.4-mm isothermal (50°C) column packed with 80–100 mesh Porasil D. Measurements of CFC-11 were also made from a 5- or 7-mL air sample by using a column that was the same size and the same temperature as the first but packed with 10% SP2100 silicone coated on 100–120 mesh Supelcoport. The carrier gas consisted of a mixture of 95% argon and 5% methane. Halocarbon mixing ratios in the samples were determined from integrated chromatographic peak areas or, occasionally, peak heights, by comparison with peaks from the nearest (in time) run of a reference gas. The reference gas was prepared from primary standards by exponential dilution and coulometric techniques (see Rasmussen and Lovelock 1983).

All data were subjected to extensive review procedures to detect any errors or malfunctions. In general, the first 6 months of ALE and GAGE data at each site are less reliable than later data because of uncertainties associated with the start-up of a new field instrument (Prinn et al. 1990). Measurements were also flagged to reflect "pollution" events (i.e., contamination by air masses containing higher than background levels of the halocarbons being measured). Such events were detected by concurrent increases in at least three of the measured species, usually from among the compounds CFC-11, CFC-12, and methyl chloroform (Prinn et al. 1992). At the Adrigole site, the occurrence of measurable levels of perchloroethylene, an anthropogenic species that is usually well correlated with rises in the other measured halocarbons, was also employed as a means of detecting pollution episodes. For N₂O, local pollution events were detected by a combination of forecasting (through the use of weather maps) and inspection of the data. For further details on methodology and data selection, see Prinn et al. (1983) and Cunnold et al. (1994).

CITE AS: Prinn, R.G., R.F. Weiss, F.N. Alyea, D.M. Cunnold, P.J. Fraser, P.G. Simmonds, A.J. Crawford, R.A. Rasmussen, and R.D. Rosen. 1994. Atmospheric CFC-11 (CCl₃F), CFC-12 (CCl₂F₂), and N₂O from the ALE/GAGE network. pp. 396–420. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric CFC-11 (CCl_3F), CFC-12 (CCl_2F_2), and N_2O
from the ALE/GAGE network

R.G. Prinn, R.F. Weiss, F.N. Alyea, D.M. Cunnold, P.J. Fraser, P.G. Simmonds,
A.J. Crawford, R.A. Rasmussen, and R.D. Rosen (continued)

ADRIGOLE

Period of Record

1978–83

Trends

The ALE site at Adrigole, Ireland, was operated under the supervision of J.E. Lovelock of Reading University and P.G. Simmonds of the University of Bristol. The site is located on the west coast of Ireland about 400 m from Bantry Bay and 50 m above mean sea level. Measurements at the site began in July 1978 and continued through December 1983. Although generally receiving clean oceanic air from the westerly sector, the site at times (particularly in winter) received polluted air from eastern Ireland, Great Britain, and continental Europe. Altogether, about one-third of the measurements made at this site showed some evidence of pollution.

The monthly mean mixing ratio of CFC-11 increased from 158.2 parts per trillion (ppt) in July 1978 to 201.3 ppt by the end of 1983. The mixing ratio of CFC-12 increased from 284.4 to 380.5 ppt during the same period. For both CFC-11 and CFC-12, the increases were nearly linear during the period of measurement, averaging 8.1 ppt/year for CFC-11 and 17.5 ppt/year for CFC-12. In each case, the trend is highly significant ($P < 0.0001$).

The time series of the monthly mean mixing ratios of N_2O is interrupted from February 1979 through March 1980. Data collected during this period were discarded because of instrumental problems indicated by large variability in the analyzed N_2O values from the calibration gas (Prinn et al. 1983). Although the scatter is considerable, the remaining values nevertheless show a highly significant ($P < 0.0001$) trend. The monthly mixing ratio of N_2O increased from 301.5 parts per billion (ppb) in July 1978 to 302.9 ppb in December 1983. Prinn et al. (1990) calculated that the mixing ratio of N_2O increased on average 0.76 ± 0.17 ppb/year for the 10-year period July 1978 through June 1988. (This calculation employed data from Adrigole for the period 1978–83 and additional data from Mace Head, the successor site to Adrigole for GAGE, for an 18-month period during 1977–78.) No significant periodic oscillation was evident. Throughout the period of record, the daily N_2O variability was generally larger than that at equatorial and Southern Hemisphere sites.

CITE AS: Prinn, R.G., R.F. Weiss, F.N. Alyea, D.M. Cunnold, P.J. Fraser, P.G. Simmonds, A.J. Crawford, R.A. Rasmussen, and R.D. Rosen. 1994. Atmospheric CFC-11 (CCl_3F), CFC-12 (CCl_2F_2), and N_2O from the ALE/GAGE network. pp. 396–420. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Other Trace Gases and Atmospheric Aerosols
Atmospheric CFC-11 (CCl_3F), CFC-12 (CCl_2F_2), and N_2O
from the ALE/GAGE network

R.G. Prinn, R.F. Weiss, F.N. Alyea, D.M. Cunnold, P.J. Fraser, P.G. Simmonds,
A.J. Crawford, R.A. Rasmussen, and R.D. Rosen (continued)

ADRIGOLE

Monthly average CFC-11, CFC-12, and N_2O mixing ratios at Adrigole.

CITE AS: Prinn, R.G., R.F. Weiss, F.N. Alyea, D.M. Cunnold, P.J. Fraser, P.G. Simmonds, A.J. Crawford, R.A. Rasmussen, and R.D. Rosen. 1994. Atmospheric CFC-11 (CCl_3F), CFC-12 (CCl_2F_2), and N_2O from the ALE/GAGE network. pp. 396–420. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Other Trace Gases and Atmospheric Aerosols

Atmospheric CFC-11 (CCl₃F), CFC-12 (CCl₂F₂), and N₂O from the ALE/GAGE network

R.G. Prinn, R.F. Weiss, F.N. Alyea, D.M. Cunnold, P.J. Fraser, P.G. Simmonds, A.J. Crawford, R.A. Rasmussen, and R.D. Rosen (continued)

ADRIGOLE

Adrigole
Bantry Bay, Ireland
52° N, 10° W
50 m above MSL

Atmospheric Mixing Ratios of Trace Gases^a

CFC-11, CFC-12, and N₂O mixing ratios at Adrigole

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann ^b
CFC-11 (parts per trillion)^c													
<i>ALE</i>													
1978							158.2	159.1	159.0	159.5	160.7	162.1	
1979	160.4	161.0	160.3	161.8	163.6	165.1	165.7	166.3	167.7	169.1	169.4	171.0	165.1
1980	170.9	171.1	171.3	172.5	175.0	173.8	174.4	174.4	174.6	175.8	176.4	177.2	173.9
1981	178.1	178.5	179.4	181.2	182.1	182.1	181.8	184.1	186.4	187.3	188.2	188.9	183.1
1982	185.6	185.9	187.1	188.1	188.2	187.7	187.9	188.4	189.7	192.8	193.8	193.8	189.1
1983	192.5	194.0	194.3	196.4	198.1	198.3	197.6	199.5	198.4	200.5	201.9	201.3	197.7
CFC-12 (parts per trillion)^c													
<i>ALE</i>													
1978							284.4	285.7	285.6	288.5	288.3	292.8	
1979	296.2	295.5	294.7	296.5	300.9	300.8	304.1	307.1	306.9	310.4	317.0	315.5	303.8
1980	312.4	312.5	316.6	319.0	321.9	323.1	325.5	326.7	327.4	328.7	331.1	330.7	323.0
1981	332.2	333.4	333.5	336.8	336.8	335.6	335.3	339.5	342.0	344.3	347.0	348.4	338.7
1982	343.9	345.4	347.1	350.1	348.7	354.6	355.5	357.8	361.2	364.4	366.0	364.9	355.0
1983	362.8	365.1	366.5	368.7	373.7	371.9	371.9	375.7	375.8	378.8	380.2	380.5	372.6
N₂O (parts per billion)^c													
<i>ALE</i>													
1978							301.5	299.2	300.0	301.3	300.8	301.0	
1979	301.9												
1980				297.1	293.9	295.3	297.9	298.1	298.6	300.6	301.0	300.0	
1981	298.6	298.6	298.4	300.9	300.6	300.2	299.8	300.7	301.1	301.4	301.9	301.9	300.3
1982	303.2	303.5	303.8	304.3	303.7	304.6	304.1	303.7	303.3	302.7	303.1	303.4	303.6
1983	303.3	304.1	303.9	304.2	304.2	303.9	302.9	303.2	303.3	302.4	303.1	302.9	303.5

^aMonthly mixing ratios for CFC-11 and CFC-12 were calculated by CDIAC by averaging individual (four-times-daily) measurements. For CFC-11, "individual measurements" actually represent averages of the separate measurements made on two different chromatographic columns when both values were available. Tabulated monthly values reflect adjustment by the appropriate calibration factors (see Rasmussen and Lovelock 1983). Measurements flagged as pollution events were not used in calculating monthly averages. Data in *Trends '93*, as well as the complete set of ALE/GAGE data (including all individual measurements), are available at no cost in electronic form from CDIAC.

^bAnnual values were calculated by averaging monthly values when all 12 were available.

^cUnits are expressed as dry air mole fractions $\times 10^{12}$ (CFC-11 and CFC-12) or as dry air mole fractions $\times 10^9$ (N₂O).

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Other Trace Gases and Atmospheric Aerosols
Atmospheric CFC-11 (CCl₃F), CFC-12 (CCl₂F₂), and N₂O
from the ALE/GAGE network

R.G. Prinn, R.F. Weiss, F.N. Alyea, D.M. Cunnold, P.J. Fraser, P.G. Simmonds,
A.J. Crawford, R.A. Rasmussen, and R.D. Rosen (continued)

BARBADOS

Period of Record

1978–91

Trends

The tropical Northern Hemisphere site for the ALE/GAGE program is located at Ragged Point, on the east coast of Barbados ~15 m from the ocean and 18 m above mean sea level. The site is operated under the supervision of P.G. Simmonds of the University of Bristol. Ragged Point is under the influence of easterly winds and generally receives unpolluted oceanic air, except during certain periods of calm conditions when pollutants from the populated inland regions of Barbados reach the site. Measurements at the site began in July 1978 and continued as part of ALE through April 1986. Beginning in August 1985, measurements were also collected as part of GAGE. After the termination of ALE, measurements continued at Barbados as part of GAGE through the end of the period of record (November 1991).

The monthly mean mixing ratio of CFC-11 increased from 151.1 parts per trillion (ppt) in July 1978 to 265.1 ppt in December 1991. Meanwhile, the mixing ratio of CFC-12 increased from 279.5 to 506.6 ppt. Cunnold et al. (1994) reported that the average rate of increase of CFC-11 at Barbados was 9.4 ± 0.1 ppt/year for the period July 1978 to June 1988 but dropped to 6.9 ± 0.3 for the period July 1988 to June 1991. Similarly for CFC-12, Cunnold et al. (1994) found that the average rate of increase was 17.6 ± 0.1 ppt/year for the period July 1978 to June 1988 and 15.5 ± 0.5 for the period July 1988 to June 1991. For both CFC-11 and CFC-12, these trends are highly significant ($P < 0.0001$). Prinn et al. (1983) found a small amplitude cycle in CFC-12 at this site, with a peak in late summer; however, the daily CFC-12 variability was also highest during this season. The data for CFC-11 show no evidence of any significant periodicity.

The time series of the monthly mean mixing ratios of N₂O is somewhat more irregular. The values nevertheless show a highly significant ($P < 0.0001$) trend. The monthly mixing ratio increased from 296.6 parts per billion (ppb) in July 1978 to 310.5 ppb in December 1991. For the 10-year period July 1978 to June 1988, Prinn et al. (1990) calculated that the mixing ratio of N₂O at Barbados increased by an average of 0.94 ± 0.06 ppb/year. In addition, the data were found to exhibit a statistically significant quasi-biennial ($\tau = 2.25$ years) oscillation with an amplitude of 0.45 ppb.

CITE AS: Prinn, R.G., R.F. Weiss, F.N. Alyea, D.M. Cunnold, P.J. Fraser, P.G. Simmonds, A.J. Crawford, R.A. Rasmussen, and R.D. Rosen. 1994. Atmospheric CFC-11 (CCl₃F), CFC-12 (CCl₂F₂), and N₂O from the ALE/GAGE network. pp. 396–420. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric CFC-11 (CCl_3F), CFC-12 (CCl_2F_2), and N_2O
from the ALE/GAGE network

R.G. Prinn, R.F. Weiss, F.N. Alyea, D.M. Cunnold, P.J. Fraser, P.G. Simmonds,
A.J. Crawford, R.A. Rasmussen, and R.D. Rosen (continued)

BARBADOS

Monthly average CFC-11, CFC-12, and N_2O mixing ratios at Barbados.

CITE AS: Prinn, R.G., R.F. Weiss, F.N. Alyea, D.M. Cunnold, P.J. Fraser, P.G. Simmonds, A.J. Crawford, R.A. Rasmussen, and R.D. Rosen. 1994. Atmospheric CFC-11 (CCl_3F), CFC-12 (CCl_2F_2), and N_2O from the ALE/GAGE network. pp. 396-420. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Other Trace Gases and Atmospheric Aerosols
Atmospheric CFC-11 (CCl₃F), CFC-12 (CCl₂F₂), and N₂O
from the ALE/GAGE network

R.G. Prinn, R.F. Weiss, F.N. Alyea, D.M. Cunnold, P.J. Fraser, P.G. Simmonds,
A.J. Crawford, R.A. Rasmussen, and R.D. Rosen (continued)

Barbados (Ragged Point)
Atlantic Ocean
Island seashore
13°10' N, 59°26' W
3 m above MSL

BARBADOS

Atmospheric Mixing Ratios of Trace Gases^a

CFC-11, CFC-12, and N₂O mixing ratios at Barbados

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann ^b
CFC-11 (parts per trillion)^c													
<i>ALE</i>													
1978							151.1	151.3	150.6	150.9	150.5	153.3	
1979	155.5	153.5	154.5	154.8	158.1	157.5	159.4	161.0	159.7	159.4	160.7	162.4	158.0
1980	162.9	163.6	166.8	166.0	166.4	167.3	168.6	169.5	169.8	168.6	171.4	172.2	167.7
1981	172.8	172.9	171.8	173.6	174.2	174.0	175.9	176.1	176.7	177.1	178.3	178.8	175.2
1982	180.2	180.6	180.9	181.7	182.9	183.8	184.9	187.2	186.9	186.7	188.0	189.6	184.4
1983	189.4	189.2	189.3	191.4	191.0	191.1	193.8	196.2	196.3	196.1	196.4	198.1	193.2
1984	198.4	198.9	200.1	199.4	200.0	200.9	202.5	205.4	204.8	205.4	204.6	206.5	202.2
1985	206.8	206.3	207.4	207.3	210.0	208.8	211.6	212.5	211.9	213.6	212.5	216.0	210.4
1986	215.4	217.2	217.5	219.3									
<i>GAGE</i>													
1985								214.1	213.6	215.1	213.9	216.4	
1986	215.4	216.9	217.2	216.8	219.4	222.4	224.6	225.6	227.2	226.1	227.1	228.6	222.2
1987	229.6	230.0	230.0	230.7	232.1	234.7	236.1	237.4	238.4	238.6	236.3	237.5	234.3
1988	239.4	239.3	238.4	238.3	240.6	242.4	244.2	244.7	246.1	240.2	244.0	246.4	242.0
1989	247.7	246.9	248.2	249.1	250.0	251.2	253.6	252.4	251.3	251.9	253.5	253.3	250.7
1990	255.1	254.7		259.0	258.8	258.4	259.1	259.9	260.7	258.5	259.8	260.5	
1991	259.9	259.6	259.2	261.1	261.0	263.8	263.9	264.0	264.1	263.6	263.4	265.1	262.4
CFC-12 (parts per trillion)^c													
<i>ALE</i>													
1978							279.5	280.7	278.9	279.9	278.6	284.1	
1979	287.5	285.8	287.6	291.0	291.3	291.2	294.7	298.9	297.0	297.8	297.4	298.7	293.2
1980	300.0	300.9	304.0	304.5	305.7	309.8	313.0	314.1	314.9	316.2	317.8	319.1	310.0
1981	319.9	320.7	317.1	320.9	322.4	322.4	326.9	327.7	330.7	332.0	333.3	330.0	325.3
1982	333.0	333.9	334.8	339.6	340.8	343.7	344.8	345.8	345.5	345.4	348.2	354.8	342.5
1983	354.8	354.4	354.9	354.9	354.2	354.6	360.0	364.5	365.1	364.6	365.1	367.1	359.5
1984	368.6	369.1	371.3	371.4	375.2	377.1	381.4	384.6	385.3	386.1	385.0	388.7	378.7
1985	389.4	389.6	391.0	391.4	396.0	394.4	399.8	401.1	400.0	402.5	400.7	406.4	396.9
1986	405.4	409.4	408.9	411.2									
<i>GAGE</i>													
1985								397.7	397.6	398.7	402.8	407.3	
1986	405.7	405.1	407.5	408.1	410.5	414.9	419.8	420.9	422.6	422.0	425.1	428.6	415.9
1987	428.6	427.0	427.1	428.4	430.2	433.7	436.0	439.2	441.5	440.1	441.3	443.0	434.7
1988	446.2	447.2	447.7	447.9	451.4	450.1	452.4	454.0	456.0	457.2	463.1	466.5	453.3
1989	466.6		464.3	465.6	467.1	469.5	473.9	476.0	474.8	475.5	478.8	478.6	
1990	482.1	481.8		484.1	486.3	488.0	490.4	491.6	492.4	489.3	492.1	493.5	
1991	493.9	493.9	493.2	496.4	496.6	499.2	501.0	504.3	504.2	503.8	503.4	506.6	499.7

Other Trace Gases and Atmospheric Aerosols

Atmospheric CFC-11 (CCl₃F), CFC-12 (CCl₂F₂), and N₂O from the ALE/GAGE network

R.G. Prinn, R.F. Weiss, F.N. Alyea, D.M. Cunnold, P.J. Fraser, P.G. Simmonds, A.J. Crawford, R.A. Rasmussen, and R.D. Rosen (continued)

BARBADOS

Atmospheric Mixing Ratios of Trace Gases (continued)^a

CFC-11, CFC-12, and N₂O mixing ratios at Barbados

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann ^b
N ₂ O (parts per billion) ^c													
ALE													
1978							296.6	298.8	298.6	298.9	299.3	298.4	
1979	299.2	300.8	299.7	301.0	300.1	300.1	299.6	299.2	299.8	300.2	300.1	300.1	300.0
1980	300.1	299.4	299.5	299.8	300.3	301.0	301.6	301.0	302.5	302.9	301.5	300.6	300.9
1981	300.7	300.6	300.5	301.0	300.2	300.2	300.0	300.2	300.7	301.0	301.2	300.7	300.6
1982	300.6	300.7	301.0	302.8	303.8	304.4	303.8	302.2	302.9	303.0	303.2	303.3	302.6
1983	302.9	303.1	303.5	302.9	302.2	301.0	301.7	302.7	302.4	302.6	302.6	302.5	302.5
1984	302.5	302.8	302.9	302.6	302.9	303.4	303.3	303.8	304.6	305.3	305.7	305.5	303.8
1985	305.3	305.5	305.5	305.7	306.4	306.5	305.8	305.2	305.5	305.9	305.5	305.7	305.7
1986	306.4	307.1	306.6	307.9									
GAGE													
1985								305.2	305.5	306.3	305.4	305.3	
1986	305.5	305.9	306.6	306.3	305.9	306.8	306.9	307.0	307.2	306.8	306.8	307.0	306.6
1987	307.4	307.3	307.0	307.1	307.1	306.7	306.4	306.6	307.5	307.8	307.6	307.5	307.2
1988	307.4	307.4	307.0	307.1	307.0	307.2	307.2	307.1	307.7	307.3	307.4	307.2	307.3
1989	307.0		307.5	307.7	307.8	308.0	308.0	306.4	306.8	307.1	306.8	307.1	
1990	306.9	306.8		307.9	308.2	308.3	308.4	308.6	308.4	308.3	308.6	308.5	
1991	308.3	308.7	308.8	309.1	309.3	308.9	309.0	310.1	310.3	310.8	310.7	310.5	309.5

^aMonthly mixing ratios for CFC-11 and CFC-12 were calculated by CDIAC by averaging individual (four-times-daily for ALE and 12-times-daily for GAGE) measurements. For CFC-11, "individual measurements" actually represent averages of the separate measurements made on two different chromatographic columns when both values were available. Tabulated monthly values reflect adjustment by the appropriate calibration factors (see Rasmussen and Lovelock 1983). Measurements flagged as pollution events were not used in calculating monthly averages. Data in *Trends '93*, as well as the complete set of ALE/GAGE data (including all individual measurements), are available at no cost in electronic form from CDIAC.

^bAnnual values were calculated by averaging monthly values when all 12 were available.

^cUnits are expressed as dry air mole fractions $\times 10^{12}$ (CFC-11 and CFC-12) or as dry air mole fractions $\times 10^9$ (N₂O).

CITE AS: Prinn, R.G., R.F. Weiss, F.N. Alyea, D.M. Cunnold, P.J. Fraser, P.G. Simmonds, A.J. Crawford, R.A. Rasmussen, and R.D. Rosen. 1994. Atmospheric CFC-11 (CCl₃F), CFC-12 (CCl₂F₂), and N₂O from the ALE/GAGE network. pp. 396-420. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Other Trace Gases and Atmospheric Aerosols
Atmospheric CFC-11 (CCl₃F), CFC-12 (CCl₂F₂), and N₂O
from the ALE/GAGE network

R.G. Prinn, R.F. Weiss, F.N. Alyea, D.M. Cunnold, P.J. Fraser, P.G. Simmonds,
A.J. Crawford, R.A. Rasmussen, and R.D. Rosen (continued)

CAPE GRIM

Period of Record

1978–91

Trends

In the ALE/GAGE program, the site in the middle-latitude of the Southern Hemisphere is at Cape Grim, on the northwest coast of Tasmania, Australia. The site is 80 m from the shoreline and 93 m above mean sea level. (From 1980 through 1982 the station was temporarily moved 165 m north of the previous site to a location ~35 m from the shoreline and 80 m above mean sea level.) The site generally receives unpolluted oceanic air from the southwest, with rare but increasingly frequent instances of pollution originating in Tasmania or the Australian mainland. The site at Cape Grim was initially supervised jointly by R.A. Rasmussen and A.J. Crawford of the Oregon Graduate Institute and by P.J. Fraser of the Commonwealth Scientific and Industrial Research Organisation's (CSIRO's) Division of Atmospheric Research. Currently, P.J. Fraser supervises the measurements here. Measurements at Cape Grim began in July 1978 and continued as part of ALE through June 1985. Since December 1981, measurements were also collected as part of GAGE. Following the termination of ALE, measurements at Cape Grim continued as part of GAGE for the remainder of the record period (Fraser and Derek 1992).

The monthly mean mixing ratio of CFC-11 increased from 134.9 parts per trillion (ppt) in July 1978 to 256.6 ppt in December 1991. Cunnold et al. (1994) reported that the average rate of increase was 9.0 ± 0.1 ppt/year from July 1978 to June 1988 but dropped to 7.8 ± 0.2 from July 1988 to June 1991. From July 1978 to December 1991, the mixing ratio of CFC-12 increased from 251.3 to 490.3 ppt. For CFC-12, Cunnold et al. (1994) determined that the average rate of increase was 17.4 ± 0.1 ppt/year from July 1978 to June 1988 and 16.8 ± 0.4 from July 1988 to June 1991. For both CFC-11 and CFC-12, these trends are highly significant ($P < 0.0001$). According to Cunnold et al. (1994), the data from Cape Grim also show a consistent seasonal cycle for CFC-11 and CFC-12.

The time series of the monthly mean mixing ratios of N₂O is generally linear, and the values show a highly significant ($P < 0.0001$) trend during the period of record. The monthly mixing ratio increased from 297.7 parts per billion (ppb) in July 1978 to 308.4 ppb in December 1991. For the 10-year period July 1978 to June 1988, Prinn et al. (1990) calculated that the mixing ratio of N₂O increased by an average of 0.90 ± 0.05 ppb/year. In addition, the data were found to exhibit a statistically significant quasi-biennial ($\tau = 2.25$ years) oscillation with an amplitude of 0.28 ppb.

CITE AS: Prinn, R.G., R.F. Weiss, F.N. Alyea, D.M. Cunnold, P.J. Fraser, P.G. Simmonds, A.J. Crawford, R.A. Rasmussen, and R.D. Rosen. 1994. Atmospheric CFC-11 (CCl₃F), CFC-12 (CCl₂F₂), and N₂O from the ALE/GAGE network. pp. 396–420. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Other Trace Gases and Atmospheric Aerosols

Atmospheric CFC-11 (CCl_3F), CFC-12 (CCl_2F_2), and N_2O from the ALE/GAGE network

R.G. Prinn, R.F. Weiss, F.N. Alyea, D.M. Cunnold, P.J. Fraser, P.G. Simmonds, A.J. Crawford, R.A. Rasmussen, and R.D. Rosen (continued)

CAPE GRIM

Monthly average CFC-11, CFC-12, and N_2O mixing ratios at Cape Grim.

CITE AS: Prinn, R.G., R.F. Weiss, F.N. Alyea, D.M. Cunnold, P.J. Fraser, P.G. Simmonds, A.J. Crawford, R.A. Rasmussen, and R.D. Rosen. 1994. Atmospheric CFC-11 (CCl_3F), CFC-12 (CCl_2F_2), and N_2O from the ALE/GAGE network. pp. 396–420. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Other Trace Gases and Atmospheric Aerosols
Atmospheric CFC-11 (CCl₃F), CFC-12 (CCl₂F₂), and N₂O
from the ALE/GAGE network

R.G. Prinn, R.F. Weiss, F.N. Alyea, D.M. Cunnold, P.J. Fraser, P.G. Simmonds,
A.J. Crawford, R.A. Rasmussen, and R.D. Rosen (continued)

Cape Grim
Tasmania, Australia
Promontory seashore
40°41' S, 144°41' E
93 m above MSL

CAPE GRIM

Atmospheric Mixing Ratios of Trace Gases^a

CFC-11, CFC-12, and N₂O mixing ratios at Cape Grim

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann ^b
CFC-11 (parts per trillion)^c													
<i>ALE</i>													
1978							134.9	136.8	138.4	138.2	140.4	140.7	
1979	143.2	143.3	143.6	144.3	145.2	146.4	147.0	147.8	148.8	149.9	150.7	150.9	146.7
1980	151.7	152.8	153.8	154.4	156.4	157.2	157.3	158.0	159.7	159.1	160.4	161.5	156.8
1981	161.9	160.6	161.7	162.3	163.8	165.3	165.8		166.0	167.3	167.5	167.9	
1982	168.6	169.3	170.5	171.1	171.6	173.2	173.9	174.6	175.3	176.6	177.7	177.9	173.3
1983	178.4	178.8	178.6	179.2	179.9	180.7	181.6	183.0	184.0	184.8	185.5	186.1	181.7
1984	186.4	187.0	187.7	189.0	190.0	190.2	191.1	191.7	192.4	192.6	193.0	193.6	190.4
1985	194.1	194.7	195.5	196.8	197.7	198.0							
<i>GAGE</i>													
1981												169.5	
1982	169.9	170.3	171.2	172.1	173.3	173.9	174.7	175.6	176.1	176.3	177.1	177.5	174.0
1983	177.7	178.7	179.3	180.0	180.8	181.5	182.4	182.3	181.6	182.6	183.1	183.7	181.1
1984	184.0	184.6	185.7	187.7	188.6	189.4	190.4	191.2	191.7	192.4	192.9	193.8	189.3
1985	194.7	195.2	196.5	197.8	198.4	199.0	199.9	200.9	201.7	202.2	203.0	203.4	199.4
1986	203.5	204.1	205.2	206.6	208.1	208.9	209.8	211.0	211.4	211.5	210.8	211.4	208.5
1987	212.1	212.4			217.1	217.9		221.4	221.4	222.6	223.4	223.7	
1988	224.9	225.4	226.9	227.5	229.1	229.6	230.7	231.6	232.4	233.1	232.8	233.0	229.7
1989	233.5	234.1	235.5	236.8	237.6	238.6	238.7	239.6	240.6	241.5	241.8	242.8	238.4
1990	243.2	243.8	244.8	245.8	246.3	246.5	247.1	247.4	248.3	248.9	249.3	249.4	246.7
1991	249.8	249.5	249.9	250.7	251.5	252.5	253.4	254.3	255.0	255.6	255.9	256.6	252.9
CFC-12 (parts per trillion)^c													
<i>ALE</i>													
1978							251.3	252.5	255.3	257.2	262.9	262.7	
1979	266.0	266.7	267.7	269.0	270.8	272.4	273.2	275.0	276.4	276.5	277.7	278.2	272.5
1980	279.4								295.0	295.2	297.1	297.6	
1981	298.8	297.9	300.2	301.9	303.9	305.6	306.3		308.8	309.2	310.8	311.9	
1982	313.2	314.2	316.5	317.9	318.3	321.6	323.1	324.8	325.6	328.9	331.2	331.6	322.2
1983	332.5	334.5	336.6	337.9	339.1	340.8	342.4	343.1	343.3	345.0	346.2	347.3	340.7
1984	348.1	349.4	350.7	353.5	357.5	358.7	360.4	361.4	362.5	363.6	364.8	365.6	358.0
1985	366.4	368.1	369.7	372.1	373.5	374.3							
<i>GAGE</i>													
1981												315.6	
1982	317.2	318.1	319.9	321.9	324.3	325.5	326.6	328.5	329.7	330.2	331.6	332.2	325.5
1983	332.9	335.8	338.0	339.4	340.8	341.9	343.3	343.4	342.5	344.4	345.4	346.1	341.2
1984	346.4	347.3	348.3	352.1	355.1	356.2	357.4	359.1	359.3	360.2	362.5	365.7	355.8
1985	368.1	368.9	371.0	373.5	374.5	375.6	377.0	379.0	380.0	381.1	382.7	384.0	376.3

Other Trace Gases and Atmospheric Aerosols

Atmospheric CFC-11 (CCl₃F), CFC-12 (CCl₂F₂), and N₂O from the ALE/GAGE network

R.G. Prinn, R.F. Weiss, F.N. Alyea, D.M. Cunnold, P.J. Fraser, P.G. Simmonds, A.J. Crawford, R.A. Rasmussen, and R.D. Rosen (continued)

CAPE GRIM

Atmospheric Mixing Ratios of Trace Gases (continued)^a

CFC-11, CFC-12, and N₂O mixing ratios at Cape Grim

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann ^b
CFC-12 (parts per trillion)^c													
GAGE (continued)													
1986	384.2	385.6	387.4	392.2	393.8	395.5	396.9	398.1	399.5	398.9	399.3	400.3	394.3
1987	401.1	400.4			409.8	411.3		415.8	416.2	418.2	419.1	419.7	
1988	421.7	422.8	425.4	426.8	434.0	433.7	436.2	437.9	439.1	440.3	440.3	440.7	433.2
1989	441.9	443.1	445.2	447.8	449.5	451.0	451.8	453.3	454.9	456.2	457.7	461.0	451.1
1990	462.1	464.0	465.8	467.2	469.5	469.4	470.7	472.0	473.7	475.0	476.1	476.6	470.2
1991	476.6	476.9	478.1	479.9	481.9	482.7	484.0	485.7	487.8	488.6	489.2	490.3	483.5
N₂O (parts per billion)^c													
ALE													
1978							297.7	298.5	297.8	298.3	299.3	297.2	
1979	299.2	299.0	298.8	298.6	298.6	299.5	299.4	299.2	299.2	299.0	299.1	299.2	299.1
1980	299.2	299.3	299.2	299.3	299.7	299.5	299.6	299.7	300.6	300.1	300.5	301.0	299.8
1981	300.6	299.3	299.6	299.7	299.2	298.7	298.4		299.3	299.7	300.1	300.2	
1982	300.2	300.3	300.7	300.8	301.2	302.0	302.1	302.3	302.4	303.2	303.2	302.9	301.8
1983	303.0	302.9	302.6	302.8	302.9	302.8	302.6	302.1	301.3	301.4	301.5	301.5	302.3
1984	301.5	301.5	301.4	301.9	304.3	304.2	304.4	304.6	304.6	304.7	304.4	303.9	303.5
1985	304.3	304.5	304.0	304.2	304.2	304.0							
GAGE													
1981													301.4
1982	301.5	301.4	301.3	301.3	301.9	301.9	301.9	302.0	302.0	301.2	301.3	301.4	301.6
1983	301.5	301.6	301.9	301.9	302.0	301.9	301.9	302.7	303.1	303.4	303.5	303.7	302.4
1984	303.6	303.5	303.0	302.9	303.3	303.2	303.4	303.6	303.5	303.5	303.6	304.3	303.5
1985	304.7	304.7	304.8	304.9	304.9	304.8	304.9	304.7	304.5	304.6	304.6	304.7	304.7
1986	304.7	304.6	304.6	305.2	305.4	305.7	306.1	305.9	306.2	305.3	305.9	305.9	305.5
1987	306.0	305.7	306.0	306.0	306.0	306.3		305.9	305.7	306.0	305.6	305.7	
1988	306.1	305.5	305.5	305.5	306.6	306.4	306.6	306.8	306.8	306.9	306.4	306.8	306.3
1989	306.6	306.1	306.1	306.4	306.3	306.5	306.0	306.5	306.5	306.4	306.5	306.8	306.4
1990	306.9	306.8	306.7	306.6	307.1	307.5	307.8	307.6	308.2	308.1	308.3	308.2	307.5
1991	307.6	307.5	307.5	307.5	307.7	307.8	307.8	308.0	308.3	308.2	308.2	308.4	307.9

^aMonthly mixing ratios for CFC-11 and CFC-12 were calculated by CDIAC by averaging individual (four-times-daily for ALE and 12-times-daily for GAGE) measurements. For CFC-11, "individual measurements" actually represent averages of the separate measurements made on two different chromatographic columns when both values were available. Tabulated monthly values reflect adjustment by the appropriate calibration factors (see Rasmussen and Lovelock 1983). Measurements flagged as pollution events were not used in calculating monthly averages. Data in *Trends '93*, as well as the complete set of ALE/GAGE data (including all individual measurements), are available at no cost in electronic form from CDIAC.

^bAnnual values were calculated by averaging monthly values when all 12 were available.

^cUnits are expressed as dry air mole fractions $\times 10^{12}$ (CFC-11 and CFC-12) or as dry air mole fractions $\times 10^9$ (N₂O).

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Other Trace Gases and Atmospheric Aerosols
Atmospheric CFC-11 (CCl₃F), CFC-12 (CCl₂F₂), and N₂O
from the ALE/GAGE network

R.G. Prinn, R.F. Weiss, F.N. Alyea, D.M. Cunnold, P.J. Fraser, P.G. Simmonds,
A.J. Crawford, R.A. Rasmussen, and R.D. Rosen (continued)

CAPE MEARES

Period of Record

1979–89 (CFC-11); 1980–89 (CFC-12 and N₂O)

Trends

The ALE/GAGE site at Cape Meares, Oregon, U.S.A., was operated under the supervision of R.A. Rasmussen and A.J. Crawford of the Oregon Graduate Institute of Science and Technology. The site is located on the Pacific coast of Oregon, immediately overlooking the ocean ~30 m above mean sea level. The site initially appeared to receive largely unpolluted Pacific air, but pollution episodes increased in more recent years. Measurements for CFC-11 began as part of ALE in December 1979. Due to start-up problems, reliable measurements for N₂O began in March 1980 and for CFC-12 in November 1980. These measurements continued as part of ALE through July 1984 and as part of GAGE from September 1983 through June 1989.

The monthly mean mixing ratio of CFC-11 increased from 169.4 parts per trillion (ppt) in December 1979 to 253.9 ppt in June 1989. Cunnold et al. (1994) reported that the average rate of increase of CFC-11 was 8.8 ± 0.1 ppt/year from July 1978 to June 1988. The mixing ratio of CFC-12 increased from 326.2 ppt in November 1980 to 481.8 ppt in June 1989. For the period July 1978 to June 1988, Cunnold et al. (1994) determined that the average rate of increase of CFC-12 was 16.7 ± 0.2 ppt/year. For both CFC-11 and CFC-12, the trends are highly significant ($P < 0.0001$).

The time series of the monthly mean mixing ratios of N₂O shows little evidence of an upward trend until about mid-1981, after which the mixing ratio begins to increase in a generally linear fashion. During 1980–89, the monthly values show a highly significant ($P < 0.0001$) trend. The monthly mixing ratio increased from 301.1 parts per billion (ppb) in March 1980 to a high of 309.1 ppb in December 1988 and then dropped slightly to 307.2 ppb in June 1989. For 1980–88, Prinn et al. (1990) calculated that the mixing ratio of N₂O increased by an average of 0.94 ± 0.07 ppb/year. No significant periodic oscillation is evident. Throughout the period of record, the daily N₂O variability is generally larger than at equatorial and Southern Hemisphere sites.

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Other Trace Gases and Atmospheric Aerosols

Atmospheric CFC-11 (CCl_3F), CFC-12 (CCl_2F_2), and N_2O from the ALE/GAGE network

R.G. Prinn, R.F. Weiss, F.N. Alyea, D.M. Cunnold, P.J. Fraser, P.G. Simmonds, A.J. Crawford, R.A. Rasmussen, and R.D. Rosen (continued)

CAPE MEARES

Monthly average CFC-11, CFC-12, and N_2O mixing ratios at Cape Meares.

CITE AS: Prinn, R.G., R.F. Weiss, F.N. Alyea, D.M. Cunnold, P.J. Fraser, P.G. Simmonds, A.J. Crawford, R.A. Rasmussen, and R.D. Rosen. 1994. Atmospheric CFC-11 (CCl_3F), CFC-12 (CCl_2F_2), and N_2O from the ALE/GAGE network. pp. 396–420. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Other Trace Gases and Atmospheric Aerosols
Atmospheric CFC-11 (CCl₃F), CFC-12 (CCl₂F₂), and N₂O
from the ALE/GAGE network

R.G. Prinn, R.F. Weiss, F.N. Alyea, D.M. Cunnold, P.J. Fraser, P.G. Simmonds,
A.J. Crawford, R.A. Rasmussen, and R.D. Rosen (continued)

CAPE MEARES

*Cape Meares
Oregon, U.S.A.
Promontory seashore
45°29' N, 123°58' W
30 m above MSL*

Atmospheric Mixing Ratios of Trace Gases^a

CFC-11, CFC-12, and N₂O mixing ratios at Cape Meares

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann ^b
CFC-11 (parts per trillion)^c													
<i>ALE</i>													
1979													169.4
1980	169.5	167.6	170.4	171.8	172.5	172.5	172.2	173.7	176.3	177.7	177.9	176.7	173.2
1981	176.3	177.3	177.4	178.5	178.9	179.5	180.0	180.7	182.7	184.8	185.8	186.0	180.6
1982	184.4	184.7	185.6	187.0	186.8	186.9	187.1	187.3	188.4	191.0	192.7	193.0	187.9
1983	192.9	193.0	194.4	196.1	196.8	198.8	200.5	201.1	199.9	203.2	204.0	202.1	198.5
1984		203.9	203.5	205.5	205.4	205.2	204.9						
<i>GAGE</i>													
1983									196.1	198.6	199.1	200.6	
1984	199.7	200.4	200.6	202.5	202.7	202.6	202.8	202.6	205.4	207.8	208.9	209.8	203.8
1985	208.4	209.2	210.5	211.8	212.0	210.9	212.4	214.5	217.0	217.8	219.0	218.0	213.4
1986	218.1	219.1	220.6	223.9	225.1	225.4	224.3	225.0	229.5	230.5	231.5	232.8	225.5
1987	233.1	232.0	234.1	236.7	237.9	239.4	238.5	239.3	241.8	245.1	245.2	246.3	239.1
1988	245.7	245.2	246.4	247.7	248.5	248.6	248.5	250.0	252.4	253.3	253.3	253.2	249.4
1989	251.8	251.3	251.5	253.4	253.5	253.9							
CFC-12 (parts per trillion)^c													
<i>ALE</i>													
1980											326.2	325.4	
1981	326.9	328.1	328.7	329.5	330.7	332.3	333.2	336.0	339.4	342.9	343.4	343.3	334.5
1982	342.9	343.6	345.2	346.3	346.5	347.6	348.0	349.7	353.2	355.5	358.0	358.5	349.6
1983	355.1	355.4	357.8	359.2	360.3	363.4	365.1	367.2	369.9	374.5	376.8	378.6	365.3
1984		378.5	377.4	379.8	379.5	381.1	382.2						
<i>GAGE</i>													
1983									368.8	372.7	373.5	376.3	
1984	374.5	375.7	375.0	377.6	378.3	379.5	380.3	381.1	385.0	391.0	392.2	393.2	382.0
1985	394.8	392.7	394.2	394.2	394.8	396.5	400.1	403.5	408.6	408.0	410.0	410.6	400.7
1986	409.4	410.9	412.8	416.0	416.3	418.1	417.4	419.7	430.3	432.9	431.9	434.7	420.9
1987	435.0	432.8	435.0	439.9	441.1	440.2	439.6	434.3	441.3	456.9	453.9	455.8	442.2
1988	456.0	455.0	456.9	460.0	461.3	462.1	462.8	466.2	471.3	473.5	471.9	473.6	464.2
1989	471.9	473.0	472.8	480.2	480.5	481.8							
N₂O (parts per billion)^c													
<i>ALE</i>													
1980			301.1	301.0	300.9	301.0	300.7	300.4	301.0	300.6	300.3	300.4	
1981	300.8	300.6	300.6	301.0	301.1	300.8	300.7	301.3	301.4	301.7	301.8	301.8	301.1
1982	302.0	302.3	302.5	302.3	302.5	302.5	302.4	302.5	302.9	303.1	302.9	302.6	302.5

Other Trace Gases and Atmospheric Aerosols

Atmospheric CFC-11 (CCl₃F), CFC-12 (CCl₂F₂), and N₂O from the ALE/GAGE network

R.G. Prinn, R.F. Weiss, F.N. Alyea, D.M. Cunnold, P.J. Fraser, P.G. Simmonds, A.J. Crawford, R.A. Rasmussen, and R.D. Rosen (continued)

CAPE MEARES

Atmospheric Mixing Ratios of Trace Gases (continued)^a

CFC-11, CFC-12, and N ₂ O mixing ratios at Cape Meares													
Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann ^b
N ₂ O (parts per billion) ^c													
ALE (continued)													
1983	302.3	302.2	302.0	302.1	302.3	303.3	303.4	303.2	302.9	303.1	303.3	302.9	302.8
1984		303.4	302.8	303.3	303.5	303.2	303.1						
GAGE													
1983									301.0	301.3	301.7	302.5	
1984	302.6	302.6	302.7	302.9	303.7	304.0	303.9	303.8	303.7	303.8	304.1	304.1	303.5
1985	304.3	304.3	304.4	305.3	305.2	304.6	305.5	305.5	305.5	305.7	305.7	306.1	305.2
1986	305.9	306.6	307.0	307.1	306.2	306.5	306.8	307.3	307.4	307.8	307.1	306.8	306.9
1987	307.4	306.7	307.5	307.9	308.0	307.3	307.1	307.4	307.4	308.2	308.1	308.0	307.6
1988	308.2	308.4	308.5	308.7	309.2	309.1	308.7	308.5	308.7	308.8	308.9	309.1	308.7
1989	308.8	308.4	308.2	307.3	307.2	307.2							

^aMonthly mixing ratios for CFC-11 and CFC-12 were calculated by CDIAC by averaging individual (four-times-daily for ALE and 12-times-daily for GAGE) measurements. For CFC-11, "individual measurements" actually represent averages of the separate measurements made on two different chromatographic columns when both values were available. Tabulated monthly values reflect adjustment by the appropriate calibration factors (see Rasmussen and Lovelock 1983). Measurements flagged as pollution events were not used in calculating monthly averages. Data in *Trends '93*, as well as the complete set of ALE/GAGE data (including all individual measurements), are available at no cost in electronic form from CDIAC.

^bAnnual values were calculated by averaging monthly values when all 12 were available.

^cUnits are expressed as dry air mole fractions $\times 10^{12}$ (CFC-11 and CFC-12) or as dry air mole fractions $\times 10^9$ (N₂O).

CITE AS: Prinn, R.G., R.F. Weiss, F.N. Alyea, D.M. Cunnold, P.J. Fraser, P.G. Simmonds, A.J. Crawford, R.A. Rasmussen, and R.D. Rosen. 1994. Atmospheric CFC-11 (CCl₃F), CFC-12 (CCl₂F₂), and N₂O from the ALE/GAGE network. pp. 396-420. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Other Trace Gases and Atmospheric Aerosols

Atmospheric CFC-11 (CCl₃F), CFC-12 (CCl₂F₂), and N₂O
from the ALE/GAGE network

R.G. Prinn, R.F. Weiss, F.N. Alyea, D.M. Cunnold, P.J. Fraser, P.G. Simmonds,
A.J. Crawford, R.A. Rasmussen, and R.D. Rosen (continued)

MACE HEAD

Period of Record

1987–91

Trends

The monitoring station at Mace Head, Ireland, was opened in January 1987 to serve as a middle-latitude Northern Hemisphere site for GAGE. The site is located on the west coast of Ireland in Galway, ~25 m above mean sea level. It is operated under the supervision of P.G. Simmonds of the University of Bristol. Although generally receiving clean oceanic air, the site is at times (particularly in winter) subject to pollution events originating from sources in eastern Ireland, Great Britain, and continental Europe.

The monthly mean mixing ratio of CFC-11 increased from 238.4 parts per trillion (ppt) in February 1987 to 266.2 ppt in December 1991. During the same period, the mixing ratio of CFC-12 increased from 433.7 to 509.9 ppt. According to Cunnold et al. (1994), the average rate of atmospheric CFC increase at Mace Head from July 1988 to June 1991 was 5.3 ± 0.2 ppt/year for CFC-11 and 13.6 ± 0.4 ppt/year for CFC-12. For both CFC-11 and CFC-12, the trends are highly significant ($P < 0.0001$).

The mean monthly N₂O mixing ratio at Mace Head increased from 305.8 parts per billion (ppb) in January 1987 to 309.6 ppb in December 1991. The values show a highly significant ($P < 0.0001$) trend during this period, with an average rate of increase of 0.857 ppb/year. No significant periodic oscillation is evident.

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Other Trace Gases and Atmospheric Aerosols

Atmospheric CFC-11 (CCl_3F), CFC-12 (CCl_2F_2), and N_2O from the ALE/GAGE network

R.G. Prinn, R.F. Weiss, F.N. Alyea, D.M. Cunnold, P.J. Fraser, P.G. Simmonds, A.J. Crawford, R.A. Rasmussen, and R.D. Rosen (continued)

MACE HEAD

Monthly average CFC-11, CFC-12, and N_2O mixing ratios at Mace Head.

CITE AS: Prinn, R.G., R.F. Weiss, F.N. Alyea, D.M. Cunnold, P.J. Fraser, P.G. Simmonds, A.J. Crawford, R.A. Rasmussen, and R.D. Rosen. 1994. Atmospheric CFC-11 (CCl_3F), CFC-12 (CCl_2F_2), and N_2O from the ALE/GAGE network. pp. 396-420. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Other Trace Gases and Atmospheric Aerosols
Atmospheric CFC-11 (CCl₃F), CFC-12 (CCl₂F₂), and N₂O
from the ALE/GAGE network

R.G. Prinn, R.F. Weiss, F.N. Alyea, D.M. Cunnold, P.J. Fraser, P.G. Simmonds,
A.J. Crawford, R.A. Rasmussen, and R.D. Rosen (continued)

MACE HEAD

Mace Head
County Galway, Ireland
53°20' N, 09°54' W
25 m above MSL

Atmospheric Mixing Ratios of Trace Gases^a

CFC-11, CFC-12, and N₂O mixing ratios at Mace Head

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann ^b
CFC-11 (parts per trillion)^c													
<i>GAGE</i>													
1987		238.4	235.9	232.2	234.8	237.9	238.4	239.3	242.3	245.3	246.4	245.3	
1988	245.6	246.7	244.0	247.6	248.4	249.0	249.1	249.7	251.7	254.2	252.9	253.1	249.3
1989	252.0	253.6	253.1	255.7	255.4	255.7	256.8	256.7	258.6	258.0	259.5	260.6	256.3
1990	259.1	259.5	259.9	261.6	262.5	262.3	260.3	261.4	263.0	263.7	265.0	263.1	261.8
1991	263.3	265.9	264.9	264.0	263.6	264.0	264.7	264.6	265.1	265.1	266.0	266.2	264.8
CFC-12 (parts per trillion)^c													
<i>GAGE</i>													
1987		433.7	430.9	433.7	436.5	435.5	437.5	439.8	443.2	447.7	449.9	448.6	
1988	453.8	454.9	450.8	454.8	457.9	460.6	461.8	463.4	466.9	470.2	474.1	474.1	461.9
1989	473.4	475.1	474.4	477.7	478.1	479.5	480.9	482.1	486.4	484.9	487.0	488.8	480.7
1990	487.7	488.1	487.8	488.8	492.9	492.7	491.6	493.9	496.8	498.4	500.5	500.4	493.3
1991	502.8	504.2	502.3	501.7	501.7	502.3	503.4	503.4	506.6	507.5	508.3	509.9	504.5
N₂O (parts per billion)^c													
<i>GAGE</i>													
1987	305.8	305.5	305.2	305.6	305.5	305.4	305.2	305.2	305.8	305.9	306.0	306.2	305.6
1988	306.1	305.8	305.4	305.9	306.2	306.4	306.0	306.6	306.7	306.9	306.4	306.4	306.2
1989	306.5	306.4	306.4	308.1		308.2	308.4	308.6	308.5	307.3	308.2	308.7	
1990	307.9	308.0	308.1	308.5	308.8	308.4	308.2	307.9	308.2	308.3	308.8	308.9	308.3
1991	309.1	310.1	309.4	309.6	309.2	308.9	308.8	308.5	307.4	308.0	308.1	309.6	308.9

^aMonthly mixing ratios for CFC-11 and CFC-12 were calculated by CDIAC by averaging individual (12-times-daily) measurements. For CFC-11, "individual measurements" actually represent averages of the separate measurements made on two different chromatographic columns when both values were available. Tabulated monthly values reflect adjustment by the appropriate calibration factors (see Rasmussen and Lovelock 1983). Measurements flagged as pollution events were not used in calculating monthly averages. Data in *Trends '93*, as well as the complete set of ALE/GAGE data (including all individual measurements), are available at no cost in electronic form from CDIAC.

^bAnnual values were calculated by averaging monthly values when all 12 were available.

^cUnits are expressed as dry air mole fractions $\times 10^{12}$ (CFC-11 and CFC-12) or as dry air mole fractions $\times 10^9$ (N₂O).

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Atmospheric CFC-11 (CCl₃F), CFC-12 (CCl₂F₂), and N₂O
from the ALE/GAGE network

R.G. Prinn, R.F. Weiss, F.N. Alyea, D.M. Cunnold, P.J. Fraser, P.G. Simmonds,
A.J. Crawford, R.A. Rasmussen, and R.D. Rosen (continued)

SAMOA

Period of Record

1978–89

Trends

The ALE/GAGE monitoring site in Samoa is located at the National Oceanic and Atmospheric Administration (NOAA) station at Cape Matatula, on a rocky promontory overlooking the Pacific ocean ~30 m above mean sea level. The ALE/GAGE operation at Samoa through 1989 was carried out under the supervision of R.A. Rasmussen and A.J. Crawford of the Oregon Graduate Institute of Science and Technology. The site is now supervised by R.F. Weiss of the Scripps Institution of Oceanography (SIO). The site receives unpolluted oceanic air almost exclusively; during the southern summer, however, conditions during the Northern Hemisphere winter often allow air from the Northern Hemisphere to reach Samoa. Measurements at the site began in July 1978 and continued as part of ALE through May 1986. Beginning in July 1985, measurements were also collected as part of GAGE. After the conclusion of ALE, measurements at Samoa continued as part of GAGE through June 1989 and then began again in late 1990.

The monthly mean mixing ratio of CFC-11 increased from 138.9 parts per trillion (ppt) in July 1978 to 240.8 ppt in June 1989. The mixing ratio of CFC-12 increased from 251.1 to 457.8 ppt during the same period. Cunnold et al. (1994) determined that the average rate of increase in atmospheric mixing ratios at Samoa from July 1978 to June 1988 was 9.2 ± 0.1 ppt/year for CFC-11 and 17.3 ± 0.2 ppt/year for CFC-12. For both CFC-11 and CFC-12, the trends are highly significant ($P < 0.0001$). In addition, annual cycles are evident for both CFC-11 and CFC-12; maximum mixing ratios are observed in late summer and minima in late winter (Prinn et al. 1983; Cunnold et al. 1994).

The time series of the monthly mean mixing ratios of N₂O is generally linear, except for an anomalously large increase during the first 4 months of record. The values show a highly significant ($P < 0.0001$) trend over the period of record. The monthly mixing ratio increased from 293.8 parts per billion (ppb) in July 1978 to a high of 307.6 ppb in January 1989 to 306.1 ppb in June 1989. For January 1979 to June 1988, Prinn et al. (1990) calculated that the mixing ratio of N₂O increased by an average of 0.91 ± 0.04 ppb/year. No significant periodic oscillation is evident.

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Other Trace Gases and Atmospheric Aerosols
Atmospheric CFC-11 (CCl_3F), CFC-12 (CCl_2F_2), and N_2O
from the ALE/GAGE network

R.G. Prinn, R.F. Weiss, F.N. Alyea, D.M. Cunnold, P.J. Fraser, P.G. Simmonds,
A.J. Crawford, R.A. Rasmussen, and R.D. Rosen (continued)

SAMOA

Monthly average CFC-11, CFC-12, and N_2O mixing ratios at Samoa.

CITE AS: Prinn, R.G., R.F. Weiss, F.N. Alyea, D.M. Cunnold, P.J. Fraser, P.G. Simmonds, A.J. Crawford, R.A. Rasmussen, and R.D. Rosen. 1994. Atmospheric CFC-11 (CCl_3F), CFC-12 (CCl_2F_2), and N_2O from the ALE/GAGE network. pp. 396-420. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Other Trace Gases and Atmospheric Aerosols

Atmospheric CFC-11 (CCl₃F), CFC-12 (CCl₂F₂), and N₂O from the ALE/GAGE network

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A.J. Crawford, R.A. Rasmussen, and R.D. Rosen (continued)

SAMOA

Samoa (Cape Matatula)
U.S. Territory
South Pacific Ocean
Island rock promontory
14°15' S, 170°34' W
42 m above MSL

Atmospheric Mixing Ratios of Trace Gases^a

CFC-11, CFC-12, and N₂O mixing ratios at Samoa

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann ^b
CFC-11 (parts per trillion) ^c													
ALE													
1978							138.9	141.6	142.0	144.0	144.6	146.2	
1979	147.8	147.5	146.4	147.5	147.2	147.1	147.4	148.7	148.3	149.2	150.6	150.8	148.2
1980	154.1	154.9	155.8	156.7	157.2	157.2	158.6	159.1	160.1	159.9	162.9	163.7	158.3
1981	164.9		167.3	166.1	165.9	166.8	166.6	168.4	170.7	171.4	172.5	173.7	
1982	174.1	173.7	172.6			175.2	175.2	176.0	176.3	176.8	176.7	177.2	
1983	177.7	180.1	181.6	182.2	182.8	184.0	184.4	184.7	186.2	186.4	187.1	189.0	183.8
1984	190.7	191.5	192.1	192.0	190.4	191.3	192.3	193.0	194.6	194.1	195.3	198.3	193.0
1985	198.3	198.8	198.7	198.6	199.7	199.4	199.6	199.8	200.0		203.4	206.1	
1986	208.1	209.4	208.9	209.4	208.7								
GAGE													
1985							201.4	202.2	202.8	204.6	204.2	206.6	
1986	208.1	209.3	209.0	210.2	209.8	211.5	210.3	210.9	213.2	214.2	214.0	216.4	211.4
1987	219.3	221.2	220.9	219.2	220.0	220.8	221.2	222.5	223.6	223.7	226.0	227.6	222.1
1988	230.0	228.9	231.4	233.5	232.0	232.6	232.6	234.1	235.4	235.6	235.5	236.4	233.1
1989	238.3	240.8	241.4	241.1	241.9	240.8							
CFC-12 (parts per trillion) ^c													
ALE													
1978							251.1	252.6	257.6	261.1	266.8	270.2	
1979	274.5	275.0	276.3	277.3	275.7	275.5	276.3	278.9	278.9	281.3	282.7	284.3	278.1
1980	289.4	290.2	292.0	293.7	295.0	295.8	297.5	298.7	300.0	295.6	301.0	303.1	296.0
1981	304.7				307.7	308.7	308.3	312.5	316.0	315.5	317.2	320.0	
1982	322.7	323.9	323.3			326.7	326.7	329.1	329.4	330.1	332.1	333.5	
1983	335.0	336.7	336.6	337.5	339.0	342.3	344.0	348.7	351.4	352.4	353.9	357.1	344.6
1984	360.4	359.1	359.2	359.4	357.2	358.0	360.1	361.7	364.8	364.3	367.8	372.1	362.0
1985	373.4	375.8	375.9	376.2	377.3	377.8	379.1	380.2	380.5		383.3	387.4	
1986	390.1	392.1	391.5	392.5	391.8								
GAGE													
1985							381.4	382.5	383.5	382.9	383.4	387.3	
1986	390.1	391.8	392.0	394.8	394.2	401.0	398.5	400.6	404.7	406.2	406.1	407.3	398.9
1987	410.1		413.1	408.2	408.6	416.0	417.5	419.3	419.4	420.5	423.7	426.3	
1988	428.4		432.3	436.0	434.0	434.7	437.3	443.2	445.1	445.9	445.8	447.8	
1989	450.9	457.0	458.4	457.7	459.2	457.8							

Other Trace Gases and Atmospheric Aerosols
 Atmospheric CFC-11 (CCl₃F), CFC-12 (CCl₂F₂), and N₂O
 from the ALE/GAGE network

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 A.J. Crawford, R.A. Rasmussen, and R.D. Rosen (continued)

SAMOA

Atmospheric Mixing Ratios of Trace Gases (continued)^a

CFC-11, CFC-12, and N₂O mixing ratios at Samoa

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann ^b
N ₂ O (parts per billion) ^c													
ALE													
1978							293.8	292.7	294.4	294.8	297.6	300.1	
1979	300.1	300.1	299.7	299.6	299.2	299.0	299.4	299.5	299.2	299.5	300.3	299.7	299.6
1980	299.9	300.3	299.9	299.9	299.7	299.8	299.7	299.3	299.7	299.5	300.1	300.1	299.8
1981	300.3				300.4	300	299.4	300.4	300.1	299.9	300.3	300.2	
1982	301.1	302.1	302.0			303.7	302.0	302.3	302.1	302.1	302.2	302.3	
1983	302.3	302.0	301.7	301.7	301.4	301.6	301.6	302.8	302.9	302.7	302.9	303.2	302.2
1984	303.4	302.9	302.4	302.5	302.2	302.3	302.3	302.3	302.6	302.4	302.5	303.3	302.6
1985	303.4	304.2	304.0	303.8	303.9	303.8	303.8	303.8	303.8		304.6	304.7	
1986	304.8	305.0	304.7	304.6	304.5								
GAGE													
1985							304.8	304.6	304.7	305.5	305.4	305.6	
1986	305.6	305.7	306.4	306.8	306.4	306.7	306.1	306.1	306.4	306.5	306.4	306.2	306.3
1987	306.2	306.1	306.4	305.9	306.3	307.0	306.9	306.8	306.9	306.5	307.0	307.3	306.6
1988	307.4	306.3	307.8	308.2	307.3	307.7	307.4	307.1	307.2	307.2	307.3	307.4	307.4
1989	307.6	306.9	306.5	306.7	306.7	306.1							

^aMonthly mixing ratios for CFC-11 and CFC-12 were calculated by CDIAC by averaging individual (four-times-daily for ALE and 12-times-daily for GAGE) measurements. For CFC-11, "individual measurements" actually represent averages of the separate measurements made on two different chromatographic columns when both values were available. Tabulated monthly values reflect adjustment by the appropriate calibration factors (see Rasmussen and Lovelock 1983). Measurements flagged as pollution events were not used in calculating monthly averages. Data in *Trends '93*, as well as the complete set of ALE/GAGE data (including all individual measurements), are available at no cost in electronic form from CDIAC.

^bAnnual values were calculated by averaging monthly values when all 12 were available.

^cUnits are expressed as dry air mole fractions $\times 10^{12}$ (CFC-11 and CFC-12) or as dry air mole fractions $\times 10^9$ (N₂O).

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from the ALE/GAGE network

R.G. Prinn, R.F. Weiss, F.N. Alyea, D.M. Cunnold, P.J. Fraser, P.G. Simmonds,
A.J. Crawford, R.A. Rasmussen, and R.D. Rosen (continued)

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Other Trace Gases and Atmospheric Aerosols

Global and hemispheric means of CFC-11 and CFC-12 from the NOAA/CMDL flask sampling program

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Period of Record

1977–92

Methods

Measurements of CFC-11 (CCl_3F) and CFC-12 (CCl_2F_2) were made from flask samples collected for the National Oceanic and Atmospheric Administration (NOAA) Climate Monitoring and Diagnostics Laboratory (CMDL) at climate monitoring stations (Barrow,

NOAA/CMDL
sites from
which data
were used to
generate the
global and
hemispheric
CFC data sets.

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Alaska, U.S.A.; Mauna Loa, Hawaii, U.S.A.; Cape Matatula, American Samoa; and the South Pole) and cooperative sampling sites (Niwot Ridge, Colorado, U.S.A.; Alert, Northwest Territories, Canada; and Cape Grim Baseline Air Pollution Station, Tasmania, Australia).

Starting in 1977, paired samples were collected each week in 300-mL or 850-mL electropolished, stainless steel flasks at the four NOAA/CMDL stations and Niwot Ridge. After 1980, flask pairs at the South Pole were collected once a week only during the austral summer, when the station was open. Collection of flask pairs began at Alert in 1988 and at Cape Grim in 1991. All flasks were shipped back to Boulder, Colorado, for analysis by electron capture–gas chromatography (EC-GC). For further details concerning sampling, measurement, and calibration procedures, see Elkins et al. (1993, 1988) and Thompson et al. (1985).

During data selection, outliers were removed if they were greater than 3σ away from the fits to fourth order polynomial and simple harmonic series (Elkins et al. 1993).

Values for monthly global and hemispheric means were generated from individual station data by averaging flask values weighted by the cosine of station latitude (except for the South Pole, whose latitude was assigned a value of 67° S for purposes of weighting).

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GLOBAL AND HEMISPHERIC

Trends

The most obvious feature is the leveling off of the globally and hemispherically averaged mixing ratios of the CFCs, particularly CFC-11. This decline in growth is consistent with the decreased production and use of CFCs reported by the CFC producers (see AFEAS 1992) and is due primarily to decreased CFC use in aerosol propellants and foam-blowing applications. The leveling off is most significant in the Northern Hemisphere, where most CFCs are used and emitted. Growth in the Southern Hemisphere has decreased less rapidly, however, because growth rates there are determined mainly by interhemispheric transport. Previous reports (Rasmussen and Khalil 1986; Cunnold et al. 1986; Elkins et al. 1988) found that the mean global mixing ratios between 1977 and 1984 were increasing linearly at a constant rate; the collective results presented here for the seven NOAA/CMDL monitoring sites during 1977–84 give global rates of 9 ± 1 (1 σ) parts per trillion by mole per year (ppt/year) for CFC-11 and 17 ± 3 ppt/year for CFC-12. The gap in the data for CFC-12 during 1984–85 resulted from a gas chromatograph problem that affected only CFC-12. A surge in CFC production during 1985–88 caused the observed global growth rates [calculated as average yearly maxima (Elkins et al. 1993)] to climb to 11 ± 1 ppt/year for CFC-11 and 19.5 ± 2 ppt/year for CFC-12. Since 1988, the growth rates have been decreasing rapidly, reaching levels of 2.7 ± 0.7 ppt/year for CFC-11 and 10.5 ± 0.3 ppt/year for CFC-12 by the beginning of 1993 (Elkins et al. 1993). The absolute values (Montzka et al. 1992) presented here for CFC-11 are $\sim 3.2 \pm 1.3\%$ lower and for CFC-12 are $\sim 3.4 \pm 1.5\%$ higher than those measured by Cunnold et al. (1986), according to a comparison of data from a jointly monitored station at Samoa. Results from a recent laboratory intercomparison of two cylinders showed that this scale is 0.1% higher for CFC-11 and 1.3% higher for CFC-12 than the scale of R.F. Weiss (Bullister and Weiss 1988).

The CFC-11 and CFC-12 records for the Northern and Southern Hemispheres also show a divergence in growth rates during the El Niño-Southern Oscillation (ENSO) event of 1986–87. This period was also coincident with a quasi-biennial oscillation event (QBO), followed by the strongest cold event in 15 years, the La Niña of 1988–89. According to Elkins et al. (1993), all of these processes inhibit interhemispheric transport and therefore slow CFC growth rates in the Southern Hemisphere.

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D.E.J. Worthy, V. Hudec, V. Chorney, P.J. Fraser, and L.W. Porter (continued)

GLOBAL AND HEMISPHERIC

Monthly global and hemispheric mixing ratios of CFC-11 and CFC-12.

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Other Trace Gases and Atmospheric Aerosols

Global and hemispheric means of CFC-11 and CFC-12 from the NOAA/CMDL flask sampling program

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GLOBAL AND HEMISPHERIC

Atmospheric CFC-11 and CFC-12 Mixing Ratios^a

Global and hemispheric mixing ratios													
Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
CFC-11 (parts per trillion)													
Global													
1977	139.6	135.2						139.1	139.5	141.9	141.1	142.3	
1978	145.0	143.8	144.5	145.8	147.8	146.5	148.1	150.5	151.3	151.1	155.3	152.8	148.5
1979	153.9	155.1	155.6	155.9	154.9	155.3	156.9	158.4	157.9	162.7	161.9	162.9	157.6
1980	163.2	163.5	165.9	164.9	166.7	166.0	166.6	166.6	168.0	169.7	168.9	169.2	166.6
1981	170.2	171.8	172.4	172.8	175.0	173.9	175.7	175.8	177.2	180.2	177.8	180.3	175.3
1982	180.9	180.6	180.7	182.3	182.2	181.9	183.4	184.1	185.1	185.9	188.5	188.1	183.6
1983	190.0	188.4	191.0	191.2	191.1	192.9	192.9	192.3	194.2	195.8	195.2	197.5	192.7
1984	199.0	198.8	198.7	200.2	199.3	199.3	199.7	200.5	203.7	204.3	205.0	208.9	201.5
1985	209.5	210.1	211.7	212.0	212.0	211.0	211.6	213.3	215.1	217.0	216.6	219.3	213.3
1986	218.1	216.9	219.7	221.7	223.6	224.1	223.3	225.3	226.0	227.2	228.5	229.3	223.6
1987	229.0	233.7	232.1	231.6	235.4	232.7	233.0		237.3	238.5	239.8	239.7	
1988	240.6	242.5	240.6	244.8	244.3	244.6	245.2	247.0	245.8	247.7	251.1	250.4	245.4
1989	252.9	252.8	252.1	254.2	254.4	254.3	255.5	257.7	258.1	258.3	259.5	259.7	255.8
1990	261.5	260.5	262.1	261.1	259.4	261.8	260.9	262.8	262.7	263.0	264.0	266.6	262.2
1991	266.1	264.4	266.5	267.5	267.3	267.9	267.1	268.2	268.1	268.0	269.3	269.4	267.5
1992	270.1	270.7	269.6	270.4	269.1	270.7	268.3	270.1	270.8	271.9	272.6	272.9	270.6
Northern Hemisphere													
1977	145.0	144.5	141.5	140.5	142.1	142.1	141.6	144.6	145.2	148.5	147.8	151.0	144.5
1978	150.2	149.8	150.9	150.7	154.2	151.6	154.9	155.2	159.2	157.4	159.5	157.9	154.3
1979	158.9	158.9	161.5	160.6	159.7	160.8	161.7	164.6	163.8	168.9	168.4	167.9	163.0
1980	168.8	168.2	172.8	171.4	170.9	171.6	173.0	173.0	172.0	174.6	176.2	174.6	172.3
1981	175.0	177.3	178.1	177.6	179.0	179.6	180.5	180.7	182.5	183.9	183.2	185.0	180.2
1982	184.0	184.7	186.0	186.6	186.9	186.8	188.1	187.8	189.9	190.3	192.1	191.9	187.9
1983	192.4	193.8	195.3	196.3	196.4	198.3	198.3	198.1	200.3	200.9	201.1	203.1	197.9
1984	202.9	202.8	204.1	204.0	204.3	204.7	204.8	205.6	207.8	211.1	212.0	213.4	206.5
1985	213.7	213.9	216.3	215.9	217.0	216.2	215.8	218.3	220.3	223.3	223.1	224.8	218.2
1986	222.3	224.1	225.1	228.7	227.6	228.2	227.4	229.7	230.6	233.9	235.4	234.8	229.0
1987	234.7	237.9	237.1	238.8	242.4	239.9	239.6	241.2	242.7	247.4	247.1	246.5	241.3
1988	246.3	248.8	247.3	251.2	252.5	251.6	252.3	253.2	253.8	254.1	260.3	256.5	252.3
1989	257.8	258.1	257.9	259.8	260.1	260.5	261.9	262.3	264.1	264.6	266.4	266.2	261.6
1990	267.2	267.9	268.3	266.1	265.7	268.1	265.8	267.0	267.4	269.3	269.3	271.1	267.8
1991	270.6	270.4	270.5	272.5	271.5	270.5	271.8	270.8	272.0	271.3	273.5	275.5	271.7
1992	274.9	273.7	272.0	275.6	274.4	274.5	273.6	273.8	274.8	275.9	277.4	276.8	274.8
Southern Hemisphere													
1977	134.3	125.9						133.6	133.9	135.2	134.4	133.5	
1978	139.7	137.8	138.1	141.0	141.5	141.3	141.2	145.9	143.3	144.9	151.2	147.7	142.8
1979	148.9	151.4	149.7	151.3	150.2	149.8	152.1	152.2	152.0	156.4	155.4	157.9	152.3
1980	157.7	158.9	159.0	158.5	162.6	160.3	160.2	160.3	163.9	164.7	161.6	163.8	161.0
1981	165.3	166.3	166.7	168.0	171.0	168.3	170.9	170.8	171.9	176.5	172.5	175.6	170.3
1982	177.9	176.6	175.4	178.1	177.6	177.0	178.8	180.4	180.3	181.5	185.0	184.4	179.4
1983	187.7	183.0	186.8	186.2	185.8	187.4	187.5	186.4	188.0	190.8	189.3	191.9	187.6
1984	195.0	194.7	193.3	196.3	194.3	193.9	194.7	195.5	199.6	197.6	198.1	204.5	196.5
1985	205.2	206.4	207.1	208.0	206.9	205.8	207.4	208.3	210.0	210.6	210.1	213.8	208.3
1986	213.9	209.8	214.2	214.7	219.6	220.0	219.1	220.9	221.4	220.5	221.7	223.8	218.3

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GLOBAL AND HEMISPHERIC

Atmospheric CFC-11 and CFC-12 Mixing Ratios (continued)^a

Global and hemispheric mixing ratios													
Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
CFC-11 (parts per trillion)													
<i>Southern Hemisphere (continued)</i>													
1987	223.3	229.5	227.0	224.4	228.5	225.6	226.3		231.9	229.7	232.5	232.9	
1988	235.0	236.1	233.8	238.4	236.2	237.5	238.1	240.8	237.8	241.3	241.9	244.4	238.4
1989	248.1	247.5	246.3	248.6	248.7	248.1	249.1	253.1	252.1	252.1	252.7	253.2	250.0
1990	255.9	253.1	255.9	256.0	253.1	255.6	256.1	258.6	258.0	256.7	258.8	262.1	256.7
1991	261.6	258.3	262.4	262.5	263.0	265.3	262.5	265.6	264.2	264.8	265.2	263.3	263.2
1992	265.3	267.7	267.1	265.3	263.7	267.0	262.9	266.5	266.8	267.8	267.7	269.1	266.4
CFC-12 (parts per trillion)													
<i>Global</i>													
1977								252.4	250.4	255.2	255.4	262.8	
1978	265.2	264.0	262.5			274.5	272.1	271.6	273.5	274.4	275.9	280.0	
1979	280.3	279.0	282.9	282.1	283.1	285.0	285.8	287.6	292.2	293.3	294.1	293.2	286.6
1980	297.0	300.0	297.3	299.2	296.7	298.5	298.7	299.2	302.8	304.1	304.2	306.3	300.3
1981	306.6	310.9	312.8	316.8	318.7	321.2	323.6	323.9	324.2	328.0	326.6	330.9	320.4
1982	331.3	334.4	331.9	335.7	332.8	334.5	336.8	337.9	339.6	342.4	344.6	343.3	337.1
1983	346.2	347.8	349.7	349.7	350.2	350.7	354.0	354.0	359.4	362.1	364.7	363.3	354.3
1984	364.9	369.1	363.5										
1985		379.4	377.3	377.3	384.4	386.4	380.9	381.6	394.7	399.0	398.8	401.0	
1986	402.0	403.9	405.2	405.9	407.2	409.5	408.0	411.0	411.6	415.9	414.9	417.7	409.4
1987	419.9	419.2	430.5	422.8	428.0	421.9	425.8			434.1	435.9	434.8	
1988	435.7	439.4	438.7	445.4	443.5	442.1	448.9	448.9	449.7	452.9	459.5	455.0	446.6
1989	456.9	458.7	455.2	458.9	461.2	456.3	463.6	464.5	467.0	469.2	470.9	471.5	462.8
1990	476.8	474.8	474.5	475.4	474.5	476.7	474.1	476.2	479.5	480.7	482.6	484.5	477.5
1991	487.1	481.9	487.6	490.5	487.9	488.0	489.8	491.8	494.2	496.0	495.4	498.8	490.8
1992	498.3	500.1	501.7	504.3	506.1	508.3	505.2	507.0	508.6	511.2	509.9	510.3	505.9
<i>Northern Hemisphere</i>													
1977					258.0		257.8	262.8	259.4	266.6	266.8	274.8	
1978	276.7	272.0	275.6	285.3		289.0	286.5	284.4	284.7	288.0	287.8	294.2	
1979	290.3	288.7	292.6	290.2	293.8	296.8	295.6	295.7	303.9	306.0	301.6	305.7	296.7
1980	310.1	315.2	309.6	311.4	307.3	307.7	308.2	309.2	309.0	314.6	316.1	316.4	311.2
1981	314.8	319.4	321.0	326.8	329.4	332.0	333.9	333.9	335.8	339.6	334.8	342.0	330.3
1982	340.1	340.2	339.0	343.7	341.7	342.9	344.9	345.2	348.2	350.9	351.9	353.0	345.1
1983	351.9	356.2	356.1	357.0	358.5	359.3	365.7	359.5	366.6	369.1	372.7	372.7	362.1
1984	372.4	375.9	367.7										
1985		385.3	384.4	383.6	389.5	394.9	385.9	389.5	401.3	407.8	408.5	410.1	
1986	409.3	408.0	412.4	413.2	415.2	416.7	413.7	417.9	416.8	425.4	425.1	427.1	416.7
1987	428.7	423.5	439.3	433.8	440.7	436.0	435.7	437.9	445.9	449.1	449.3	446.7	438.9
1988	447.3	449.1	451.1	455.6	454.7	453.9	459.7	459.8	461.3	461.1	473.4	467.5	457.9
1989	467.6	465.6	464.2	468.5	470.4	469.3	472.4	474.8	477.0	478.1	482.4	480.9	472.6
1990	484.1	487.9	484.0	486.7	486.3	486.9	484.3	485.4	490.4	490.3	491.7	493.5	487.6
1991	494.1	491.7	493.9	498.2	494.4	497.1	498.0	498.9	502.3	504.9	504.1	507.0	498.7
1992	509.1	508.5	508.9	515.8	512.3	516.3	515.0	515.6	517.2	520.6	519.6	521.7	515.1

Other Trace Gases and Atmospheric Aerosols

Global and hemispheric means of CFC-11 and CFC-12 from the NOAA/CMDL flask sampling program

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GLOBAL AND HEMISPHERIC

Atmospheric CFC-11 and CFC-12 Mixing Ratios (continued)^a

Global and hemispheric mixing ratios													
Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
CFC-12 (parts per trillion)													
Southern Hemisphere													
1977						231.0		242.1	241.4	243.8	244.1	250.9	
1978	253.6	256.0	249.3		261.5	260.0	257.6	258.9	262.3	260.9	264.1	265.9	
1979	270.4	269.3	273.1	274.0	272.3	273.2	276.0	279.5	280.4	280.6	286.6	280.8	276.4
1980	283.9	284.8	285.0	287.0	286.1	289.3	289.2	289.2	296.6	293.6	292.4	296.1	289.4
1981	298.4	302.4	304.6	306.8	307.9	310.4	313.3	313.9	312.5	316.4	318.4	319.9	310.4
1982	322.6	328.5	324.7	327.6	324.0	326.0	328.8	330.5	331.1	333.9	337.4	333.5	329.1
1983	340.5	339.5	343.2	342.5	341.9	342.1	342.2	348.5	352.2	355.0	356.6	353.9	346.5
1984	357.4	362.4	359.3										
1985		373.4	370.3	371.1	379.3	377.9	375.9	373.7	388.2	390.2	389.1	392.0	
1986	394.8	399.8	397.9	398.6	399.3	402.3	402.3	404.0	406.5	406.5	404.8	408.3	402.1
1987	411.1	415.0	421.8	411.8	415.2	407.8	415.8			419.0	422.4	422.8	
1988	424.0	429.8	426.3	435.2	432.3	430.3	438.1	438.0	438.1	444.6	445.6	442.5	435.4
1989	446.1	451.9	446.2	449.2	451.9	443.4	454.9	454.2	457.0	460.4	459.3	462.1	453.1
1990	469.6	461.7	464.9	464.0	462.7	466.5	463.8	467.1	468.6	471.2	473.5	475.4	467.4
1991	480.2	472.1	481.3	482.7	481.4	478.8	481.6	484.6	486.2	487.0	486.7	490.5	482.8
1992	487.5	491.7	494.4	492.9	499.8	500.4	495.5	498.5	500.0	501.8	500.2	498.8	496.8

^aCFC-11 and CFC-12 mixing ratios are expressed in parts per trillion by mole (ppt). Values represent global and hemispheric averages derived from atmospheric air samples collected at sites in the NOAA/CMDL halocarbon monitoring network. Annual averages represent arithmetic means of the monthly values, for years when data for all 12 months are available.

These global and hemispheric means of CFC-11 and CFC-12 from the National Oceanic and Atmospheric Administration (NOAA)/Climate Monitoring and Diagnostics Laboratory (CMDL) flask sampling program are available at no cost in electronic form from CDIAC. Readers who wish to use these data in any presentation or publication must give credit to NOAA/CMDL and should first contact one of the following principal investigators:

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Other Trace Gases and Atmospheric Aerosols

Global and hemispheric means of CFC-11 and CFC-12
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Other Trace Gases and Atmospheric Aerosols

Atmospheric halocarbon records from the NOAA/CMDL flask sampling program

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Alert • Barrow • Cape Grim • Mauna Loa • Niwot Ridge • Samoa (U.S.) • South Pole

Period of Record

1977–92 (varies with site)

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Other Trace Gases and Atmospheric Aerosols

Atmospheric halocarbon records from the NOAA/CMDL
flask sampling program

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Methods

Measurements of CFC-11 (CCl_3F), CFC-12 (CCl_2F_2), HCFC-22 (CHClF_2), H-1301 (CBrF_3), and H-1211 (CBrClF_2) were made from flask samples collected for the National Oceanic and Atmospheric Administration (NOAA) Climate Monitoring and Diagnostics Laboratory (CMDL) at climate monitoring stations (Barrow, Alaska, U.S.A.; Mauna Loa, Hawaii, U.S.A.; Cape Matatula, American Samoa; and the South Pole) and cooperative sampling sites (Niwot Ridge, Colorado, U.S.A.; Alert, Northwest Territories, Canada; and Cape Grim Baseline Air Pollution Station, Tasmania, Australia).

CFC-11 and CFC-12

Starting in 1977, paired samples were collected each week in 300-mL or 850-mL electropolished, stainless steel flasks at the four NOAA/CMDL stations and Niwot Ridge. After 1980, flask pairs at the South Pole were collected once a week only during the austral summer, when the station was open. Collection of flask pairs began at Alert in 1988 and at Cape Grim in 1991. All flasks were shipped back to Boulder, Colorado, for analysis by electron capture–gas chromatography (EC-GC) (Thompson et al. 1985; Elkins et al. 1988). The same GC was used throughout the entire sampling; the only major modifications were automating the EC-GC, adding a precolumn, and replacing a gas sampling valve in 1987 to permit backflushing and more rapid sampling.

During the period of record, calibration of the flask measurements involved only three secondary gas standards, filled with air from Niwot Ridge. The first secondary standard was compared yearly against the calibration scale of R.A. Rasmussen (Rasmussen and Khalil 1986) until it was depleted in 1985. After this time, the other two secondary standards were compared periodically to a new set of gravimetric standards (Novelli et al. 1991) and agreed with older sets to better than 1% (Montzka et al. 1992). Analysis of long-term drift of the three secondary standards revealed that the first standard (used from 1977 to 1984) had a statistically significant drift rate and that the other two standards (used after 1984) did not drift significantly (Montzka et al. 1992).

During data selection, outliers were removed if they were greater than 3σ away from the fits to fourth order polynomial and simple harmonic series (Elkins et al. 1993).

HCFC-22

Measurements of atmospheric HCFC-22 were made from air samples collected in electropolished, stainless steel flasks every 1–2 months from November 1991 through December 1992 at three of the four NOAA/CMDL flask network sites: Barrow, Mauna Loa, and Samoa. The fourth station, located at the South Pole, was sampled only during the austral summer. Sample collection for HCFC-22 also took place at three cooperative sampling sites: Alert, Niwot Ridge, and Cape Grim.

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Subsamples of 150–250-mL were cryotrapped onto uncoated, fused-silica tubing and analyzed for HCFC-22 by gas chromatography–mass spectrometry (GC-MS) as described in Montzka et al. (1993). All mixing ratios are traceable to gravimetrically prepared standards, made up in the laboratory at NOAA/CMDL. This procedure for preparing standards is similar to that used by the National Institute for Standards and Technology (Zielinski et al. 1986). The absolute calibration is believed to be accurate within 5%. The coefficient of variation (standard deviation : mean) for repeat measurement or analytical precision of these samples was ~1.5%. The average difference (range) between the two simultaneously collected flasks was 1.4 parts per trillion by mole (ppt). Because of occasional problems with contamination of the flasks and with analytical instrumentation, obvious outliers have been removed by visual inspection.

H-1301 and H-1211

Paired samples were collected every 1–2 months in electropolished, stainless steel flasks from mid-1989 through early 1992 at three of the four NOAA/CMDL flask network sites (Barrow, Mauna Loa, and Samoa) and at Niwot Ridge. The fourth station, located at the South Pole, was sampled only during the austral summers of two years; hence the record is not contiguous. In 1991, sample collection for halons was begun at two cooperative sampling sites, Alert and Cape Grim. Approximately 100-mL subsamples from the flasks were cryotrapped onto Al₂O₃-lined, fused-silica tubing and analyzed by temperature-programmed, electron capture–gas chromatography (EC-GC) as described in Butler et al. (1989). In 1992, 250-mL subsamples were also cryotrapped onto uncoated, fused-silica tubing and analyzed for H-1211 by gas chromatography–mass spectrometry (GC-MS). Measurements between the two systems agreed within 0.1 ppt (1 σ). All mixing ratios are traceable to gravimetrically prepared standards made up in the laboratory at NOAA/CMDL. This procedure for preparing standards is similar to that used by the National Institute for Standards and Technology (Zielinski et al. 1986) and typically is accurate within 1% (1 σ). The coefficient of variation (standard deviation : mean) for repeat measurements of the samples was ~5%. Because H-1301 and H-1211 are present at extremely low mixing ratios (1–3 ppt), problems occasionally result from contamination of the flasks and analytical instrumentation. Thus, data selection is sometimes required: outliers >3 σ are removed from the fitted curve.

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ALERT

Period of Record

1988–92 (CFC-11 and CFC-12); 1991–92 (HCFC-22, H-1301, and H-1211)

Trends

CFC-11 and CFC-12

From February 1988 to November 1992, the monthly average mixing ratio of CFC-11 at Alert, Northwest Territories, Canada, increased from 256.2 to 283.7 parts per trillion by mole (ppt). Over nearly the same period (February 1988–December 1992), the monthly average mixing ratio of CFC-12 increased from 458.5 to 537.5 ppt. For both CFC-11 and CFC-12, the increases were nearly linear from 1988 through 1989, averaging 10.6 ppt/year ($R^2 = .90$) for CFC-11 and 18.1 ppt/year ($R^2 = .91$) for CFC-12. Since 1989 the growth rates at Alert have decreased rapidly, and trends for 1992 were not statistically significant (at the $P = .05$ level) for either CFC-11 or CFC-12. These decreases reflect the recent worldwide declines in production and emissions of CFCs (Elkins et al. 1993). The magnitudes of the declines at Alert are greater than those at low- and middle-latitude sites in the NOAA/CMDL network but are consistent with those at the other high-latitude sites (i.e., Barrow and the South Pole).

The records at Alert also show a seasonal pattern, with peak mixing ratios during the winter months. These maxima reflect the composition of cold air trapped in the polar tropospheric vortex, which forms during the winter months and restricts ventilation with cleaner air from low latitudes (Elkins et al. 1993).

HCFC-22

From November 1991 to November 1992, the mixing ratio of HCFC-22 at Alert increased from 110.2 to 115.0 ppt, averaging 4.3 ppt/year. This trend is highly significant ($P = .02$).

The collective results presented here for HCFC-22 from the seven monitoring sites show a mean global mixing ratio of 100 ppt for March 1992, with a mean interhemispheric ratio (Northern hemispheric mixing ratio : Southern hemispheric mixing ratio) of 1.14. The mean global growth rate of HCFC-22 over the period of record was 7% per year (Montzka et al. 1993).

H-1301 and H-1211

From May 1991 to February 1992, the mixing ratio of H-1211 at Alert averaged 2.32 ppt, and the mixing ratio of H-1301 averaged 1.96 ppt. The data do not show a significant (at the $P = .05$ level) trend for either H-1211 or H-1301. Comparing their data with published results from other investigators (covering the period 1978–92), Butler et al. (1992) concluded that significant declines have occurred in the growth rates of the atmospheric mixing ratios of both halons. These recent drops in growth are supported in general by industry production figures, emission estimates, and current appraisals of atmospheric lifetimes.

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Other Trace Gases and Atmospheric Aerosols

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ALERT

Monthly atmospheric mixing ratios of CFC-12, CFC-11, HCFC-22, H-1211, and H-1301 at Alert.

CITE AS: Elkins, J.W., T.M. Thompson, J.H. Butler, S.A. Montzka, R.C. Myers, A.D. Clarke, T.H. Swanson, D.J. Endres, A.M. Yoshinaga, R.C. Schnell, M. Winey, B.G. Mendonca, M.V. Losleben, N.B.A. Trivett, D.E.J. Worthy, V. Hudec, V. Chorney, P.J. Fraser, and L.W. Porter. 1994. Atmospheric halocarbon records from the NOAA/CMDL flask sampling program. pp. 432-471. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Atmospheric halocarbon records from the NOAA/CMDL
flask sampling program

J.W. Elkins, T.M. Thompson, J.H. Butler, S.A. Montzka, R.C. Myers, A.D. Clarke, T.H. Swanson, D.J. Endres,
A.M. Yoshinaga, R.C. Schnell, M. Winey, B.G. Mendonca, M.V. Losleben, N.B.A. Trivett,
D.E.J. Worthy, V. Hudec, V. Chorney, P.J. Fraser, and L.W. Porter (continued)

ALERT

Alert
Northwest Territories
Canada
Tundra
82°30' N, 62°18' W
210 m above MSL

Atmospheric Mixing Ratios of Chlorofluorocarbons^a

Mixing ratios at Alert

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann ^b
CFC-11 (parts per trillion) ^c													
1988		256.2		258.1		255.2					264.2	262.5	
1989					267.6	268.8		266.5		272.4	273.0	278.2	
1990	273.8	279.3	276.7	275.3		274.6	272.0	278.3	273.0	276.4	274.8	277.3	
1991	279.1	276.4	275.0	279.0	282.6	278.3	277.2	274.7	275.2	275.9	280.8	282.6	278.1
1992	279.4	275.0	279.1	279.1	279.3	281.5	276.1	278.3	277.5		283.7		
CFC-12 (parts per trillion) ^c													
1988		458.5	453.4	463.9	463.9	460.0		465.5	468.2		472.3	476.9	
1989		472.0		476.4	486.6		476.4	481.9	483.9	489.1	488.1	494.3	
1990	490.7	492.2	493.0	497.9	495.0		492.6	490.4	486.6	495.5	497.3	497.3	
1991	501.4	502.0	504.5	506.9	501.6	495.6	504.7	507.1	507.8	508.1	509.8	526.5	506.3
1992	518.2	523.7	525.1	520.8	519.8	520.0	521.9	520.6	520.7	526.6	519.3	537.5	522.9

^aThese atmospheric chlorofluorocarbon records from the National Oceanic and Atmospheric Administration (NOAA)/Climate Monitoring and Diagnostics Laboratory (CMDL) flask sampling program are available at no cost in electronic form from CDIAC. Readers who wish to use these data in any presentation or publication must give credit to NOAA/CMDL and should first contact one of the following principal investigators:

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T.M. Thompson, phone: (303) 497-6671, Internet (electronic mail): tthompson@cmdl.noaa.gov.

^bAnnual values were calculated by averaging monthly values when all 12 were available.

^cEach point represents the average of 1–5 flask pairs that were measured six times for each pair by EC-GC with an average standard deviation of 0.8 ppt for CFC-11 and 1.0 ppt for CFC-12.

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Other Trace Gases and Atmospheric Aerosols

Atmospheric halocarbon records from the NOAA/CMDL flask sampling program

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ALERT

Atmospheric Mixing Ratios of Other Halocarbons^a

HCFC-22 (parts per trillion)		H-1301 (parts per trillion) ^b		H-1211 (parts per trillion) ^b	
Decimal year ^c	Mixing ratio	Decimal year ^c	Mixing ratio	Decimal year ^c	Mixing ratio
1991.8712	110.2	1991.359	2.23	1991.359	2.44
1992.0519	110.0	1991.529	1.77	1991.529	1.91
1992.1284	109.5	1991.759	1.89	1991.759	2.27
1992.3279	110.5	1991.874	1.92	1991.874	
1992.3852	113.4	1992.131	1.99	1992.131	2.65
1992.6202	111.5				
1992.7131	112.1				
1992.9071	115.0				

^aThese atmospheric halocarbon records from the National Oceanic and Atmospheric Administration (NOAA)/Climate Monitoring and Diagnostics Laboratory (CMDL) flask sampling program are available at no cost in electronic form from CDIAC. Readers who wish to use these data in any presentation or publication must give credit to NOAA/CMDL and should first contact one of the following principal investigators:

- **For HCFC-22**—S.A. Montzka, phone: (303) 497-6657, Internet (electronic mail): smontzka@cmdl.noaa.gov;
- **For H-1301 or H-1211**—J.H. Butler, phone: (303) 497-6898, Internet (electronic mail): jbutler@cmdl.noaa.gov.

^bThe values reported here differ from those given in earlier NOAA/CMDL annual reports (Butler et al. 1989)—H-1301: new value = $0.871 \times$ old value; H-1211: new value = $1.327 \times$ old value. The changes reflect a reanalysis of the assigned values for the two halons in a working standard against the gravimetric standards, not a change in the absolute scale of the original gravimetric standards.

$$^c\text{Decimal year} = \text{calendar year} + \frac{\text{day of year} - 1 + \frac{\text{hour of day}}{24}}{\text{total number of days in year}}$$

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BARROW

Period of Record

1977–92 (CFC-11 and CFC-12); 1991–92 (HCFC-22); 1989–92 (H-1301 and H-1211)

Trends

CFC-11 and CFC-12

From January 1977 to December 1992, the monthly average mixing ratio of CFC-11 at Barrow, Alaska, U.S.A., increased from 145.4 to 279.3 parts per trillion by mole (ppt). The increase was nearly linear during 1977–84, averaging 8.6 ppt/year ($R^2 = .99$). From September 1977 to December 1992, the monthly average mixing ratio of CFC-12 increased from 271.2 to 524.5 ppt. Although a number of gaps occur in the record, the increase was again nearly linear during 1977–84, averaging 16.4 ppt/year ($R^2 = .98$). The gap in the CFC-12 record during 1984–85 resulted from a gas chromatograph problem affecting only CFC-12. A surge in CFC production worldwide beginning in 1985 caused a corresponding rise in the atmospheric growth rates at Barrow; these reached average 1985–88 values of 11.9 ppt/year ($R^2 = .97$) for CFC-11 and 20.9 ppt/year ($R^2 = .96$) for CFC-12. Since 1988 the growth rates at Barrow have decreased rapidly, particularly for CFC-11: in 1992, the mean growth rate of CFC-11 was essentially zero, and the mean growth rate of CFC-12 was 11.0 ppt/year (Elkins et al. 1993). These decreases reflect the recent worldwide declines in production and emissions of CFCs (Elkins et al. 1993). The decline in CFC-11 mixing ratios at Barrow is consistent with that at the other high-latitude sites (i.e., Alert and the South Pole) in the NOAA/CMDL network but is greater than that at low- and middle-latitude sites.

The records at Barrow also show a seasonal pattern: peak mixing ratios occur during the period November–March. These peaks are the result of cold air trapped in the polar tropospheric vortex, which forms during the winter months and restricts ventilation with cleaner air from low latitudes (Elkins et al. 1993).

HCFC-22

From December 1991 to December 1992, the mixing ratio of HCFC-22 at Barrow increased from 109.2 to 115.7 ppt, averaging 5.7 ppt/year. This trend is highly significant ($P = .003$).

The collective results presented here for HCFC-22 from the seven monitoring sites show a mean global mixing ratio of 100 ppt for March 1992, with a mean interhemispheric ratio (Northern hemispheric mixing ratio : Southern hemispheric mixing ratio) of 1.14. The mean global growth rate of HCFC-22 over the period of record was 7% per year (Montzka et al. 1993).

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BARROW

H-1301 and H-1211

Over the period of record (September 1989–February 1992), the mixing ratio of H-1211 at Barrow averaged 2.27 ppt but showed no significant (at the $P = .05$ level) trend. Over nearly the same period (August 1989–February 1992), the mixing ratio of H-1301 averaged 1.91 ppt and showed a significant ($P = .02$) increase of 0.11 ppt/year. Comparing their data with published results from other investigators (covering the period 1978–92), Butler et al. (1992) concluded that significant declines have occurred in the growth rates of the atmospheric mixing ratios of both halons. These recent drops in growth are supported in general by industry production figures, emission estimates, and current appraisals of atmospheric lifetimes.

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Other Trace Gases and Atmospheric Aerosols
**Atmospheric halocarbon records from the NOAA/CMDL
 flask sampling program**

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 D.E.J. Worthy, V. Hudec, V. Chorney, P.J. Fraser, and L.W. Porter (continued)

BARROW

*Monthly atmospheric mixing ratios of CFC-12, CFC-11, HCFC-22,
 H-1211, and H-1301 at Barrow.*

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Other Trace Gases and Atmospheric Aerosols

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BARROW

Barrow
Alaska, U.S.A.
Arctic coastal seashore
71°18' N, 156°36' W
11 m above MSL

Atmospheric Mixing Ratios of Chlorofluorocarbons^a

Mixing ratios at Barrow

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann ^b
CFC-11 (parts per trillion) ^c													
1977	145.4	148.1	143.9	145.5	150.7	143.2		146.6	147.6	154.6	155.0	157.8	
1978	156.4	155.5	156.6	158.9	156.7	156.9	157.6	158.6	161.5	163.1	167.7	165.9	159.6
1979	164.6	165.3	167.8	167.3	166.1	165.7	166.1	165.6	167.8	172.2	173.1	174.9	168.0
1980	175.8	174.5	176.6	175.2	174.6	175.7	175.2	176.1	177.2	178.2	176.4	181.5	176.4
1981	180.9	185.1	182.1	183.8	182.5	183.5	183.5	184.1	183.4	187.8	190.0	192.2	184.9
1982	190.6	192.8	193.6	192.1	190.3	189.7	190.9	191.8	193.8	195.3	196.9	198.0	193.0
1983	199.5	198.9	199.1	200.8		201.6	202.1	200.1	203.9	204.4	207.5	205.8	
1984	209.1	209.7	208.8	206.9	208.8	207.9	209.3	209.0	210.8	213.7	215.5	218.3	210.7
1985	218.9	224.5	220.2	222.8	221.0	218.4	218.9	223.0	223.1	227.6	229.7	230.1	223.2
1986	230.8	230.5	231.7	237.6	231.9	231.5	231.2	233.8	232.4	238.7	239.0	242.8	234.3
1987	242.1	242.3	242.4	245.2	245.5	244.6	246.7	246.4	248.6	252.7	255.3	256.2	247.3
1988	254.0	256.6	256.2	258.2	255.9	256.6	256.3	257.9	258.8	261.4	266.3	265.3	258.6
1989	263.8	265.4	266.4	267.0	265.2	263.6	264.1	263.1	265.9	271.6	271.5	275.5	266.9
1990	275.7	277.3	274.0	272.4	270.3	271.8	268.6	270.5	270.4	272.2	273.1	276.1	272.7
1991	276.0	277.8	278.6	275.0	274.1	273.7	272.7	274.1	274.1	276.5	276.8	279.6	275.8
1992	277.8	278.5		279.7	276.0	277.7	276.0	274.1	275.3	278.8	278.4	279.3	
CFC-12 (parts per trillion) ^c													
1977									271.2				
1978				290.6			286.2		291.6	296.1	299.4	296.8	
1979	298.2	296.0	298.2	295.6	294.7	298.6	299.5	298.6	306.6	303.3	308.9	311.1	300.8
1980	312.8	307.9	310.5	316.3	315.7	313.4	309.7	313.7	319.3	318.4	327.4	335.8	316.7
1981	324.0	329.3	327.0	330.6	328.9	327.9	334.4	341.2	335.6	339.4	341.5	344.4	333.7
1982	345.3	348.5	347.0	349.0	349.9	344.6	348.8	350.1	352.5	357.9	361.3	361.1	351.3
1983	363.8	364.4	363.3	363.7	366.1	362.8	363.1	365.7	369.1	377.1	375.7	375.1	367.5
1984	383.4	385.2	384.2										
1985		400.1	392.2	392.8	397.5	402.8	391.1	394.4	406.4	414.0	417.5	419.7	
1986	419.0	421.0	422.6	424.1	420.4	420.2	420.3	418.2	420.5	429.7	433.0	437.0	423.8
1987	435.2	436.2	443.6	442.3	440.7	437.8	445.3	441.4	450.0	454.7	458.0	458.4	445.3
1988	457.4	459.4	460.7	461.1	458.2	460.9	461.4	463.3	465.8	470.7	479.9	476.3	464.6
1989	479.0	473.9	475.2	475.5	476.8	472.4	480.4	476.8	480.6	484.6	491.8	493.0	480.0

Other Trace Gases and Atmospheric Aerosols
 Atmospheric halocarbon records from the NOAA/CMDL
 flask sampling program

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BARROW

Atmospheric Mixing Ratios of Chlorofluorocarbons (continued)^a

Mixing ratios at Barrow													
Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann ^b
CFC-12 (parts per trillion) continued ^c													
1990	495.2	502.9	491.1	489.7	489.2	491.7	484.8	488.2	489.4	495.6	497.1	498.7	492.8
1991	501.1	501.9	501.4	501.0	494.7	500.4	498.8	501.3	506.3	509.9	511.7	518.7	503.9
1992	515.2	516.0		515.1	515.2	523.8	516.9	515.9	519.2	526.0	524.4	524.5	

^aThese atmospheric chlorofluorocarbon records from the National Oceanic and Atmospheric Administration (NOAA)/Climate Monitoring and Diagnostics Laboratory (CMDL) flask sampling program are available at no cost in electronic form from CDIAC. Readers who wish to use these data in any presentation or publication must give credit to NOAA/CMDL and should first contact one of the following principal investigators:

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^bAnnual values were calculated by averaging monthly values when all 12 were available.

^cEach point represents the average of 1–5 flask pairs that were measured six times for each pair by EC-GC with an average standard deviation of 0.8 ppt for CFC-11 and 1.0 ppt for CFC-12.

Atmospheric Mixing Ratios of Other Halocarbons^a

HCFC-22 (parts per trillion)		H-1301 (parts per trillion) ^b		H-1211 (parts per trillion) ^b	
Decimal year ^c	Mixing ratio	Decimal year ^c	Mixing ratio	Decimal year ^c	Mixing ratio
1991.9507	109.2	1989.589	1.62	1989.589	
1992.0219	112.3	1989.668	1.64	1989.668	2.56
1992.1202	109.1	1989.767	1.82	1989.767	1.86
1992.2678	110.7	1990.304	1.86	1990.304	2.12
1992.3716	111.2	1990.455	1.77	1990.455	2.14
1992.4590	110.0	1990.455	1.90	1990.455	2.12
1992.5383	110.4	1990.589	1.85	1990.589	2.11
1992.6175	111.4	1990.704	1.99	1990.704	2.28
1992.8661	114.5	1990.858	2.01	1990.858	2.55
1992.9399	116.3	1991.126	2.08	1991.126	
1992.9590	115.7	1991.173	1.79	1991.173	2.30
		1991.225	2.22	1991.225	
		1991.225	2.01	1991.225	2.32
		1991.449	1.96	1991.449	2.64
		1991.625	1.79	1991.625	2.00
		1991.770	2.02	1991.770	1.95

Atmospheric halocarbon records from the NOAA/CMDL flask sampling program

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BARROW

Atmospheric Mixing Ratios of Other Halocarbons (continued)^a

HCFC-22 (parts per trillion)		H-1301 (parts per trillion) ^b		H-1211 (parts per trillion) ^b	
Decimal year ^c	Mixing ratio	Decimal year ^c	Mixing ratio	Decimal year ^c	Mixing ratio
		1991.855	1.83	1991.855	
		1991.953	2.08	1991.953	2.57
		1992.025	2.26	1992.025	2.34
		1992.112	1.70	1992.112	2.40

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- For H-1301 or H-1211—J.H. Butler, phone: (303) 497-6898, Internet (electronic mail): jbutler@cmdl.noaa.gov.

^bThe values reported here differ from those given in earlier NOAA/CMDL annual reports (Butler et al. 1989):—H-1301: new value = 0.871 × old value; H-1211: new value = 1.327 × old value. The changes reflect a reanalysis of the assigned values for the two halons in a working standard against the gravimetric standards, not a change in the absolute scale of the original gravimetric standards.

$$^c\text{Decimal year} = \text{calendar year} + \frac{\text{day of year} - 1 + \frac{\text{hour of day}}{24}}{\text{total number of days in year}}$$

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Other Trace Gases and Atmospheric Aerosols

Atmospheric halocarbon records from the NOAA/CMDL
flask sampling program

J.W. Elkins, T.M. Thompson, J.H. Butler, S.A. Montzka, R.C. Myers, A.D. Clarke, T.H. Swanson, D.J. Endres,
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D.E.J. Worthy, V. Hudec, V. Chorney, P.J. Fraser, and L.W. Porter (continued)

CAPE GRIM

Period of Record

1991–92 (CFC-11, CFC-12, HCFC-22, H-1301, and H-1211)

Trends

CFC-11 and CFC-12

Since collection of flasks began in May 1991, the monthly average mixing ratio of CFC-11 at Cape Grim, Tasmania, Australia, has increased slightly [after an anomalously high initial value of 269.8 parts per trillion by mole (ppt) in June 1991] to a value of 268.4 ppt in December 1992. Over nearly the same period, the monthly average mixing ratio of CFC-12 increased from 474.6 to 498.8 ppt. In 1992, the mean growth rate of CFC-12 was 17.6 ppt/year, whereas no statistically significant (at the $P = .05$ level) trend was found for CFC-11. This absence of growth in the CFC-11 mixing ratio reflects the recent worldwide declines in the production and emission of CFCs and is consistent with findings at other sites in the NOAA/CMDL network (Elkins et al. 1993).

HCFC-22

From November 1991 to December 1992, the mixing ratio of HCFC-22 at Cape Grim increased from 93.0 to 98.6 ppt, averaging 6.0 ppt/year. This trend is highly significant ($P = .0001$).

The collective results presented here for HCFC-22 from the seven monitoring sites show a mean global mixing ratio of 100 ppt for March 1992, with a mean interhemispheric ratio (Northern hemispheric mixing ratio : Southern hemispheric mixing ratio) of 1.14. The mean global growth rate of HCFC-22 over the period of record was 7% per year (Montzka et al. 1993).

H-1301 and H-1211

From May 1991 to February 1992, the mixing ratio of H-1211 at Cape Grim averaged 2.08 ppt, while that of H-1301 averaged 1.62 ppt. Neither H-1211 nor H-1301 showed any significant (at the $P = .05$ level) trend over this period. Comparing their data with published results from other investigators (covering the period 1978–92), Butler et al. (1992) concluded that significant declines have occurred in the growth rates of the atmospheric mixing ratios of both halons. These recent drops in growth are supported in general by industry production figures, emission estimates, and current appraisals of atmospheric lifetimes.

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Atmospheric halocarbon records from the NOAA/CMDL flask sampling program

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CAPE GRIM

Monthly atmospheric mixing ratios of CFC-12, CFC-11, HCFC-22, H-1211, and H-1301 at Cape Grim.

CITE AS: Elkins, J.W., T.M. Thompson, J.H. Butler, S.A. Montzka, R.C. Myers, A.D. Clarke, T.H. Swanson, D.J. Endres, A.M. Yoshinaga, R.C. Schnell, M. Winey, B.G. Mendonca, M.V. Losleben, N.B.A. Trivett, D.E.J. Worthy, V. Hudec, V. Chorney, P.J. Fraser, and L.W. Porter. 1994. Atmospheric halocarbon records from the NOAA/CMDL flask sampling program. pp. 432-471. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Other Trace Gases and Atmospheric Aerosols

Atmospheric halocarbon records from the NOAA/CMDL flask sampling program

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D.E.J. Worthy, V. Hudec, V. Chorney, P.J. Fraser, and L.W. Porter (continued)

CAPE GRIM

Cape Grim
Tasmania, Australia
Promontory seashore
40°42' S, 144°48' E
94 m above MSL

Atmospheric Mixing Ratios of Chlorofluorocarbons^a

Mixing ratios at Cape Grim													
Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann ^b
CFC-11 (parts per trillion) ^c													
1991						269.8	261.6		262.9	264.1			
1992		268.7			263.4			267.2	268.6	268.7		268.4	
CFC-12 (parts per trillion) ^c													
1991					474.6	476.3	479.5	481.0	484.4	485.1	483.6		
1992	481.4	490.6		490.4	495.4		492.4	496.9	499.2	501.9		498.8	

^aThese atmospheric chlorofluorocarbon records from the National Oceanic and Atmospheric Administration (NOAA)/Climate Monitoring and Diagnostics Laboratory (CMDL) flask sampling program are available at no cost in electronic form from CDIAC. Readers who wish to use these data in any presentation or publication must give credit to NOAA/CMDL and should first contact one of the following principal investigators:

J.W. Elkins, phone: (303) 497-6224, Internet (electronic mail): jelkins@cmdl.noaa.gov;
T.M. Thompson, phone: (303) 497-6671, Internet (electronic mail): tthompson@cmdl.noaa.gov.

^bAnnual values were calculated by averaging monthly values when all 12 were available.

^cEach point represents the average of 1–5 flask pairs that were measured six times for each pair by EC-GC with an average standard deviation of 0.8 ppt for CFC-11 and 1.0 ppt for CFC-12.

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Other Trace Gases and Atmospheric Aerosols

Atmospheric halocarbon records from the NOAA/CMDL flask sampling program

J.W. Elkins, T.M. Thompson, J.H. Butler, S.A. Montzka, R.C. Myers, A.D. Clarke, T.H. Swanson, D.J. Endres, A.M. Yoshinaga, R.C. Schnell, M. Winey, B.G. Mendonca, M.V. Losleben, N.B.A. Trivett, D.E.J. Worthy, V. Hudec, V. Chorney, P.J. Fraser, and L.W. Porter (continued)

CAPE GRIM

Atmospheric Mixing Ratios of Other Halocarbons^a

HCFC-22 (parts per trillion)		H-1301 (parts per trillion) ^b		H-1211 (parts per trillion) ^b	
Decimal year ^c	Mixing ratio	Decimal year ^c	Mixing ratio	Decimal year ^c	Mixing ratio
1991.8849	93.0	1991.359	1.65	1991.359	2.10
1991.9096	91.9	1991.452	1.68	1991.452	
1992.0355	90.3	1991.537	1.59	1991.537	1.86
1992.1148	92.4	1991.696	1.67	1991.696	
1992.1530	92.4	1991.825	1.73	1991.825	
1992.3060	94.2	1992.038	1.42	1992.038	2.16
1992.3634	95.1	1992.117	1.63	1992.117	2.22
1992.4016	94.8				
1992.5546	94.5				
1992.5874	96.2				
1992.6694	96.3				
1992.7049	96.6				
1992.7459	96.2				
1992.7978	96.0				
1992.9699	98.6				

^aThese atmospheric halocarbon records from the National Oceanic and Atmospheric Administration (NOAA)/Climate Monitoring and Diagnostics Laboratory (CMDL) flask sampling program are available at no cost in electronic form from CDIAC. Readers who wish to use these data in any presentation or publication must give credit to NOAA/CMDL and should first contact one of the following principal investigators:

- For HCFC-22—S.A. Montzka, phone: (303) 497-6657, Internet (electronic mail): smontzka@cmdl.noaa.gov;
- For H-1301 or H-1211—J.H. Butler, phone: (303) 497-6898, Internet (electronic mail): jbutler@cmdl.noaa.gov.

^bThe values reported here differ from those given in earlier NOAA/CMDL annual reports (Butler et al. 1989)—H-1301: new value = $0.871 \times$ old value; H-1211: new value = $1.327 \times$ old value. The changes reflect a reanalysis of the assigned values for the two halons in a working standard against the gravimetric standards, not a change in the absolute scale of the original gravimetric standards.

$$^c\text{Decimal year} = \text{calendar year} + \frac{\text{day of year} - 1 + \frac{\text{hour of day}}{24}}{\text{total number of days in year}}$$

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Other Trace Gases and Atmospheric Aerosols

Atmospheric halocarbon records from the NOAA/CMDL
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MAUNA LOA

Period of Record

1977–92 (CFC-11 and CFC-12); 1991–92 (HCFC-22); 1989–92 (H-1301 and H-1211)

Trends

CFC-11 and CFC-12

From January 1977 to December 1992, the monthly average mixing ratio of CFC-11 at Mauna Loa, Hawaii, U.S.A., increased from 139.9 to 275.4 parts per trillion by mole (ppt). During 1977–84, the increase was nearly linear, averaging 9.0 ppt/year ($R^2 = .99$). From May 1977 to December 1992, the monthly average mixing ratio of CFC-12 increased from 258.0 to 518.1 ppt. The increase was again nearly linear during 1977–84, averaging 15.7 ppt/year ($R^2 = .97$). The gap in the CFC-12 record during 1984–85 resulted from a gas chromatograph problem affecting only CFC-12. A surge in CFC production worldwide beginning in 1985 caused a corresponding rise in the atmospheric growth rates at Mauna Loa; these reached average 1985–88 values of 10.7 ppt/year ($R^2 = .98$) for CFC-11 and 20.7 ppt/year ($R^2 = .96$) for CFC-12. Since 1988 the growth rates at Mauna Loa have decreased rapidly, particularly for CFC-11: in 1992, the mean growth rate of CFC-11 was 4.3 ppt/year, and the mean growth rate of CFC-12 was 17.1 ppt/year. These decreases reflect the recent worldwide declines in production and emissions of CFCs and are consistent with findings at other sites in the NOAA/CMDL network (Elkins et al. 1993).

HCFC-22

From December 1991 to December 1992, the mixing ratio of HCFC-22 at Mauna Loa increased from 102.9 to 111.0 ppt, averaging 7.0 ppt/year. This trend is highly significant ($P = .0007$).

The collective results presented here for HCFC-22 from the seven monitoring sites show a mean global mixing ratio of 100 ppt for March 1992, with a mean interhemispheric ratio (Northern hemispheric mixing ratio : Southern hemispheric mixing ratio) of 1.14. The mean global growth rate of HCFC-22 over the period of record was 7% per year (Montzka et al. 1993).

H-1301 and H-1211

From September 1989 to April 1992, the mixing ratio of H-1211 at Mauna Loa increased from 1.92 to 2.56 ppt, averaging 0.16 ppt/year ($P = .06$). From July 1989 to April 1992, the mixing ratio of H-1301 grew from 1.14 to 1.88 ppt, at an average of 0.11 ppt/year ($P = .05$). Comparing their data with published results from other investigators (covering the period 1978–92), Butler et al. (1992) concluded that significant declines have occurred in the growth rates of the atmospheric mixing ratios of both halons. These recent drops in growth are supported in general by industry production figures, emission estimates, and current appraisals of atmospheric lifetimes.

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Atmospheric halocarbon records from the NOAA/CMDL flask sampling program

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MAUNA LOA

Monthly atmospheric mixing ratios of CFC-12, CFC-11, HCFC-22, H-1211, and H-1301 at Mauna Loa.

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D.E.J. Worthy, V. Hudec, V. Chorney, P.J. Fraser, and L.W. Porter (continued)

MAUNA LOA

Mauna Loa
Hawaii, U.S.A.
Barren volcanic
mountain slope
19°30' N, 155°36' W
3397 m above MSL

Atmospheric Mixing Ratios of Chlorofluorocarbons^a

Mixing ratios at Mauna Loa

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann ^b
CFC-11 (parts per trillion) ^c													
1977	139.9	139.5	139.0	134.1	135.0	143.4	140.3	142.6	144.7	144.2	144.8	145.7	141.1
1978	148.6	144.8	148.4	147.9	149.9	149.5	152.7	151.9	155.1	153.2	154.9	154.7	151.0
1979	157.4	157.5	158.8	158.0	157.1	157.6	159.8		163.3	168.4	166.5	165.3	
1980	167.1	165.8	168.1	169.8	165.8	169.7	171.3	171.9	169.9	173.4	175.7	172.7	170.1
1981	172.1	175.2	176.2	176.6	176.8	177.6	180.0	179.1	182.2	182.1	181.5	183.8	178.6
1982	181.4	183.0	182.5	183.4	185.1	184.7	184.9	186.2	188.2	188.7	189.1	188.2	185.5
1983	189.9	191.1	192.7	192.8	194.1	197.6	197.3	197.4	198.9	198.7	198.6	201.0	195.8
1984	200.7	201.7	200.6	202.8	201.7	203.0	203.6	205.1	206.6	209.4	212.3	211.7	204.9
1985	212.5	212.0	215.6	213.8	215.2	216.6	215.4	216.8	217.4	221.2	219.4	224.0	216.7
1986	218.8	219.1	222.5	227.7	226.0	225.7	227.0	227.4	231.6	232.7	232.8	233.1	227.0
1987	233.0		235.4	237.5		237.3	236.9	238.1	241.0	243.3	243.2	240.8	
1988	240.5	244.9	241.6	246.9	247.1	248.2	248.1	249.2	251.5	252.0	256.6	251.4	248.2
1989	255.6	253.6	255.2	257.4	257.5	258.8	257.9	260.0	261.9	261.7	261.8	262.2	258.6
1990	263.7	262.9	263.6	262.3	263.3	266.8	263.9	264.0	263.5	267.2	265.5	269.3	264.7
1991	269.0	265.3	268.1	270.0	271.0	267.3	270.0	268.9	268.6	267.9	271.4	273.4	269.2
1992	272.0	271.6	269.3	273.3	273.5	272.0	272.2	272.5	273.6	274.5	275.0	275.4	272.9
CFC-12 (parts per trillion) ^c													
1977					258.0		260.8		260.4	266.6	266.8	276.5	
1978	276.7	272.0	276.3	283.5		286.2	282.4	284.4	282.3	282.4	286.7	293.3	
1979	296.1	288.1	290.7	288.3	294.6	299.6	298.8		304.0	317.8	304.3	305.2	
1980	311.0	320.5	304.6	310.6	299.0	306.2	308.4	308.4	307.3	316.1	316.5	312.8	310.1
1981	311.2	317.9	317.5	327.7	332.4	337.3	336.9	333.2	338.4	341.3	336.4	348.1	331.5
1982	340.8	341.8	337.1	338.8	339.8	340.3	338.6	341.8	346.7	347.6	348.7	352.2	342.9
1983	346.8	353.8	352.8	353.4	352.7	355.7	362.2	355.3	365.9	366.9	372.2	369.6	358.9
1984	367.5	375.8	361.7										
1985		380.3	382.2	377.3	387.2	394.5	383.3	384.5	400.6	407.7	401.6	408.6	
1986	406.5	403.4	409.7	412.2	411.3	414.3	410.1	415.7	416.9	426.3	425.0	426.3	414.8
1987	428.3	418.2	439.0	430.2		431.3	430.9	435.4	444.6	445.1	445.5	440.6	
1988	440.3	445.1	442.3	450.7	449.3	450.4	454.5	453.4	457.0	458.4		465.7	
1989	465.9	458.3	462.4	465.6	465.1	465.7	466.0	469.8	472.8	475.6	476.8	473.6	468.1

Other Trace Gases and Atmospheric Aerosols

Atmospheric halocarbon records from the NOAA/CMDL flask sampling program

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MAUNA LOA

Atmospheric Mixing Ratios of Chlorofluorocarbons (continued)^a

Mixing ratios at Mauna Loa													
Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann ^b
CFC-12 (parts per trillion) continued ^c													
1990	481.3	478.8	479.3	487.0	482.9	482.5	480.9	483.2	485.9	486.4	485.9	488.9	483.6
1991	489.6	484.5	489.7	494.7	493.5	495.3	494.9	495.5	496.9	499.5	502.1	501.9	494.8
1992	505.4	500.3	503.6	510.2	513.2	514.0	510.1	511.9	515.8	518.0	516.5	518.1	511.4

^aThese atmospheric chlorofluorocarbon records from the National Oceanic and Atmospheric Administration (NOAA)/Climate Monitoring and Diagnostics Laboratory (CMDL) flask sampling program are available at no cost in electronic form from CDIAC. Readers who wish to use these data in any presentation or publication must give credit to NOAA/CMDL and should first contact one of the following principal investigators:

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^bAnnual values were calculated by averaging monthly values when all 12 were available.

^cEach point represents the average of 1–5 flask pairs that were measured six times for each pair by EC-GC with an average standard deviation of 0.8 ppt for CFC-11 and 1.0 ppt for CFC-12.

Atmospheric Mixing Ratios of Other Halocarbons^a

HCFC-22 (parts per trillion)		H-1301 (parts per trillion) ^b		H-1211 (parts per trillion) ^b	
Decimal year ^c	Mixing ratio	Decimal year ^c	Mixing ratio	Decimal year ^c	Mixing ratio
1991.9945	102.9	1989.504	1.14	1989.504	
1992.0328	104.4	1989.600	1.28	1989.600	
1992.1093	101.8	1989.677	1.60	1989.677	1.92
1992.2623	103.7	1990.200	1.70	1990.200	2.53
1992.2814	103.6	1990.444	1.78	1990.444	1.67
1992.4727	105.7	1990.523	1.48	1990.523	
1992.5301	106.1	1990.679	1.80	1990.679	1.94
1992.5956	108.5	1990.830	1.88	1990.830	2.07
1992.6066	104.3	1990.942	2.03	1990.942	2.52
1992.6913	103.0	1991.038	1.60	1991.038	2.14
1992.7404	109.1	1991.184	1.67	1991.184	2.26
1992.7787	106.3	1991.227	1.59	1991.227	2.15
1992.8934	106.7	1991.230	1.58	1991.230	2.03
1992.9699	111.6	1991.518	1.55	1991.518	2.28
1992.9891	111.0	1991.690	1.82	1991.690	2.00
		1991.781	1.86	1991.781	

Other Trace Gases and Atmospheric Aerosols
 Atmospheric halocarbon records from the NOAA/CMDL
 flask sampling program

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 D.E.J. Worthy, V. Hudec, V. Chorney, P.J. Fraser, and L.W. Porter (continued)

MAUNA LOA

Atmospheric Mixing Ratios of Other Halocarbons (continued)^a

HCFC-22 (parts per trillion)		H-1301 (parts per trillion) ^b		H-1211 (parts per trillion) ^b	
Decimal year ^c	Mixing ratio	Decimal year ^c	Mixing ratio	Decimal year ^c	Mixing ratio
		1991.866	1.82	1991.866	2.26
		1991.921	1.89	1991.921	2.32
		1992.036	1.53	1992.036	2.26
		1992.112	1.36	1992.112	2.44
		1992.265	1.88	1992.265	2.56

^aThese atmospheric halocarbon records from the National Oceanic and Atmospheric Administration (NOAA)/Climate Monitoring and Diagnostics Laboratory (CMDL) flask sampling program are available at no cost in electronic form from CDIAC. Readers who wish to use these data in any presentation or publication must give credit to NOAA/CMDL and should first contact one of the following principal investigators:

- **For HCFC-22**—S.A. Montzka, phone: (303) 497-6657, Internet (electronic mail): smontzka@cmdl.noaa.gov;
- **For H-1301 or H-1211**—J.H. Butler, phone: (303) 497-6898, Internet (electronic mail): jbutler@cmdl.noaa.gov.

^bThe values reported here differ from those given in earlier NOAA/CMDL annual reports (Butler et al. 1989)—H-1301: new value = $0.871 \times$ old value; H-1211: new value = $1.327 \times$ old value. The changes reflect a reanalysis of the assigned values for the two halons in a working standard against the gravimetric standards, not a change in the absolute scale of the original gravimetric standards.

$$^c\text{Decimal year} = \text{calendar year} + \frac{\text{day of year} - 1 + \frac{\text{hour of day}}{24}}{\text{total number of days in year}}$$

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NIWOT RIDGE

Period of Record

1977–92 (CFC-11 and CFC-12); 1991–92 (HCFC-22); 1989–91 (H-1301 and H-1211)

Trends

CFC-11 and CFC-12

From January 1977 to December 1992, the monthly average mixing ratio of CFC-11 at Niwot Ridge, Colorado, U.S.A., increased from 151.1 to 277.5 parts per trillion by mole (ppt). During 1977–84, the increase was nearly linear, averaging 8.5 ppt/year ($R^2 = .99$). From July 1977 to December 1992, the monthly average mixing ratio of CFC-12 increased from 254.2 to 522.4 ppt. Although gaps occur in the record, the increase was again nearly linear during 1977–84, averaging 16.8 ppt/year ($R^2 = .97$). The gap in the CFC-12 record during 1984–85 resulted from a gas chromatograph problem affecting only CFC-12. A surge in CFC production worldwide beginning in 1985 caused a corresponding rise in the atmospheric growth rates at Niwot Ridge; these reached average 1985–88 values of 12.2 ppt/year ($R^2 = .98$) for CFC-11 and 22.1 ppt/year ($R^2 = .98$) for CFC-12. Since 1988 the growth rates at Niwot Ridge have decreased rapidly, particularly for CFC-11. The mean 1992 growth rate was 12.0 ppt/year for CFC-12, while no statistically significant (at the $P = .05$ level) trend was found for CFC-11. These decreases in atmospheric CFC mixing ratios reflect the recent worldwide declines in production and emissions of CFCs and are consistent with findings at other sites in the NOAA/CMDL network (Elkins et al. 1993).

HCFC-22

From December 1991 to December 1992, the mixing ratio of HCFC-22 at Niwot Ridge increased from 103.3 to 115.1 ppt, averaging 7.5 ppt/year. This trend is highly significant ($P = .02$).

The collective results presented here for HCFC-22 from the seven monitoring sites show a mean global mixing ratio of 100 ppt for March 1992, with a mean interhemispheric ratio (Northern hemispheric mixing ratio : Southern hemispheric mixing ratio) of 1.14. The mean global growth rate of HCFC-22 over the period of record was 7% per year (Montzka et al. 1993).

H-1301 and H-1211

From August 1989 to November 1991, the mixing ratio of H-1211 at Niwot Ridge increased from 1.96 to 2.53 ppt, averaging 0.19 ppt/year. Over the same period, the mixing ratio of H-1301 rose from 1.56 to 1.96 ppt, also at an average of 0.19 ppt/year. For both H-1211 and H-1301, the trends are significant (at the $P = .05$ level). Comparing their data with published results from other investigators (covering the period 1978–92), Butler et al. (1992) concluded that significant declines have occurred in the growth rates of the atmospheric mixing ratios of both halons. These recent drops in growth are supported in general by industry production figures, emission estimates, and current appraisals of atmospheric lifetimes.

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NIWOT RIDGE

Monthly atmospheric mixing ratios of CFC-12, CFC-11, HCFC-22, H-1211, and H-1301 at Niwot Ridge.

CITE AS: Elkins, J.W., T.M. Thompson, J.H. Butler, S.A. Montzka, R.C. Myers, A.D. Clarke, T.H. Swanson, D.J. Endres, A.M. Yoshinaga, R.C. Schnell, M. Winey, B.G. Mendonca, M.V. Losleben, N.B.A. Trivett, D.E.J. Worthy, V. Hudec, V. Chorney, P.J. Fraser, and L.W. Porter. 1994. Atmospheric halocarbon records from the NOAA/CMDL flask sampling program. pp. 432-471. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Other Trace Gases and Atmospheric Aerosols

Atmospheric halocarbon records from the NOAA/CMDL flask sampling program

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NIWOT RIDGE

Niwot Ridge
Colorado, U.S.A.
Alpine mountain
40°06' N, 105°36' W
3472 m above MSL

Atmospheric Mixing Ratios of Chlorofluorocarbons^a

Mixing ratios at Niwot Ridge

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann ^b
CFC-11 (parts per trillion) ^c													
1977	151.1	149.2	143.5	146.2	147.2	140.1	143.3	146.1	144.7	151.3	148.4	154.8	147.2
1978	149.5	153.7	151.6		158.4	152.1	156.6	157.9	163.3	160.1	161.7	158.5	
1979	158.3	158.0	162.3	160.9	160.2	162.8	162.2	164.2	162.7	168.2	168.9	168.3	163.1
1980	168.0	168.4	177.1	171.8	175.6	172.3	174.1		172.5	174.7	176.7	174.1	
1981	176.2	176.7	178.7	176.3	180.3	180.4	179.8	181.3	182.5	184.6	182.4	183.4	180.2
1982	184.4	183.3	187.1	188.2	187.6	188.1	190.8	188.1	190.3	190.1	193.8	193.8	188.8
1983	192.5	195.0	196.8	198.7	199.3	197.8	197.9	198.2	200.6	202.1	201.4	204.5	198.7
1984	203.1	201.3	206.4	204.3	205.7	205.5	204.3	204.7	208.0	212.1	210.1	213.4	206.6
1985	212.9	211.7	215.4	215.6	217.6	214.9	215.0	218.3	222.6	224.1	224.9	223.5	218.0
1986	223.1	227.5	225.6	226.3	227.9	229.8	226.4	230.9	228.6	233.3	237.0	233.6	229.2
1987	233.8	236.0	237.0	237.7	241.1	241.1	240.0	242.8	242.4	250.1	248.4	249.5	241.7
1988	250.1	249.2	250.7	252.5	257.6	253.1	255.7	256.1	254.5	253.6	261.7	258.0	254.4
1989	257.9	260.7	257.6	259.7	259.8	260.0	265.9	264.0	266.1	263.9	268.7	265.3	262.5
1990	266.8	268.1	270.4	266.6	266.8	267.0	265.8	267.2	270.0	269.4	271.4	270.3	268.3
1991	268.8	272.7	269.4	273.3	269.2	271.8	272.6	271.2	274.7	272.4	273.4	275.1	272.1
1992	276.5	274.1	274.2	276.0	274.1	275.0	274.0	274.4	275.7	276.5	279.0	277.5	275.6
CFC-12 (parts per trillion) ^c													
1977							254.2	262.8	253.1			272.6	
1978			274.8			292.4	291.8			291.6	284.2		
1979	279.8	286.5			292.5	292.7	290.0	294.5	302.7	292.6	295.3	304.0	
1980	307.9	311.7	315.4	310.4	314.1	307.1	307.4	308.2	306.7	311.2	310.9	312.8	310.3
1981	315.4	317.1	322.9	324.0	325.9	327.2	330.1	331.7	332.8	337.6	330.1	333.5	327.4
1982	337.0	334.8	338.1	347.6	340.6	345.4	350.9	347.4	348.2	352.0	351.9	350.6	345.4
1983	353.2	355.7	357.2	358.6	362.5	362.2	371.2	362.1	366.4	368.5	372.1	375.6	363.8
1984	373.9	372.0	368.2										
1985			383.8	387.4	389.0	392.2	386.9	393.6	399.9	405.2	413.3	407.8	
1986	408.6	408.3	411.5	409.9	417.7	418.1	415.5	420.6	415.1	422.4	421.9	424.0	416.1
1987	426.6	424.7	437.8	434.6		441.0	437.7	439.6	445.8	451.8	450.3	449.2	
1988	451.8	448.0	457.6	457.8	458.4	454.2	465.4	465.2	463.6	460.5	470.8	464.5	459.8
1989	465.0	469.9	461.8	467.9	471.5	472.4	476.2	478.9	479.4	476.5	484.5	482.4	473.9

Atmospheric halocarbon records from the NOAA/CMDL flask sampling program

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NIWOT RIDGE

Atmospheric Mixing Ratios of Chlorofluorocarbons (continued)^a

Mixing ratios at Niwot Ridge

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann ^b
CFC-12 (parts per trillion) continued ^c													
1990	481.7	492.2	485.4	483.2	487.7	490.2	487.0	486.0	496.9	491.9	495.6	496.4	489.5
1991	495.4	494.5	494.1	499.9	494.1	498.3	500.4	500.7	506.3	509.0	502.3	505.2	500.0
1992	509.5	512.9	512.7	522.1	508.7	515.3	519.1	519.1	517.4	520.5	521.6	522.4	516.8

^aThese atmospheric chlorofluorocarbon records from the National Oceanic and Atmospheric Administration (NOAA)/Climate Monitoring and Diagnostics Laboratory (CMDL) flask sampling program are available at no cost in electronic form from CDIAC. Readers who wish to use these data in any presentation or publication must give credit to NOAA/CMDL and should first contact one of the following principal investigators:

J.W. Elkins, phone: (303) 497-6224, Internet (electronic mail): jelkins@cmdl.noaa.gov;
T.M. Thompson, phone: (303) 497-6671, Internet (electronic mail): tthompson@cmdl.noaa.gov.

^bAnnual values were calculated by averaging monthly values when all 12 were available.

^cEach point represents the average of 1–5 flask pairs that were measured six times for each pair by EC-GC with an average standard deviation of 0.8 ppt for CFC-11 and 1.0 ppt for CFC-12.

Atmospheric Mixing Ratios of Other Halocarbons^a

HCFC-22 (parts per trillion)		H-1301 (parts per trillion) ^b		H-1211 (parts per trillion) ^b	
Decimal year ^c	Mixing ratio	Decimal year ^c	Mixing ratio	Decimal year ^c	Mixing ratio
1991.9781	103.3	1989.641	1.56	1989.641	1.96
1992.1311	107.3	1989.756	1.54	1989.756	1.88
1992.2650	108.4	1989.852	1.60	1989.852	1.99
1992.3224	112.7	1990.101	1.50	1990.101	1.96
1992.5519	111.5	1990.178	1.77	1990.178	2.03
1992.5710	109.7	1990.449	1.65	1990.449	1.92
1992.6093	111.7	1990.523	1.85	1990.523	2.03
1992.7268	111.8	1990.526	1.71	1990.526	1.92
1992.8770	108.7	1990.871	2.07	1990.871	1.95
1992.9536	115.1	1990.945	1.75	1990.945	2.32
		1991.022	1.59	1991.022	2.03
		1991.148	1.79	1991.148	2.45
		1991.214	1.73	1991.214	2.06
		1991.521	1.74	1991.521	2.26

Other Trace Gases and Atmospheric Aerosols

Atmospheric halocarbon records from the NOAA/CMDL flask sampling program

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NIWOT RIDGE

Atmospheric Mixing Ratios of Other Halocarbons (continued)^a

HCFC-22 (parts per trillion)		H-1301 (parts per trillion) ^b		H-1211 (parts per trillion) ^b	
Decimal year ^c	Mixing ratio	Decimal year ^c	Mixing ratio	Decimal year ^c	Mixing ratio
		1991.616	1.85	1991.616	1.96
		1991.712	2.28	1991.712	2.28
		1991.901	1.96	1991.901	2.53

^aThese atmospheric halocarbon records from the National Oceanic and Atmospheric Administration (NOAA)/Climate Monitoring and Diagnostics Laboratory (CMDL) flask sampling program are available at no cost in electronic form from CDIAC. Readers who wish to use these data in any presentation or publication must give credit to NOAA/CMDL and should first contact one of the following principal investigators:

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- **For H-1301 or H-1211**—J.H. Butler, phone: (303) 497-6898, Internet (electronic mail): jbutler@cmdl.noaa.gov.

^bThe values reported here differ from those given in earlier NOAA/CMDL annual reports (Butler et al. 1989)—H-1301: new value = $0.871 \times$ old value; H-1211: new value = $1.327 \times$ old value. The changes reflect a reanalysis of the assigned values for the two halons in a working standard against the gravimetric standards, not a change in the absolute scale of the original gravimetric standards.

$$^c\text{Decimal year} = \text{calendar year} + \frac{\text{day of year} - 1 + \frac{\text{hour of day}}{24}}{\text{total number of days in year}}$$

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SAMOA (U.S.)

Period of Record

1977–92 (CFC-11 and CFC-12); 1991–92 (HCFC-22); 1989–92 (H-1301 and H-1211)

Trends

CFC-11 and CFC-12

From August 1977 to December 1992, the monthly average mixing ratio of CFC-11 at Cape Matatula, American Samoa, increased from 133.6 to 269.6 parts per trillion by mole (ppt). Over nearly the same period (August 1977–November 1992), the monthly average mixing ratio of CFC-12 increased from 242.1 to 500.1 ppt. During 1977–84, the increases were nearly linear, averaging 9.1 ppt/year ($R^2 = .99$) for CFC-11 and 17.6 ppt/year ($R^2 = .99$) for CFC-12. The gap in the CFC-12 record during 1984–85 resulted from a gas chromatograph problem affecting only CFC-12. A surge in CFC production worldwide beginning in 1985 caused a corresponding rise in the atmospheric growth rates at Samoa; these reached average 1985–88 values of 10.2 ppt/year ($R^2 = .98$) for CFC-11 and 18.4 ppt/year ($R^2 = .96$) for CFC-12. Since 1988 the growth rates at Samoa have decreased rapidly, particularly for CFC-11: in 1992, the mean growth rate of CFC-11 was 3.6 ppt/year, and the mean growth rate of CFC-12 was 11.5 ppt/year. These decreases reflect the recent worldwide declines in production and emissions of CFCs and are consistent with findings at other sites in the NOAA/CMDL network (Elkins et al. 1993).

The records for Samoa also show a seasonal pattern: peak mixing ratios occur during November–March, when a high frequency of northwesterly flow transports air masses enriched in CFCs from the Northern Hemisphere (Elkins et al. 1993).

HCFC-22

From November 1991 to December 1992, the mixing ratio of HCFC-22 at Samoa increased (after an anomalously high initial value of 96.2 ppt) at an average rate of 4.4 ppt/year, reaching a value of 97.5 ppt by the end of the period. This trend is highly significant ($P = .02$).

The collective results presented here for HCFC-22 from the seven monitoring sites show a mean global mixing ratio of 100 ppt for March 1992, with a mean interhemispheric ratio (Northern hemispheric mixing ratio : Southern hemispheric mixing ratio) of 1.14. The mean global growth rate of HCFC-22 over the period of record was 7% per year (Montzka et al. 1993).

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Atmospheric halocarbon records from the NOAA/CMDL
flask sampling program

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SAMOA (U.S.)

H-1301 and H-1211

From July 1989 to February 1992, the mixing ratio of H-1211 at Samoa averaged 2.12 ppt but showed no significant (at the $P = .05$ level) trend. Over the same period, the mixing ratio of H-1301 increased from 1.51 to 1.96 ppt and showed a significant ($P = .01$) increase of 0.13 ppt/year. Comparing their data with published results from other investigators (covering the period 1978–92), Butler et al. (1992) concluded that significant declines have occurred in the growth rates of the atmospheric mixing ratios of both halons. These recent drops in growth are supported in general by industry production figures, emission estimates, and current appraisals of atmospheric lifetimes.

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flask sampling program

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A.M. Yoshinaga, R.C. Schnell, M. Winey, B.G. Mendonca, M.V. Losleben, N.B.A. Trivett,
D.E.J. Worthy, V. Hudec, V. Chorney, P.J. Fraser, and L.W. Porter (continued)

SAMOA (U.S.)

Monthly atmospheric mixing ratios of CFC-12, CFC-11, HCFC-22,
H-1211, and H-1301 at Samoa.

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Other Trace Gases and Atmospheric Aerosols

Atmospheric halocarbon records from the NOAA/CMDL flask sampling program

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SAMOA (U.S.)

Samoa (Cape Matatula)
U.S. Territory
South Pacific Ocean
Rocky promontory
14°18' S, 170°36' W
77 m above MSL

Atmospheric Mixing Ratios of Chlorofluorocarbons^a

Mixing ratios at Samoa

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann ^b
CFC-11 (parts per trillion) ^c													
1977								133.6	133.9	135.2	134.4	133.5	
1978	138.3	137.8	138.1	141.0	141.5	141.3	141.2	143.4	143.3	144.9	147.6	146.6	142.1
1979	149.4	152.1	149.7	151.3	150.2	149.8	152.1	152.2	152.0	156.4	155.5	155.4	152.2
1980	158.0	158.9	159.0	159.0	159.7	161.2	160.2	160.3	163.9	162.3	162.2	163.0	160.6
1981	165.7	166.9	166.7	168.0	168.2	168.3	170.9	170.8	171.9	172.5	174.5	174.5	169.9
1982	176.4	176.6	175.4	178.1	177.6	177.0	178.8	180.4	180.3	181.5	181.8	181.1	178.8
1983	185.6	183.0	186.8	186.2	185.8	187.4	187.5	186.4	188.0	190.8	189.3	193.7	187.5
1984	195.0	196.4	193.3	196.3	194.3	193.9	194.7	195.5	199.6	197.6	197.9	204.2	196.6
1985	204.7	206.4	207.1	208.0	206.9	205.8	207.4	208.3	210.0	210.6	209.8	213.1	208.2
1986	213.9	209.8	214.2	214.7	219.6	220.0	219.1	220.9	221.4	220.5	221.5	223.8	218.3
1987	223.5	229.5	227.0	224.4	228.5	225.6	226.3		231.9	229.7	232.5	233.5	
1988	235.0	236.1	233.8	238.4	236.2	237.5	238.1	240.8	237.8	241.3	242.8	247.3	238.8
1989	248.1	247.5	246.3	248.6	248.7	248.1	249.1	253.1	252.1	252.1	252.7	254.1	250.0
1990	256.9	253.1	255.9	256.0	253.1	255.6	256.1	258.6	258.0	256.7	258.8	262.8	256.8
1991	261.7		262.4	262.5	263.0	261.8	263.2	265.6	265.2	265.3	265.2	262.9	
1992	265.3	263.7	265.0	265.3	264.0	266.7	262.9	265.9	265.0	266.6	266.6	269.6	265.6
CFC-12 (parts per trillion) ^c													
1977								242.1	241.4	243.8	244.1	250.7	
1978	253.6	256.0	249.3		261.5	260.0	257.6	258.9	262.3	263.1	266.9	266.9	
1979	273.8	273.3	273.1	274.0	272.3	273.2	276.0	279.5	280.4	280.6	283.9	280.8	276.7
1980	285.2	284.8	285.0	288.3	286.8	289.4	290.1	289.2	293.5	292.9	292.6	296.7	289.5
1981	300.2	303.5	304.6	306.8	309.9	310.4	313.3	313.9	312.5	316.4	318.4	319.8	310.8
1982	324.7	328.5	324.7	327.6	324.0	326.0	328.8	330.5	331.1	333.9	333.2	333.5	328.9
1983	338.6	339.5	343.2	342.5	341.9	342.1	342.2	348.5	352.2	355.0	356.6	357.9	346.7
1984	357.4	364.6	359.3										
1985		373.4	370.3	371.1	379.3	377.9	375.9	373.7	388.2	390.2	390.3	393.3	
1986	395.6	399.8	397.9	398.6	399.3	402.3	402.3	404.0	406.5	406.5	405.9	409.7	402.4
1987	412.2	415.0	421.8	411.8	415.2	407.8	415.8			419.0	423.2	424.2	
1988	426.5	429.8	426.3	435.2	432.3	430.3	438.1	438.0	438.1	444.6	449.2	445.3	436.1
1989	448.7	451.9	446.2	449.2	451.9	443.4	454.9	454.2	457.0	460.4	459.3	463.2	453.4

Atmospheric halocarbon records from the NOAA/CMDL flask sampling program

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SAMOA (U.S.)

Atmospheric Mixing Ratios of Chlorofluorocarbons (continued)^a

Mixing ratios at Samoa													
Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann ^b
CFC-12 (parts per trillion) continued ^c													
1990	471.8	461.7	464.9	464.0	462.7	466.5	463.8	467.1	468.6	471.2	473.5	476.7	467.7
1991	482.4		481.3	482.7	486.7	480.8	483.3	487.5	487.6	488.5	489.2	491.4	
1992	492.3	493.2	492.8	494.8	503.3	502.8	497.0	500.6	501.6	504.1	500.1		

^aThese atmospheric chlorofluorocarbon records from the National Oceanic and Atmospheric Administration (NOAA)/Climate Monitoring and Diagnostics Laboratory (CMDL) flask sampling program are available at no cost in electronic form from CDIAC. Readers who wish to use these data in any presentation or publication must give credit to NOAA/CMDL and should first contact one of the following principal investigators:

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^bAnnual values were calculated by averaging monthly values when all 12 were available.

^cEach point represents the average of 1–5 flask pairs that were measured six times for each pair by EC-GC with an average standard deviation of 0.8 ppt for CFC-11 and 1.0 ppt for CFC-12.

Atmospheric Mixing Ratios of Other Halocarbons^a

HCFC-22 (parts per trillion)		H-1301 (parts per trillion) ^b		H-1211 (parts per trillion) ^b	
Decimal year ^c	Mixing ratio	Decimal year ^c	Mixing ratio	Decimal year ^c	Mixing ratio
1991.9014	96.2	1989.515	1.51	1989.515	2.26
1991.9945	94.2	1989.515	1.27	1989.515	
1992.0464	93.6	1989.693	1.38	1989.693	1.87
1992.1120	90.4	1989.767	1.45	1989.767	2.00
1992.2623	95.2	1990.112	1.92	1990.112	2.53
1992.3005	95.7	1990.282	1.83	1990.282	1.74
1992.4563	95.5	1990.438	1.63	1990.438	2.11
1992.5301	95.0	1990.512	1.58	1990.512	2.02
1992.6066	96.3	1990.690	1.55	1990.690	1.94
1992.6858	98.2	1990.833	1.72	1990.833	2.51
1992.7842	98.3	1990.956	1.84	1990.956	2.64
1992.9208	97.5	1991.112	1.55	1991.112	1.90
		1991.233	1.84	1991.233	2.18
		1991.405	1.72	1991.405	
		1991.447	1.77	1991.447	2.35

Other Trace Gases and Atmospheric Aerosols

Atmospheric halocarbon records from the NOAA/CMDL flask sampling program

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SAMOA (U.S.)

Atmospheric Mixing Ratios of Other Halocarbons (continued)^a

HCFC-22 (parts per trillion)		H-1301 (parts per trillion) ^b		H-1211 (parts per trillion) ^b	
Decimal year ^c	Mixing ratio	Decimal year ^c	Mixing ratio	Decimal year ^c	Mixing ratio
		1991.619	1.43	1991.619	1.99
		1991.699	1.66	1991.699	1.87
		1991.866	1.69	1991.866	2.16
		1992.049	1.95	1992.049	2.20
		1992.115	1.96	1992.115	1.92

^aThese atmospheric halocarbon records from the National Oceanic and Atmospheric Administration (NOAA)/Climate Monitoring and Diagnostics Laboratory (CMDL) flask sampling program are available at no cost in electronic form from CDIAC. Readers who wish to use these data in any presentation or publication must give credit to NOAA/CMDL and should first contact one of the following principal investigators:

- **For HCFC-22**—S.A. Montzka, phone: (303) 497-6657, Internet (electronic mail): smontzka@cmdl.noaa.gov;
- **For H-1301 or H-1211**—J.H. Butler, phone: (303) 497-6898, Internet (electronic mail): jbutler@cmdl.noaa.gov.

^bThe values reported here differ from those given in earlier NOAA/CMDL annual reports (Butler et al. 1989)—H-1301: new value = $0.871 \times$ old value; H-1211: new value = $1.327 \times$ old value. The changes reflect a reanalysis of the assigned values for the two halons in a working standard against the gravimetric standards, not a change in the absolute scale of the original gravimetric standards.

$$^c\text{Decimal year} = \text{calendar year} + \frac{\text{day of year} - 1 + \frac{\text{hour of day}}{24}}{\text{total number of days in year}}$$

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Atmospheric halocarbon records from the NOAA/CMDL
flask sampling program

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SOUTH POLE

Period of Record

1977–92 (CFC-11 and CFC-12); 1991–92 (HCFC-22); 1990–92 (H-1301 and H-1211)

Trends

CFC-11 and CFC-12

From January 1977 to November 1992 at the South Pole, Antarctica, the monthly average mixing ratio of CFC-11 increased from 134.3 to 270.6 parts per trillion by mole (ppt). Over much the same period (June 1977 to November 1992), the monthly average mixing ratio of CFC-12 increased from 231.0 to 500.3 ppt. Despite the sparsity of the data (measurements generally were made only during the austral summer, when the station was open), the CFC records nevertheless show nearly linear trends during 1977–84, with average increases of 8.9 ppt/year ($R^2 = .91$) for CFC-11 and 18.8 ppt/year ($R^2 = .95$) for CFC-12. The gap in the CFC-12 record during 1984–85 resulted from a gas chromatograph problem affecting only CFC-12. A surge in CFC production worldwide beginning in 1985 caused a corresponding rise in the atmospheric growth rates at the South Pole; these reached average 1985–88 values of 8.4 ppt/year ($R^2 = .98$) for CFC-11 and 15.7 ppt/year ($R^2 = .99$) for CFC-12. Since 1989 the growth rates at the South Pole have decreased rapidly, and trends for 1992 were not statistically significant (at the $P = .05$ level) for either CFC-11 or CFC-12. These decreases reflect the recent worldwide declines in production and emissions of CFCs (Elkins et al. 1993). The magnitudes of the declines at the South Pole are greater than those at low- and middle-latitude sites in the NOAA/CMDL network but are consistent with those at the other high-latitude sites (i.e., Alert and Barrow).

HCFC-22

From December 1991 to November 1992, the mixing ratio of HCFC-22 at the South Pole increased from 92.0 to 97.1 ppt, averaging 6.8 ppt/year. This trend is highly significant ($P = .0002$).

The collective results presented here for HCFC-22 from the seven monitoring sites show a mean global mixing ratio of 100 ppt for March 1992, with a mean interhemispheric ratio (Northern hemispheric mixing ratio : Southern hemispheric mixing ratio) of 1.14. The mean global growth rate of HCFC-22 over the period of record was 7% per year (Montzka et al. 1993).

H-1301 and H-1211

From January 1990 to January 1992, the mixing ratio of H-1211 at the South Pole averaged 2.15 ppt, while that of H-1301 averaged 1.62 ppt. Neither H-1211 nor H-1301 showed any significant (at the $P = .05$ level) trend. Comparing their data with published results from other investigators (covering the period 1978–92), Butler et al. (1992) concluded that significant declines have occurred in the growth rates of the atmospheric mixing ratios of both halons. These recent

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SOUTH POLE

drops in growth are supported in general by industry production figures, emission estimates, and current appraisals of atmospheric lifetimes.

Monthly atmospheric mixing ratios of CFC-12, CFC-11, HCFC-22, H-1211, and H-1301 at the South Pole.

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Other Trace Gases and Atmospheric Aerosols

Atmospheric halocarbon records from the NOAA/CMDL flask sampling program

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D.E.J. Worthy, V. Hudec, V. Chorney, P.J. Fraser, and L.W. Porter (continued)

*South Pole
Antarctica
Ice- and snow-
covered plateau
89°59' S, 24°48' W
2841 above MSL*

SOUTH POLE

Atmospheric Mixing Ratios of Chlorofluorocarbons^a

Mixing ratios at the South Pole

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann ^b
CFC-11 (parts per trillion) ^c													
1977	134.3	125.9											
1978	143.3							152.0			160.0	150.3	
1979	147.7	149.5									155.1	164.0	
1980	156.8			157.2	169.7	158.1				170.5	160.1	165.7	
1981	164.3	164.9			178.1					186.5	167.6	178.4	
1982	181.5										192.9	192.6	
1983	192.8											187.6	
1984		190.6									198.6	205.1	
1985	206.6										211.0	215.7	
1986											222.3		
1987	222.9										232.4	231.4	
1988											239.8	237.1	
1989												250.9	
1990	253.3											260.4	
1991	261.4	258.3										264.4	
1992		275.7	272.3			267.7			267.7	269.2	270.6		
CFC-12 (parts per trillion) ^c													
1977						231.0						251.3	
1978										255.3	257.1	263.4	
1979	262.0	259.4									293.2	280.7	
1980	280.8			283.7	284.4	289.0	286.8		304.3	295.2	291.8	294.6	
1981	294.0	299.7			303.0							320.1	
1982	317.4										347.8		
1983	345.2											343.9	
1984		357.1											
1985											386.1	388.9	
1986	392.7										402.0	404.7	
1987	408.4										420.5	419.5	
1988	417.8										436.5	435.6	
1989	439.8											459.3	

Other Trace Gases and Atmospheric Aerosols

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SOUTH POLE

Atmospheric Mixing Ratios of Chlorofluorocarbons (continued)^a

Mixing ratios at the South Pole													
Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann ^b
CFC-12 (parts per trillion) continued ^c													
1990	464.1												472.3
1991	474.8	472.1									486.6	488.3	
1992		489.9	498.5			494.4	497.6	496.4	497.8	495.8	500.3		

^aThese atmospheric chlorofluorocarbon records from the National Oceanic and Atmospheric Administration (NOAA)/Climate Monitoring and Diagnostics Laboratory (CMDL) flask sampling program are available at no cost in electronic form from CDIAC. Readers who wish to use these data in any presentation or publication must give credit to NOAA/CMDL and should first contact one of the following principal investigators:

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^bAnnual values were calculated by averaging monthly values when all 12 were available.

^cEach point represents the average of 1–5 flask pairs that were measured six times for each pair by EC-GC with an average standard deviation of 0.8 ppt for CFC-11 and 1.0 ppt for CFC-12.

Atmospheric Mixing Ratios of Other Halocarbons^a

HCFC-22 (parts per trillion)		H-1301 (parts per trillion) ^b		H-1211 (parts per trillion) ^b	
Decimal year ^c	Mixing ratio	Decimal year ^c	Mixing ratio	Decimal year ^c	Mixing ratio
1991.9479	92.0	1990.008	1.50	1990.008	2.04
1992.0628	92.1	1990.068	1.56	1990.068	1.80
1992.0792	90.3	1990.213	1.38	1990.213	2.10
1992.4344	93.8	1992.008	1.56	1992.008	1.86
1992.5055	96.9	1992.044	1.82	1992.044	2.27
1992.5902	96.2	1992.066	1.91	1992.066	2.64
1992.6940	96.4	1992.082	1.60	1992.082	2.35
1992.7814	96.8				

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SOUTH POLE

Atmospheric Mixing Ratios of Other Halocarbons (continued)^a

HCFC-22 (parts per trillion)		H-1301 (parts per trillion) ^b		H-1211 (parts per trillion) ^b	
Decimal year ^c	Mixing ratio	Decimal year ^c	Mixing ratio	Decimal year ^c	Mixing ratio
1992.8169	96.2				
1992.8525	97.1				

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- **For H-1301 or H-1211**—J.H. Butler, phone: (303) 497-6898, Internet (electronic mail): jbutler@cmdl.noaa.gov.

^bThe values reported here differ from those given in earlier NOAA/CMDL annual reports (Butler et al. 1989)—H-1301: new value = $0.871 \times \text{old value}$; H-1211: new value = $1.327 \times \text{old value}$. The changes reflect a reanalysis of the assigned values for the two halons in a working standard against the gravimetric standards, not a change in the absolute scale of the original gravimetric standards.

$$^c\text{Decimal year} = \text{calendar year} + \frac{\text{day of year} - 1 + \frac{\text{hour of day}}{24}}{\text{total number of days in year}}$$

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Atmospheric halocarbon records from the NOAA/CMDL
flask sampling program

J.W. Elkins, T.M. Thompson, J.H. Butler, S.A. Montzka, R.C. Myers, A.D. Clarke, T.H. Swanson, D.J. Endres, A.M. Yoshinaga, R.C. Schnell, M. Winey, B.G. Mendonca, M.V. Losleben, N.B.A. Trivett, D.E.J. Worthy, V. Hudec, V. Chorney, P.J. Fraser, and L.W. Porter (continued)

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Other Trace Gases and Atmospheric Aerosols

Atmospheric halocarbon records from the NOAA/CMDL
flask sampling program

J.W. Elkins, T.M. Thompson, J.H. Butler, S.A. Montzka, R.C. Myers, A.D. Clarke, T.H. Swanson, D.J. Endres,
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D.E.J. Worthy, V. Hudec, V. Chorney, P.J. Fraser, and L.W. Porter (continued)

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Alternative Fluorocarbons Environmental Acceptability Study

The West Tower, Suite 400, 1333 H Street N.W., Washington, D.C. 20005, U.S.A.

Period of Record

1938–92 (CFC-11); 1931–92 (CFC-12)

Methods

Worldwide production of the chlorofluorocarbons CFC-11 (CCl_3F) and CFC-12 (CCl_2F_2) by companies participating in the Alternative Fluorocarbons Environmental Acceptability Study (AFEAS) is reported on an annual basis to Grant Thornton, an independent accounting firm. (AFEAS replaced the former Chemical Manufacturers Association Fluorocarbon Program Panel.) The data are essentially sales figures categorized to reflect end use: aerosols (propellants), hermetically sealed refrigeration, nonhermetically sealed refrigeration, closed-cell foams, open-cell foams, and all other uses. The figures provided by Grant Thornton are corrected for inventory changes but do not reflect losses ("fugitive emissions") during manufacturing and packing. AFEAS corrects the estimates for fugitive emissions and calculates release estimates of CFCs for each end-use category on the basis of the reported production figures and information about the pattern of release to the atmosphere. The release estimates are based solely on data for CFCs produced by companies participating in AFEAS. The estimates encompass most or all production in Argentina, Australia, Brazil, Canada, the European Economic Community (EEC), Japan, Mexico, South Africa, the United States, and Venezuela. Unreported production occurs in the republics of the former Soviet Union, the former Czechoslovakia, India, the Peoples Republic of China, Romania, South Korea, and Taiwan. The uncertainty in the overall estimate of CFC releases stems largely from the lack of data from these countries. Based upon informal estimates by AFEAS member companies, the unreported production of CFCs appears to have increased from ~12% of the worldwide total in 1982 to ~25% in 1992. An

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Other Trace Gases and Atmospheric Aerosols
CFC-11 and CFC-12 release estimates from AFEAS

Alternative Fluorocarbons Environmental Acceptability Study (continued)

additional uncertainty for CFC-11 involves the estimate of release from closed-cell foams: the release rate depends on a number of highly variable factors, such as the lifetime of the products in which the foam is incorporated, the rate of breakdown of the foam cells, and the method of disposal. For CFC-12, additional uncertainty exists in the estimate of release from nonhermetically sealed refrigeration: the length of refrigerant charge life varies, particularly in industrial refrigerators.

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CFC-11

Trends

Significant production of CFC-11 began in the late 1930s for use in refrigeration. Production (and release) increased very slowly until after World War II, when CFCs began to be used as propellants for aerosol sprays. By the 1950s, the use of CFC-11 as the blowing agent in open-cell (foam rubber) and closed-cell (rigid polyurethane) foams constituted an additional significant source of release. During the 1960s and early 1970s, production and release of CFC-11 grew very rapidly. Over the 10-year period 1964–74, for example, total CFC-11 release grew exponentially, increasing at an average rate of 13.0% per year, primarily because of the rapid worldwide expansion of CFC use in aerosols. In 1975, however, fluorocarbon production and release began to decline after the U.S. ban on CFCs in aerosols. By the early 1980s, however, this decline reversed, partly because of growth in aerosol production in countries not participating in the ban. In addition, the use of CFC-11 as the blowing agent in rigid polyurethane foams grew unabatedly throughout the 1970s and 1980s. For the period 1974–89, CFC-11 release from this end use grew exponentially, increasing at an average rate of 9.8% per year. By 1992, however, release from closed-cell foam appeared to begin leveling off. Nevertheless, as other end uses of CFC-11 declined precipitously, release from closed-cell foams in 1992 constituted >60% of the total release worldwide. The recent decline in the release of CFC-11 from all sources (primarily aerosols) has occurred largely in response to efforts to limit emissions of fully halogenated CFCs as prescribed by the 1987 Montreal Protocol and its subsequent revisions.

CFC-11 releases, 1938–92.

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Other Trace Gases and Atmospheric Aerosols
CFC-11 and CFC-12 release estimates from AFEAS

Alternative Fluorocarbons Environmental Acceptability Study (continued)

CFC-11

Atmospheric CFC-11 Releases^a

Releases (million kilograms)					Releases (million kilograms)				
Year	Total	Refriger- ation ^b	Blowing agents (closed-cell foam)	Open-cell foam, aerosols, and all other	Year	Total	Refriger- ation ^b	Blowing agents (closed-cell foam)	Open-cell foam, aerosols, and all other
1938	0.1	0.1	0.0	0.0	1966	121.3	6.5	4.6	110.2
1939	0.1	0.1	0.0	0.0	1967	137.6	7.1	5.8	124.7
1940	0.1	0.1	0.0	0.0	1968	156.8	7.9	7.6	141.3
1941	0.1	0.1	0.0	0.0	1969	181.9	8.7	9.5	163.6
1942	0.1	0.1	0.0	0.0	1970	206.6	9.7	11.4	185.6
1943	0.2	0.2	0.0	0.0	1971	226.9	10.5	14.2	202.2
1944	0.2	0.2	0.0	0.0	1972	255.8	11.8	17.4	226.6
1945	0.3	0.3	0.0	0.0	1973	292.4	13.0	21.2	258.1
1946	0.6	0.3	0.0	0.4	1974	321.4	14.5	24.0	283.0
1947	1.3	0.3	0.0	1.0	1975	310.9	15.8	25.8	269.3
1948	2.3	0.3	0.0	2.0	1976	316.7	17.6	27.8	271.4
1949	3.8	0.2	0.0	3.6	1977	303.9	19.0	32.0	252.8
1950	5.5	0.2	0.0	5.2	1978	283.6	20.7	35.0	228.0
1951	7.6	0.3	0.0	7.4	1979	263.7	22.4	40.1	201.1
1952	11.0	0.3	0.1	10.6	1980	250.8	24.3	44.0	182.6
1953	15.0	0.4	0.0	14.5	1981	248.2	25.9	49.9	172.4
1954	18.6	0.6	0.1	17.9	1982	239.5	26.8	53.3	159.4
1955	23.0	0.8	0.1	22.2	1983	252.8	27.4	57.9	167.4
1956	28.7	1.0	0.1	27.5	1984	271.1	27.2	63.5	180.5
1957	32.2	1.3	0.2	30.7	1985	280.8	26.7	69.0	185.2
1958	30.2	1.7	0.2	28.3	1986	295.1	26.0	75.1	193.9
1959	30.9	2.1	0.3	28.5	1987	310.6	25.9	84.7	200.1
1960	40.5	2.7	0.5	37.4	1988	314.5	26.2	91.4	196.9
1961	52.1	3.2	0.6	48.2	1989	265.2	26.5	97.5	141.1
1962	65.4	3.9	1.3	60.3	1990	216.1	26.7	100.1	89.2
1963	80.0	4.5	1.8	73.6	1991	188.3	26.4	105.5	56.4
1964	95.0	5.2	2.7	87.2	1992	171.1	25.5	108.1	37.6
1965	108.3	5.8	3.5	98.9					

^aAtmospheric release figures are derived from data obtained from the Alternative Fluorocarbons Environmental Acceptability Study. All values have been rounded to the nearest 0.1 million kilograms. Because of rounding effects, values for total yearly release may differ slightly from the sum of the subtotals. These atmospheric CFC release data are available at no cost in electronic form from CDIAC.

^bRelease figures for refrigeration represent the sum of releases for hermetically sealed and nonhermetically sealed refrigeration.

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CFC-11 and CFC-12 release estimates from AFEAS

Alternative Fluorocarbons Environmental Acceptability Study (continued)

CFC-12

Trends

Significant production of CFC-12 began in the early 1930s for use in refrigeration. Production (and release) increased slowly but steadily until after World War II, when CFCs began to be used as propellants for aerosol sprays. Very quickly, CFC-12 production for use in aerosols exceeded that for use in refrigeration. By the late 1950s, the use of CFC-12 as the blowing agent in closed-cell foams (mostly Styrofoam®) constituted an additional significant source of release. The period from the early 1950s to the mid-1970s was characterized by essentially exponential growth in total CFC-12 release; from 1952 to 1974, for example, CFC-12 release grew at a nearly constant rate, averaging 12.2% per year. This growth was primarily due to the rapid worldwide expansion of CFC use in aerosols, although refrigerant use continued to contribute a significant fraction of the total CFC-12 release. In 1975, fluorocarbon production and release began to decline after the U.S. ban on CFCs in aerosols. By the early 1980s, however, this decline reversed, partly because of growth in aerosol production in countries not participating in the ban. In addition, CFC-12 remained the preferred cooling agent in home refrigerators and, until very recently, in automobile air-conditioners. For the period 1966–81, CFC-12 release from refrigeration grew exponentially, at an average rate of 8.5% per year. Since then, release from this end use has continued to increase, though at a slower rate, averaging ~3.6% per year for period 1982–91. By 1992, however, CFC-12 release from refrigerant use appeared to level off and decline slightly. Nevertheless, as other end uses of CFC-12 declined dramatically, release from refrigerant use constituted ~80% of the worldwide total in 1992. The recent decline in the release of CFC-12 from all sources has occurred largely in response to efforts to limit emissions of fully halogenated CFCs as prescribed by the 1987 Montreal Protocol and its subsequent revisions.

CFC-12 releases, 1931–92.

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Other Trace Gases and Atmospheric Aerosols
CFC-11 and CFC-12 release estimates from AFEAS

Alternative Fluorocarbons Environmental Acceptability Study (continued)

CFC-12

Atmospheric CFC-12 Releases^a

Releases (million kilograms)					Releases (million kilograms)				
Year	Total	Refriger- ation ^b	Blowing agents (closed-cell foam)	Open-cell foam, aerosols, and all other	Year	Total	Refriger- ation ^b	Blowing agents (closed-cell foam)	Open-cell foam, aerosols, and all other
1931	0.1	0.1	0.0	0.0	1962	114.5	33.4	0.5	80.7
1932	0.1	0.1	0.0	0.0	1963	133.9	35.3	0.8	97.6
1933	0.1	0.1	0.0	0.0	1964	155.5	37.6	1.8	116.3
1934	0.2	0.2	0.0	0.0	1965	175.4	39.9	2.2	133.2
1935	0.4	0.3	0.0	0.1	1966	195.0	42.8	2.5	149.7
1936	0.5	0.5	0.0	0.0	1967	219.9	46.2	2.8	170.9
1937	0.8	0.7	0.0	0.1	1968	246.5	50.4	3.1	193.1
1938	1.2	1.1	0.0	0.1	1969	274.3	54.9	4.0	215.2
1939	1.7	1.6	0.0	0.1	1970	299.9	60.0	4.9	235.1
1940	2.3	2.2	0.0	0.1	1971	321.8	65.2	5.2	251.4
1941	3.0	2.8	0.0	0.1	1972	349.9	70.7	6.3	272.9
1942	3.7	3.5	0.0	0.2	1973	387.3	77.0	8.0	302.2
1943	4.5	4.3	0.0	0.2	1974	418.6	83.6	9.3	325.8
1944	6.1	5.7	0.0	0.4	1975	404.1	89.8	9.6	304.7
1945	8.0	7.5	0.0	0.5	1976	390.4	97.0	8.0	285.3
1946	13.9	8.9	0.0	5.1	1977	371.2	105.3	8.3	257.6
1947	21.3	10.4	0.0	10.9	1978	341.3	113.9	14.1	213.4
1948	24.8	11.5	0.0	13.2	1979	337.5	123.9	18.1	195.4
1949	26.6	11.6	0.0	15.0	1980	332.5	134.4	21.0	177.1
1950	29.5	11.6	0.0	18.0	1981	340.7	144.7	22.6	173.5
1951	32.4	11.6	0.0	20.8	1982	337.4	151.6	22.0	163.6
1952	33.7	12.0	0.0	21.6	1983	343.3	157.7	24.4	161.2
1953	37.9	13.2	0.0	24.8	1984	359.4	162.0	28.5	169.0
1954	42.9	14.7	0.0	28.1	1985	368.4	165.4	30.4	172.6
1955	48.2	16.6	0.1	31.5	1986	376.5	170.3	34.2	172.0
1956	56.1	18.9	0.0	37.2	1987	386.5	177.7	49.0	160.0
1957	63.8	21.0	0.1	42.7	1988	392.8	186.9	59.6	146.2
1958	66.9	23.6	0.1	43.2	1989	364.7	197.1	52.0	115.5
1959	74.8	26.3	0.1	48.4	1990	310.5	202.9	33.8	73.9
1960	89.1	28.8	0.2	60.0	1991	271.6	207.5	20.9	43.3
1961	99.7	31.2	0.3	68.3	1992	255.3	205.9	16.2	33.2

^aAtmospheric release figures are derived from data obtained from the Alternative Fluorocarbons Environmental Acceptability Study. All values have been rounded to the nearest 0.1 million kilograms. Because of rounding effects, values for total yearly release may differ slightly from the sum of the subtotals. These atmospheric CFC release data are available at no cost in electronic form from CDIAC.

^bRelease figures for refrigeration represent the sum of releases for hermetically sealed and nonhermetically sealed refrigeration.

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E.G. Dutton

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Period of Record

1958–92

Methods

The atmospheric transmission of solar irradiation at Mauna Loa, Hawaii, U.S.A., was measured over a broad spectral band by means of a normal-incidence pyrheliometer having a quartz window transmitting over the range 300–3000 nm. In order to ensure that measurements were independent of instrument changes (including differences among the several pyrheliometers used over the period of record, instrument errors and drift, and variations in the transmittance of the quartz window due to temperature changes) and the effects of Sun-Earth geometry (i.e., seasonal and time of day changes in solar irradiance), a ratioing method was used whereby daily values of atmospheric transmission [known as atmospheric transmission factor (ATF)] were calculated by using the equation

$$\text{ATF} = 1/3 (I_5/I_4 + I_4/I_3 + I_3/I_2) ,$$

where I is the measured direct-incidence solar irradiation and the subscripts of I are the secants of the zenith angle at the time of measurement (see Ellis and Pueschel 1971; also Mendonca et al. 1978; Dutton 1992). Variations in ATF can be interpreted as instrumentally and temporally stable equivalents of changes in the vertical transmission of the direct solar beam. Thus, they are measures of the relative changes in total optical depth. The data base presented here in *Trends '93* consists of monthly averages of ATF for cloud-free mornings at the Mauna Loa Observatory in Hawaii. At Mauna Loa, a month typically has from 5 to 20 cloud-free mornings, with an average of 15.

Mauna Loa
Hawaii, U.S.A.
Barren lava field
of an active volcano
19°32' N, 155°35' W
3397 m above MSL

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Atmospheric solar transmission at Mauna Loa

E.G. Dutton (continued)

MAUNA LOA

Trends

Direct solar irradiance has been measured at the same location at Mauna Loa since 1958. The record from Mauna Loa is unique because of its long duration and essential completeness (data are missing for only 10 months since 1958) and because of the site's clear-sky and high-altitude location. The most prominent features of the record are the dramatic decreases in atmospheric transmission after the major explosive volcanic eruptions of Agung in 1963, El Chichón in 1982, and Pinatubo in 1991. A number of other smaller eruptions (e.g., Awu in 1965 and De Fuego in 1974) have also visibly affected the record (Mendonca et al. 1978). In addition, the data show an annual cycle: a statistically significant decrease in transmission from March through June (with a minimum in May) and a second, statistically insignificant, minimum in October. The spring minimum has been attributed primarily to an influx of tropospheric aerosols that are carried over Mauna Loa from Asia by seasonal winds (Dutton 1992). Other fluctuations, potentially random, are evident in the data; however, there is no evidence of a linear trend extending over the entire period of record.

Monthly atmospheric solar transmission at Mauna Loa.

CITE AS: Dutton, E.G. 1994. Atmospheric solar transmission at Mauna Loa. pp. 479-482. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Other Trace Gases and Atmospheric Aerosols
Atmospheric solar transmission at Mauna Loa

E.G. Dutton (continued)

MAUNA LOA

Atmospheric Solar Transmission at Mauna Loa

Atmospheric transmission factor^a

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1958	0.9364	0.9325	0.9340	0.9277	0.9286	0.9304	0.9328	0.9327	0.9339	0.9348	0.9332	0.9350
1959	0.9376	0.9357	0.9339	0.9338	0.9344	0.9303	0.9327	0.9354	0.9343	0.9354	0.9344	0.9368
1960	0.9362	0.9333	0.9341	0.9239	0.9281	0.9254	0.9363	0.9316	0.9381	0.9334	0.9373	0.9345
1961	0.9370	0.9311	0.9339	0.9334	0.9328	0.9303	0.9342	0.9355	0.9335	0.9315	0.9359	0.9365
1962	0.9340	0.9357	0.9288	0.9303	0.9278	0.9330	0.9360	0.9324	0.9362	0.9368	0.9353	0.9362
1963	0.9326	0.9347	0.9339	0.9263	0.9083	0.9202	0.9218	0.9204	0.9177	0.9207	0.9231	0.9251
1964	0.9208	0.9181	0.9130	0.9091	0.9092	0.9179	0.9150	0.9152	0.9171	0.9191	0.9128	0.9178
1965	0.9171	0.9158	0.9168	0.9145	0.9123	0.9134	0.9213	0.9244	0.9218	0.9232	0.9246	0.9246
1966	0.9291	0.9286	0.9217	0.9214	0.9189	0.9220	0.9289	0.9296	0.9210	0.9199	0.9226	0.9247
1967	0.9268	0.9217	0.9253	0.9163	0.9179	0.9214	0.9189	0.9261	0.9188	0.9257	0.9241	0.9260
1968	0.9298	0.9294	0.9277		0.9233	0.9221	0.9227	0.9252	0.9270	0.9286	0.9281	0.9292
1969	0.9304	0.9236	0.9258	0.9255	0.9311	0.9275	0.9328	0.9313	0.9322	0.9274	0.9300	0.9288
1970	0.9367	0.9348	0.9302	0.9309	0.9283	0.9275	0.9339	0.9336	0.9305	0.9315	0.9327	0.9348
1971	0.9341	0.9334	0.9302	0.9280	0.9249	0.9283	0.9305	0.9341	0.9348	0.9363	0.9338	0.9297
1972	0.9304	0.9334	0.9323	0.9274	0.9245	0.9284	0.9299	0.9351	0.9305	0.9247	0.9308	0.9362
1973	0.9376	0.9314					0.9332	0.9312	0.9305	0.9370	0.9303	0.9341
1974	0.9319	0.9292	0.9326	0.9257	0.9248	0.9373	0.9365	0.9297	0.9322	0.9331	0.9305	0.9330
1975	0.9285	0.9278	0.9262	0.9180	0.9224	0.9294	0.9314	0.9297	0.9288	0.9285	0.9297	0.9300
1976	0.9239	0.9311	0.9310	0.9324	0.9240	0.9270	0.9260	0.9220	0.9323	0.9351	0.9325	0.9388
1977	0.9404	0.9385	0.9385					0.9305	0.9289	0.9313	0.9362	0.9342
1978	0.9359	0.9347	0.9313	0.9292	0.9244	0.9258	0.9310	0.9295	0.9344	0.9334	0.9303	0.9337
1979	0.9326	0.9314	0.9258	0.9219	0.9200	0.9275	0.9302	0.9309	0.9330	0.9293	0.9261	0.9322
1980	0.9336	0.9339	0.9307	0.9257	0.9229	0.9277	0.9289	0.9314	0.9280	0.9308	0.9309	0.9309
1981	0.9324	0.9343	0.9307	0.9269	0.9288	0.9261	0.9302	0.9292	0.9266	0.9287	0.9313	0.9312
1982	0.9176	0.9219	0.9200		0.7857	0.7859	0.8044	0.8252	0.8356	0.8386	0.8611	0.8874
1983	0.8952	0.8966	0.8881	0.8931	0.8863	0.8929	0.8984	0.9010	0.9006	0.9022	0.9061	0.9114
1984	0.9126	0.9164	0.9142	0.9045	0.9054	0.9169	0.9234	0.9225	0.9231	0.9198	0.9214	0.9175
1985	0.9256	0.9292	0.9016	0.9230	0.9183	0.9210	0.9297	0.9296	0.9278	0.9298	0.9299	0.9284
1986	0.9307	0.9260	0.9290	0.9225	0.9264	0.9240	0.9244	0.9262	0.9247	0.9298	0.9288	0.9299
1987	0.9312	0.9325	0.9289	0.9275	0.9240	0.9273	0.9272	0.9314	0.9276	0.9299	0.9325	0.9317
1988	0.9314	0.9325	0.9300	0.9282	0.9270	0.9292	0.9341	0.9341	0.9313	0.9279	0.9285	0.9326
1989	0.9327	0.9280	0.9265	0.9251	0.9239	0.9304	0.9323	0.9342	0.9329	0.9279	0.9333	0.9335
1990	0.9354	0.9338	0.9327	0.9329	0.9290	0.9317	0.9327	0.9314	0.9304	0.9332	0.9360	0.9345
1991	0.9345	0.9345	0.9256	0.9257	0.9292	0.9288	0.8625	0.8311	0.8210	0.8251	0.8346	0.8466
1992	0.8606	0.8565	0.8557	0.8528	0.8537	0.8616	0.8711	0.8649	0.8643	0.8725	0.8818	0.8972

^aThe "apparent" transmission, or transmission ratio (Ellis and Pueschel 1977), is a unitless measure derived from broadband (300–3000 nm) direct solar irradiance observations at the NOAA/CMDL Mauna Loa Observatory in Hawaii. Data are for clear-sky mornings between solar elevations of 11.3° and 30° only. The data values are monthly averages of a variable number of days per month. These data are available at no cost in electronic form from CDIAC.

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E.G. Dutton (continued)

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Other Trace Gases and Atmospheric Aerosols

Aerosol optical depth measurements from four NOAA/CMDL monitoring sites

E.G. Dutton

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| Barrow • Mauna Loa • Samoa • South Pole

Period of Record

1977–92

Methods

Measurements of direct solar irradiance have been carried out routinely since 1977 at each of the four baseline atmospheric monitoring stations operated by the National Oceanic and Atmospheric Administration Climate Monitoring and Diagnostics Laboratory (NOAA/CMDL). The four stations are located at Barrow, Alaska, U.S.A. (71° N); Mauna Loa, Hawaii, U.S.A. (19° N); Samoa, U.S. Territory (14° S); and the South Pole (90° S). The sites were chosen for their global distribution and their relatively great distance from significant anthropogenic sources of gaseous and particulate pollutants. Monitoring is conducted by means of pyrhelimeters and wideband Schott glass cutoff filters. Although not as accurate or precise as monochromatic techniques, the wideband pyrhelimetric method is stable and has provided a long-term aerosol optical depth record from all four NOAA/CMDL baseline monitoring sites. The measured values are compared with the results of solar irradiance calculations [using the spectral one-layer radiative transfer model of Bird and Riordan (1986)] to derive aerosol optical depth (AOD), defined as the aerosol component of the exponent in the exponential decrease in solar beam intensity as the beam passes through the atmosphere. The resulting data set is presented as mean AOD for the wavelength range 0.35–0.69 μm . Individual AOD values are expressed as monthly average

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Other Trace Gases and Atmospheric Aerosols
Aerosol optical depth measurements from four
NOAA/CMDL monitoring sites

E.G. Dutton (continued)

anomalies (i.e., deviations) in relation to a baseline comprised of all AOD values from the nonvolcanic years at a given site, with mean seasonal variations removed. Over the range of the data set, these AOD anomalies are essentially proportional to the radiation loss due to aerosol backscattering to space. An approximate estimate of the climatic impact of an aerosol-generating event (such as an explosive volcanic eruption) can therefore be obtained by integrating the area under the AOD anomaly curve over the period of the event. The measurement accuracy of the computed AOD anomalies has been estimated at ± 0.04 with an overall precision of less than ± 0.02 , based on comparisons with AODs derived by sunphotometry (Dutton and Christy 1992).

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Aerosol optical depth measurements from four NOAA/CMDL monitoring sites

E.G. Dutton (continued)

BARROW

Trends

AOD anomaly data for the NOAA/CMDL Arctic baseline station at Barrow, Alaska, U.S.A., are generally available over the period of record for months during which solar irradiance measurements are possible (usually from February or March through October). The most prominent features of the record are increases in AOD following the volcanic eruptions of El Chichón (Mexico, 1982) and Pinatubo (Philippines, 1991). The El Chichón event produced a larger impact at Barrow than at the NOAA/CMDL monitoring sites in the Southern Hemisphere. AOD anomalies reached a maximum of 0.18 in June 1983 and then decayed to background levels over ~3 years. Evidence of the Pinatubo eruption appeared in April 1992 (data were missing for September through March) and reached a maximum of 0.20 in May 1992. In addition to the effects of these volcanoes, the record also shows an annual cycle with a maximum AOD in spring. This annual maximum is associated with the presence of Arctic haze, a phenomenon thought to result from particulate emissions from high-latitude anthropogenic sources.

When the seasonal cycle and the effects of the volcanoes are subtracted, the collective AOD anomaly record from Barrow does not show any significant trend. However, Bodhaine and Dutton (1993) have found a statistically significant decrease since 1982 in AOD measurements during March–April, when the Arctic haze is most evident at Barrow.

Monthly aerosol optical depth anomalies at Barrow.

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Other Trace Gases and Atmospheric Aerosols
Aerosol optical depth measurements from four
NOAA/CMDL monitoring sites

E.G. Dutton (continued)

*Barrow
Alaska, U.S.A.
Arctic coastal seashore
71°19' N, 156°36' W
11 m above MSL*

BARROW

Aerosol Optical Depth Anomalies^a

Aerosol optical depth at Barrow												
Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1977				0.04	0.01	-0.03	-0.01		0.00	0.09		
1978			0.03	-0.01	0.00	0.03	-0.02	0.00	-0.02			
1979			0.02	0.04	0.02	0.00	0.02	-0.02	-0.01	-0.02		
1980		-0.02	-0.03		-0.01	0.05	0.05			-0.01		
1981			-0.05	0.00			0.03					
1982		0.01	0.07	0.11	0.07	0.04	0.05	0.05				
1983		0.11	0.16	0.14	0.13	0.18	0.09		0.06	0.00		
1984		0.06	0.07	0.07	0.09	0.02	0.02	-0.01	0.03	-0.03	0.00	
1985		0.04	0.00	0.06	0.00	0.00	0.05					
1986			0.05	0.06		0.02	0.08	0.00	0.03			
1987			0.00	0.03	0.06	0.10	-0.03	0.02		-0.05		
1988			0.07	-0.01		0.00	0.00					
1989			-0.01	0.03		-0.05						
1990		0.01	-0.01	-0.07	-0.07	-0.03	-0.04	-0.05				
1991			-0.03	-0.03		-0.03	0.01	-0.01				
1992				0.18	0.20	0.14	0.10					

^aAerosol optical depth (AOD) is a unitless quantity. The data are presented as mean AOD for the wavelength range 0.35–0.69 μm , expressed as monthly average anomalies (i.e., deviations) in relation to a baseline comprised of all AOD values from nonvolcanic years. The calculation of AOD is detailed in Dutton and Christy (1992), Bodhaine and Rossen (1988), and Bird and Riordan (1986). These AOD anomaly data are available at no cost in electronic form from CDIAC.

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Aerosol optical depth measurements from four NOAA/CMDL monitoring sites

E.G. Dutton (continued)

MAUNA LOA

Trends

The NOAA/CMDL observatory at Mauna Loa, Hawaii, U.S.A., has obtained a nearly continuous AOD anomaly record, with values missing for only 8 months (the most recent in 1982) during 1977–92. The predominant features are the large increases in AOD that followed the volcanic eruptions of El Chichón (Mexico, 1982) and Pinatubo (Philippines, 1991). The maximum AOD anomaly following the El Chichón eruption (0.20 in July 1982) was the highest recorded for this event at any of the four NOAA/CMDL sites and is essentially equal to the maximum recorded at this site (0.19 in August 1991) following the eruption of Pinatubo. However, the decay to background values appeared to be much slower after the Pinatubo event; AOD anomalies 1 year after Pinatubo were about twice those 1 year after El Chichón. The AOD anomaly record at Mauna Loa also shows an annual cycle, with a maximum usually in May. This cycle appears to be largely the result of the seasonal arrival of Asian desert dust, which is carried over Mauna Loa by westerly winds prevailing in the region during spring.

After the annual cycle and the volcanic events are removed from the AOD anomaly record, no evidence of any long-term trend remains.

Monthly aerosol optical depth anomalies at Mauna Loa.

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Other Trace Gases and Atmospheric Aerosols
Aerosol optical depth measurements from four
NOAA/CMDL monitoring sites

E.G. Dutton (continued)

MAUNA LOA

Mauna Loa
Hawaii, U.S.A.
Barren volcanic
mountain slope
19°32' N, 155°35' W
3397 m above MSL

Aerosol Optical Depth Anomalies^a

Aerosol optical depth at Mauna Loa

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1977	-0.01	0.00	0.01	-0.02	-0.01	-0.01	-0.01				0.00	-0.01
1978	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	0.01	0.00	0.00	0.00	0.00	-0.01
1979	0.01	0.00	0.01	0.01	0.01	0.00	0.00	-0.01	-0.01	-0.01	0.00	-0.01
1980	-0.01	-0.01	0.00	-0.01	0.00	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
1981	-0.01	0.00	-0.01	-0.01	0.01	0.00	0.00	0.00				-0.02
1982	0.02	0.02	0.03	0.08			0.20	0.14	0.13	0.13	0.10	0.06
1983	0.05	0.05	0.06	0.04	0.06	0.05	0.05	0.04	0.04	0.04	0.03	0.02
1984	0.02	0.02	0.02	0.06	0.03	0.02	0.01	0.02	0.01	0.02	0.02	0.01
1985	0.01	0.01	0.03	0.01	0.03	0.02	0.02	0.01	0.00	0.01	0.01	0.00
1986	0.01	0.02	0.01	0.01	0.03	0.02	0.02	0.02	0.01	0.02	0.01	0.00
1987	0.01	0.01	0.01	0.01	0.01	0.01	0.01	-0.01	0.01	0.01	0.00	0.00
1988	0.00	0.01	0.01	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	-0.01
1989	-0.01	0.00	-0.01	0.01	0.02	0.00	0.00	0.00	0.00	-0.01	0.00	0.00
1990	0.00	0.00	-0.01	-0.01	0.01	0.00	0.00	0.00	0.00	0.00	-0.01	-0.01
1991	0.00	0.00	0.01	0.00	0.00	0.00	0.14	0.19	0.16	0.15	0.12	0.08
1992	0.08	0.08	0.08	0.09	0.10	0.07	0.06	0.06	0.06	0.05	0.05	0.02

^aAerosol optical depth (AOD) is a unitless quantity. The data are presented as mean AOD for the wavelength range 0.35–0.69 μm , expressed as monthly average anomalies (i.e., deviations) in relation to a baseline comprised of all AOD values from nonvolcanic years. The calculation of AOD is detailed in Dutton and Christy (1992), Bodhaine and Rossen (1988), and Bird and Riordan (1986). These AOD anomaly data are available at no cost in electronic form from CDIAC.

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Aerosol optical depth measurements from four NOAA/CMDL monitoring sites

E.G. Dutton (continued)

SAMOA

Trends

The NOAA/CMDL monitoring facility in Samoa, located at Cape Matatula on the island of Tutuila, was chosen as a representative tropical Southern Hemisphere baseline location. Despite characteristic wet and dry seasons and considerable cloudiness, a fairly continuous AOD anomaly record has been obtained at this site from 1977 to the present; only 1–2 monthly values are reported as missing for a typical year. The most obvious features of the record are the high-frequency background variability, attributable to fluctuations in boundary layer sea salt, and the increases in AOD associated with the explosive volcanic eruptions of El Chichón (Mexico, 1982) and Pinatubo (Philippines, 1991). For the El Chichón event, the maximum AOD anomaly at Samoa was only 0.08 (during September 1983), which was comparable to the maximum reached at the NOAA/CMDL South Pole site but much smaller than that at either of the two Northern Hemisphere baseline stations. Conversely, the Pinatubo eruption resulted in a large increase in AOD at this site: the maximum anomaly value of 0.25 occurred in August 1991. AOD anomalies have remained well above background levels through the end of the current record.

When the intrinsic variability of the data and the impact of the volcanic events are removed, the AOD record from Samoa shows no long-term trend.

Monthly aerosol optical depth anomalies at Samoa.

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Other Trace Gases and Atmospheric Aerosols
Aerosol optical depth measurements from four
NOAA/CMDL monitoring sites

E.G. Dutton (continued)

SAMOA

Samoa (Cape Matatula)
U.S. Territory
South Pacific Ocean
Rocky promontory
14°15' S, 170°34' W
42 m above MSL

Aerosol Optical Depth Anomalies^a

Aerosol optical depth at Samoa

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1977	0.00	0.01			0.04	0.03	-0.01	-0.01	-0.02	0.01	0.00	0.00
1978		-0.01	0.01		0.01	0.00	0.02	-0.01	-0.01	-0.01	-0.01	0.01
1979	0.01	0.01	-0.02	-0.01	-0.01	0.00	0.00	-0.01	0.00	0.00	-0.01	-0.01
1980	0.02	0.01	0.00	-0.01	0.00	0.00	-0.01	0.03	0.00	0.05	0.02	-0.02
1981	-0.02	-0.01	0.03	0.04	0.01	-0.01		0.01	0.01		-0.01	-0.03
1982			0.01	0.00		0.03	0.03	0.05	0.05	0.03		0.03
1983	0.04	0.03	0.02	0.03	0.05	0.04	0.04	0.03	0.08	0.03	0.01	0.02
1984	0.00	0.02	0.01	0.01	0.04	0.02	0.06	0.02	0.01	0.01	0.02	-0.02
1985	0.00	0.01	-0.01	-0.02				0.03	0.00		-0.01	-0.01
1986	0.01		0.00	-0.02	0.00	0.02	0.00	0.00	0.02	-0.01	0.02	0.02
1987	0.02	-0.02	-0.02	0.00	-0.01	-0.01	0.00		-0.01	0.02	-0.01	0.00
1988	0.00	0.01	0.01	-0.01	0.00	0.00	0.02	0.01	0.02	0.01	0.00	-0.01
1989	0.00	0.00	-0.01	0.03	0.00		-0.01	-0.02	0.01	-0.01	-0.02	-0.01
1990	0.01	0.01		-0.02	0.02		-0.01	-0.01	0.00	-0.01	0.01	0.00
1991		0.02	0.00	-0.01		0.00	0.07	0.25	0.24	0.20	0.16	0.14
1992	0.12		0.07	0.09		0.08	0.07	0.09	0.08			0.04

^aAerosol optical depth (AOD) is a unitless quantity. The data are presented as mean AOD for the wavelength range 0.35–0.69 μm , expressed as monthly average anomalies (i.e., deviations) in relation to a baseline comprised of all AOD values from nonvolcanic years. The calculation of AOD is detailed in Dutton and Christy (1992), Bodhaine and Rossen (1988), and Bird and Riordan (1986). These AOD anomaly data are available at no cost in electronic form from CDIAC.

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Aerosol optical depth measurements from four NOAA/CMDL monitoring sites

E.G. Dutton (continued)

SOUTH POLE

Trends

Solar irradiance measurements, from which AOD anomaly data are derived, are carried out continuously during the summer months (usually October through February or March) at the NOAA/CMDL South Pole station. Aside from the seasonal gaps, the South Pole record is characterized by increases in AOD resulting from the eruptions of the volcanoes El Chichón (Mexico, 1982) and Pinatubo (Philippines, 1991). The effects of the El Chichón eruption were much smaller at this site than at the two Northern Hemisphere NOAA/CMDL monitoring locations; the maximum AOD anomaly reached only 0.07 (during the first two months of 1983) and decayed to background values over 2–3 years. In contrast, the maximum AOD anomaly at the South Pole after the Pinatubo eruption was greater (0.27 in November 1991) than at any of the other three NOAA/CMDL sites, and through the end of 1992, values remained higher than any others recorded at this site before the Pinatubo eruption. It is possible, however, that these large AOD values may partly reflect effects from the eruption of the Chilean volcano, Mt. Hudson, in August 1991.

With the effects of volcanic eruptions removed, the South Pole record is singularly lacking in background variability, and no long-term trend is evident.

Monthly aerosol optical depth anomalies at the South Pole.

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Other Trace Gases and Atmospheric Aerosols
Aerosol optical depth measurements from four
NOAA/CMDL monitoring sites

E.G. Dutton (continued)

*South Pole
Antarctica
Ice- and snow-
covered plateau
89°59' S, 24°48' W
2810 m above MSL*

SOUTH POLE

Aerosol Optical Depth Anomalies^a

Aerosol optical depth at the South Pole

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1977	0.00	0.00	0.01						0.00	0.00	0.00	0.00
1978	0.01	0.00	-0.01							0.00	0.00	-0.01
1979		0.00								0.01	0.00	0.00
1980	0.00	0.00	-0.01								0.00	0.00
1981	0.00	0.00								0.00	0.00	0.00
1982	0.00	0.01	0.04							0.04	0.02	0.03
1983	0.07	0.07	0.04							0.03	0.03	0.03
1984	0.04	0.05								0.01	0.00	0.01
1985	0.01	0.02								0.00	-0.01	0.00
1986	0.00	0.00	-0.01							-0.01	0.00	0.00
1987	0.00	0.00								0.00	0.00	0.00
1988	0.01	0.00								0.00	0.00	0.00
1989	0.00	0.00								0.00		-0.01
1990	0.00	-0.01								0.00		0.00
1991	0.00	0.00	-0.01							0.21	0.27	0.23
1992	0.22	0.12	0.13							0.07	0.08	0.09

^aAerosol optical depth (AOD) is a unitless quantity. The data are presented as mean AOD for the wavelength range 0.35–0.69 μm , expressed as monthly average anomalies (i.e., deviations) in relation to a baseline comprised of all AOD values from nonvolcanic years. The calculation of AOD is detailed in Dutton and Christy (1992), Bodhaine and Rossen (1988), and Bird and Riordan (1986). These AOD anomaly data are available at no cost in electronic form from CDIAC.

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Aerosol optical depth measurements from four
NOAA/CMDL monitoring sites

E.G. Dutton (continued)

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CARBON DIOXIDE EMISSIONS

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Introduction

CARBON DIOXIDE EMISSIONS

Atmospheric carbon dioxide (CO₂) is produced both from natural sources and from human activities. Of human activities, the most important source of CO₂ is the release during the consumption of fossil fuels. Since the Industrial Revolution, global CO₂ emissions from fossil fuel consumption have risen dramatically (see figure below). In 1991, approximately 6200 million metric tons of carbon (1 million tons = 1 teragram = 10¹² g) was emitted to the atmosphere as a result of fossil fuel burning, cement manufacturing, and gas flaring, compared to 93 million metric tons of carbon in 1860. These CO₂ emissions, although small in comparison with the amounts of carbon stored in the oceans and in the terrestrial biosphere, represent a significant component of global carbon cycling and the greenhouse

Global CO₂ emissions from fossil fuel burning, cement production, and gas flaring, 1860-1991.

INTRODUCTION

effect and, more importantly, represent the largest human contribution to the CO₂ present in the atmosphere.

Keeling (1973) was the first to describe a systematic method for estimating the amount of CO₂ emitted from fossil fuel consumption. He used energy data from the U.N. Department of International Economic and Social Affairs. Since 1973, both the energy data collection and the procedures for estimating CO₂ emissions have been refined and improved (Marland and Rotty 1984; Marland et al. 1989; United Nations 1993).

The following section presents Keeling's 1860–1949 global emission estimates along with more-recent global, regional, and national annual emission estimates calculated by Marland et al. These more recent estimates cover the period 1950–91 and were calculated by using the methods of Marland and Rotty (1984). The data used for the calculations were energy and population statistics from the U.N., cement manufacturing data from the U.S. Department of Interior's Bureau of Mines, and gas flaring data from the U.N. and from the U.S. Department of Energy's Energy Information Administration.

Emission estimates for 1950–91 are provided for nine regions (see figure below). The regional definitions are consistent with those previously used by Rotty et al. (1984), Rotty and Marland (1986), and by the U.N. The data are presented in descending order, with the highest emitting region in 1991, North America, presented first. These estimates illustrate the changing patterns in regional CO₂ emissions over the last four decades, particularly in developing regions.

I = Developing America (AMD)	VI = Western Europe (WEU)
II = Far East (FEA)	VII = Eastern Europe (CPE)
III = Africa (AFR)	VIII = Centrally Planned Asia (CPA)
IV = Oceania (OCN)	IX = North America (NAM)
V = Middle East (MDE)	

Name and geographic definition of the regions presented in this chapter.

For emphasis and brevity, national estimates are provided only for the 20 highest CO₂-emitting countries in 1991 (see figure below). The data are presented in descending order, with the highest emitting country, the United States, presented first. These 20 countries contributed slightly over 81% of all the 1991 world CO₂ emissions from fossil fuel consumption. The top three countries—the United States, the former USSR, and the Peoples Republic of China—were responsible for 48.8% of the world emissions from fossil fuel burning in 1991. Saudi Arabia, the 20th highest CO₂ emitting nation, contributed slightly less than 1% to this total.

Since the publication of *Trends '91*, much has happened around the world. Events such as the unification of Germany, breakup of the former Soviet Union, the Gulf War, and unrest in Eastern Europe have had far-reaching implications on global, regional, and national energy economies. Globally, these events, coupled with the mild winter and summer seasons of the past few years, have resulted in a modest reduction in the global growth rate of CO₂ emissions from fossil fuel consumption. This reduction would have been more marked for 1991 had it not been for the Kuwaiti oil field fires, which contributed 130 million metric tons of carbon to the atmosphere.

Regionally, a marked decline in CO₂ emissions was seen in Eastern Europe, and a slight decline was seen in North America. Regions where populations continue to grow, such as Africa, Centrally Planned Asia, Developing America, Far East, and Oceania show corresponding increases in CO₂ emissions. As a result of the Kuwaiti oil fires, the 1991 emission estimate for the Middle East grew 56% over the 1990 estimate. In 1950,

Ranking of the 20 highest CO₂-emitting countries in 1991 and their rank in 1950, contributions to global emissions, and per capita CO₂ emission rates.

INTRODUCTION

North America, Western Europe, and Eastern Europe accounted for 89.2% of global CO₂ emissions from fossil fuel burning, cement production, and gas flaring, while the remaining six regions presented here accounted for only 10.8%. Now these six regions contribute 40.5% of the CO₂ emitted globally.

Since *Trends '91*, two countries have dropped from the ranks of the 20 highest CO₂-emitting countries: Czechoslovakia and Romania. In addition, the German Democratic Republic and the Federal Republic of Germany are now presented as a unified Germany. These countries have been replaced by Iran, Democratic People's Republic of Korea or North Korea, and Saudi Arabia.

With the unification of Germany in 1990, energy consumption data are now reported for the country as a whole. Because we believe there is value in the regional time series and that fundamental differences exist in the time series for Eastern and Western Europe, we have looked for a way to maintain the continuity of the data sequences while recognizing the reality of the changes that have taken place in Germany and the nature of the data sets that will be available in the future. Regionally, CO₂ emissions from unified Germany for 1991 are included in Western Europe. Before 1991, the CO₂ emission estimates from the former German Democratic Republic and Federal Republic of Germany were included in Eastern Europe and Western Europe, respectively. In the section on regional data, we show for Germany the contributions of the two republics prior to unification whereas in the subsequent section on national emissions estimates, we show the data for all of Germany combined and by fuel type.

Growth rates shown in this chapter are the mean annual increment in passing from the first value in the time interval of interest to the last and were calculated as $(\text{last value}/\text{first value})^{1/n}$ where n is the length of the time interval in years.

We urge readers to credit the principal investigators and their organizations (listed at the beginning of each data record) when using these data. The proper citation for each record is listed at the bottom of each page. Users are cautioned to pay close attention to table footnotes concerning the nature of each data record and are encouraged to contact the principal investigators before applying the data in specific model exercises or research exercises.

C.D. Keeling

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Period of Record

1860–1949

Methods

Global CO₂ emission estimates from industrial sources were calculated by using energy statistics and fuel-production data published by the United Nations (1955; 1951–69). The energy data were compiled based on replies by officials of the various national governments to inquiries from the U.N. statistical office. These replies were reviewed and compared with official national statistical publications and, if necessary, were modified. U.S. Bureau of Mines data for 1949–69 were used to estimate CO₂ emitted during cement production. For further details on the data used to generate these emission estimates, see Keeling (1973).

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GLOBAL

Trends

These global CO₂ emission estimates compiled by Keeling (1973) represent the first fully documented emission estimates from world fossil fuel consumption and from cement production and the only fully documented annual estimates that extend back to the mid-1800s. More-recent global estimates have been made by Marland and Rotty (1984), Rotty (1987), Marland et al. (1989), and Marland and Boden (1991). This series of emission estimates shows an increase from 93.3 million metric tons of carbon in 1860 to 1485 million metric tons of carbon in 1949. Keeling (1973) estimated that the cumulative increase in carbon in the short-term carbon cycle resulting from man's industrial and domestic activities up to the year 1970 was 112 ± 14 billion tons of carbon (410 ± 50 billion tons of CO₂), or about 18% of the amount of CO₂ in the atmosphere during the late 19th century.

Annual CO₂ emissions from fossil fuel burning and cement production, 1860-1949.

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Carbon Dioxide Emissions
Global historical CO₂ emissions

C.D. Keeling (continued)

GLOBAL

Global CO₂ Emission Estimates^a

Year	Coal	Lignite	Crude petroleum	Natural gas	Total	Year	Coal	Lignite	Crude petroleum	Natural gas	Total
1860	91.5	1.7	0.1	0.0	93.3	1905	594.2	24.1	22.7	5.6	646.6
1861	96.7	1.8	0.2	0.0	98.7	1906	641.6	25.8	22.5	6.1	696.1
1862	96.1	2.0	0.3	0.0	98.4	1907	708.7	28.3	27.8	6.4	771.2
1863	103.5	2.1	0.3	0.0	106.0	1908	670.9	29.3	30.1	6.3	736.6
1864	112.5	2.4	0.2	0.0	115.1	1909	700.2	29.8	31.5	7.5	769.0
1865	119.0	2.6	0.3	0.0	121.9	1910	732.2	30.0	34.5	8.0	804.8
1866	125.7	2.6	0.4	0.0	128.7	1911	746.2	31.2	36.3	8.1	821.8
1867	134.7	2.8	0.4	0.0	137.9	1912	785.7	34.5	37.1	8.9	866.2
1868	133.3	3.0	0.4	0.0	136.7	1913	842.9	35.7	41.3	9.2	929.0
1869	138.1	3.2	0.5	0.0	141.8	1914	752.7	33.5	43.0	9.3	838.4
1870	141.0	3.4	0.6	0.0	145.0	1915	741.2	34.3	45.4	9.9	830.8
1871	157.4	3.9	0.6	0.0	161.9	1916	798.4	36.4	48.1	11.8	894.8
1872	170.9	4.3	0.7	0.0	175.9	1917	842.2	37.4	53.2	12.5	945.3
1873	182.5	4.8	1.2	0.0	188.4	1918	828.1	39.2	53.4	11.3	932.0
1874	177.3	5.3	1.2	0.0	183.8	1919	720.7	36.9	59.6	11.7	828.9
1875	182.8	5.3	1.1	0.0	189.2	1920	826.4	43.6	76.3	12.6	958.9
1876	184.9	5.5	1.2	0.0	191.6	1921	688.3	46.6	82.6	10.4	828.0
1877	188.8	5.5	1.7	0.0	196.0	1922	735.8	50.6	92.2	12.0	890.6
1878	188.9	5.7	1.9	0.0	196.5	1923	835.4	45.3	108.8	15.8	1005.3
1879	199.1	6.0	2.5	0.0	207.6	1924	824.0	47.9	108.7	17.9	998.5
1880	217.5	6.4	3.2	0.0	227.1	1925	821.3	51.8	114.4	18.9	1006.4
1881	234.0	6.8	3.4	0.2	244.4	1926	815.7	52.0	117.5	20.8	1006.0
1882	251.3	7.1	3.8	0.3	262.5	1927	883.7	56.2	134.7	22.8	1097.5
1883	268.8	7.6	3.2	0.4	280.0	1928	863.5	60.8	141.6	24.9	1090.0
1884	269.9	7.8	3.8	0.6	282.1	1929	918.3	64.4	158.9	30.3	1171.9
1885	263.8	8.0	3.8	0.8	276.4	1930	843.3	54.6	151.2	28.4	1077.5
1886	264.4	8.3	5.0	1.0	278.7	1931	744.6	50.3	145.7	27.6	968.2
1887	282.8	8.6	5.0	1.3	297.7	1932	662.0	47.1	139.0	25.7	873.8
1888	305.8	9.2	5.5	1.5	321.9	1933	693.0	48.3	151.6	25.9	918.8
1889	310.5	9.8	6.5	1.7	328.5	1934	754.0	53.0	160.1	29.4	996.5
1890	328.9	10.8	8.1	2.0	349.7	1935	770.3	57.0	174.3	30.1	1031.7
1891	342.2	11.5	9.6	2.0	365.4	1936	866.3	56.8	188.4	34.9	1146.4
1892	345.5	11.7	9.4	2.1	368.7	1937	902.3	69.8	215.3	38.8	1226.2
1893	337.6	12.2	9.7	2.2	361.6	1938	841.3	73.1	209.9	37.0	1161.4
1894	352.9	12.5	9.4	2.3	377.1	1939	892.6	80.9	219.6	39.8	1232.9
1895	371.7	13.6	10.9	2.4	398.6	1940	944.6	88.4	224.5	42.9	1300.4
1896	382.4	14.5	12.1	2.7	411.6	1941	985.4	91.7	214.6	45.4	1337.1
1897	400.0	15.7	12.8	3.0	431.5	1942	990.3	92.5	202.2	49.4	1334.4
1898	421.5	16.7	13.2	3.2	454.6	1943	991.0	96.4	221.5	55.1	1364.0
1899	462.2	17.7	13.8	3.5	497.3	1944	955.6	87.5	249.2	59.8	1352.2
1900	485.6	19.8	15.8	3.7	524.9	1945	823.3	51.9	263.0	65.5	1203.6
1901	497.2	21.3	17.7	4.1	540.3	1946	842.7	70.9	289.1	67.8	1270.5
1902	508.5	20.9	19.1	4.4	552.9	1947	952.2	75.9	318.4	75.0	1421.5
1903	559.5	21.7	20.5	4.7	606.4	1948	990.3	82.9	359.9	84.5	1517.5
1904	563.0	22.6	23.0	4.9	613.4	1949 ^b	930.0	92.0	358.4	89.2	1485.4

^aEmission estimates are expressed in million metric tons of carbon.

^bCement production emission estimate of 15.8 is included in 1949 total emissions. Cement production emission data for previous years are not available.

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Global • North America • Eastern Europe • Western Europe • Centrally
Planned Asia • Far East • Oceania • Middle East • Developing America •
Africa • United States • Former USSR • Peoples Republic of China • Japan •
Germany • India • United Kingdom • Canada • Italy • France • Mexico •
Poland • South Africa • South Korea • Australia • North Korea • Iran •
Spain • Brazil • Saudi Arabia

Period of Record

1950–91

Methods

These CO₂ emission estimates, derived primarily from energy statistics published by the United Nations (1993), were calculated by using the methods of Marland and Rotty (1984). The energy statistics were compiled primarily from annual questionnaires distributed by the U.N. Statistical Office and supplemented by official national statistical publications. As stated in the introduction of the 1991 *Energy Statistics Yearbook*, "where official data are not available or are inconsistent, estimates are made by the Statistical Office based on governmental, professional or commercial materials. Estimates include, but are not limited to, extrapolated data based on partial year information, use of annual trends, trade data based on partner country reports, breakdowns of aggregated data as well as analysis of current energy events and activities." Data from the U.S. Department of Interior's Bureau of Mines (Solomon 1993) were used to estimate CO₂ emitted during cement production. Values for emissions from gas flaring were derived primarily from U.N. data but were supplemented with data from the U.S. Department of Energy's Energy Information Administration (1992), and Rotty (1974) and with a few national estimates provided by G. Marland. Greater details about these methods are provided in Marland and Rotty (1984) and Marland et al. (1989).

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Global, regional, and national CO₂ emissions

G. Marland, R.J. Andres, and T.A. Boden (continued)

GLOBAL

Trends

Global CO₂ emissions from fossil fuel consumption, cement manufacturing, and gas flaring have risen significantly since 1950. The 1991 estimate for global CO₂ emissions, 6188 million metric tons of carbon, marks the eighth consecutive year that global emissions have increased. The 1991 estimate is the highest emission estimate since the data record began in 1950. The 1991 estimate represents a 1.5% growth over 1990, continuing a recent decline in the global emission growth rate and roughly half the growth rates of the mid-1980s. Were it not for the Kuwaiti oil field fires, which accounted for 130 million metric tons of CO₂ being emitted to the atmosphere, global emissions would have declined during 1991.

Globally, liquid and solid fuels accounted for ~80% of the emissions from fossil fuel burning in 1991. Combustion of gas fuels (e.g., natural gas) accounted for 16.5% (1024 million metric tons) of the total emissions from fossil fuels in 1991 and reflects a gradually increasing global utilization of natural gas. Emissions from cement production increased slightly. Emissions from gas flaring rose almost 13% to 70 million metric tons but still remain well below the levels of the 1970s. This trend for gas flaring is not fully clear because of uncertainty about the gas-flaring data for the former USSR. Collectively, emissions from cement production and gas flaring contributed less than 4% to the total emissions for 1991.

Carbon Dioxide Emissions

Global, regional, and national CO₂ emissions

G. Marland, R.J. Andres, and T.A. Boden (continued)

GLOBAL

Global CO₂ emissions from fossil fuel burning, cement production, and gas flaring for 1950-91.

Global per capita CO₂ emission estimates.

CITE AS: Marland, G., R.J. Andres, and T.A. Boden. 1994. Global, regional, and national CO₂ emissions. pp. 505-584. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Carbon Dioxide Emissions

Global, regional, and national CO₂ emissions

G. Marland, R.J. Andres, and T.A. Boden (continued)

GLOBAL

Global CO₂ Emission Estimates

Year	Global emissions (million metric tons of carbon)						Per capita emissions (metric tons of carbon)
	Total	Solid	Liquid	Gas	Cement	Gas flaring	
1950	1638	1077	423	97	18	23	0.65
1951	1775	1137	479	115	20	24	0.69
1952	1803	1127	504	124	22	26	0.69
1953	1848	1132	533	131	24	27	0.70
1954	1871	1123	557	138	27	27	0.69
1955	2050	1215	625	150	30	31	0.74
1956	2185	1281	679	161	32	32	0.78
1957	2278	1317	714	178	34	35	0.80
1958	2338	1344	732	192	36	35	0.80
1959	2471	1390	790	214	40	36	0.83
1960	2586	1419	850	235	43	39	0.86
1961	2602	1356	905	254	45	42	0.85
1962	2708	1358	981	277	49	44	0.86
1963	2855	1404	1053	300	51	47	0.89
1964	3016	1442	1138	328	57	51	0.92
1965	3154	1468	1221	351	59	55	0.95
1966	3314	1485	1325	380	63	60	0.97
1967	3420	1455	1424	410	65	66	0.98
1968	3596	1456	1552	445	70	73	1.01
1969	3809	1494	1674	487	74	80	1.05
1970	4084	1564	1838	516	78	87	1.10
1971	4235	1564	1946	554	84	88	1.12
1972	4403	1580	2055	583	89	94	1.14
1973	4641	1588	2240	608	95	110	1.18
1974	4649	1585	2244	618	96	107	1.16
1975	4622	1679	2131	623	95	93	1.13
1976	4889	1717	2313	647	103	109	1.18
1977	5028	1780	2389	646	108	104	1.19
1978	5076	1796	2383	674	116	107	1.18
1979	5358	1892	2534	714	119	100	1.23
1980	5292	1950	2407	726	120	89	1.19
1981	5121	1922	2270	736	121	72	1.13
1982	5081	1985	2176	731	121	69	1.10
1983	5072	1991	2161	733	125	63	1.08
1984	5237	2083	2185	785	128	57	1.10
1985	5413	2239	2170	818	131	55	1.12
1986	5601	2300	2276	835	137	53	1.13
1987	5727	2351	2287	897	143	48	1.14
1988	5953	2413	2394	940	152	55	1.16
1989	6068	2454	2429	976	156	53	1.17
1990	6098	2393	2482	1004	157	62	1.15
1991	6188	2342	2591	1024	162	70	1.15

CITE AS: Marland, G., R.J. Andres, and T.A. Boden. 1994. Global, regional, and national CO₂ emissions. pp. 505-584. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

NORTH AMERICA

Trends

North America, as defined here, consists of the United States and Canada. Because over 92% of current CO₂ emissions from the region are from the United States, the 41-year time series closely resembles that for the United States. In addition, the patterns of change for the two countries have been similar in gross features, although they differ in detail because of political and resource differences. Both countries and the region have shown slight declines in total emissions during the past 2 years, having reached all-time highs in 1989. In contrast with CO₂ emissions from other regions, the striking features are a relatively uniform growth rate from 1950 to 1973 (2.7% per year), an essentially constant rate of emissions from 1973 to 1987, record emissions during 1988–89, and a small drop the past 2 years. Because of more rapid growth elsewhere, emissions from North America have shrunk from 46.5% of the global total in 1950 to 24.3% in 1991. Per capita emissions have been consistently high and well above those for any other region, almost 20 times the per capita emissions from the Far East.

NORTH AMERICA

CO₂ emissions from North America.

Per capita CO₂ emission estimates for North America.

CITE AS: Marland, G., R.J. Andres, and T.A. Boden. 1994. Global, regional, and national CO₂ emissions. pp. 505-584. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Carbon Dioxide Emissions
Global, regional, and national CO₂ emissions

G. Marland, R.J. Andres, and T.A. Boden (continued)

NORTH AMERICA

Regional CO₂ Emission Estimates

Year	Emissions for North America (million metric tons of carbon)						Per capita emissions (metric tons of carbon)
	Total	Solid	Liquid	Gas	Cement	Gas flaring	
1950	738	374	259	88	5.6	11.8	4.45
1951	761	361	279	104	6.1	11.7	4.51
1952	742	321	291	111	6.2	12.5	4.32
1953	758	317	306	117	6.6	12.3	4.33
1954	725	274	311	123	6.8	10.6	4.07
1955	792	303	337	133	7.8	11.9	4.36
1956	834	317	355	140	8.3	13.6	4.51
1957	825	301	353	151	7.9	13.0	4.38
1958	801	261	362	159	8.2	10.4	4.17
1959	832	266	373	175	8.9	9.3	4.26
1960	852	267	381	186	8.3	9.1	4.29
1961	855	258	386	194	8.5	8.8	4.24
1962	888	267	399	206	8.9	7.5	4.33
1963	933	285	415	216	9.2	6.9	4.48
1964	978	304	429	229	9.7	6.2	4.63
1965	1017	316	447	238	9.9	5.8	4.75
1966	1070	327	468	258	10.2	6.7	4.94
1967	1116	337	490	271	9.7	8.3	5.09
1968	1163	331	521	291	10.4	8.7	5.25
1969	1216	336	547	314	10.5	8.9	5.43
1970	1256	339	570	329	10.0	8.5	5.55
1971	1267	321	588	342	10.8	5.4	5.54
1972	1329	327	636	348	11.4	4.8	5.75
1973	1377	348	668	344	11.9	4.8	5.89
1974	1334	343	645	331	11.4	3.4	5.65
1975	1285	334	629	309	9.8	2.7	5.38
1976	1370	368	674	315	10.3	2.7	5.68
1977	1380	373	708	286	11.0	2.6	5.66
1978	1406	379	721	290	11.8	2.9	5.70
1979	1421	398	706	301	12.0	3.2	5.70
1980	1379	416	651	299	10.7	2.7	5.48
1981	1327	425	600	290	10.2	2.2	5.22
1982	1262	413	565	272	9.0	2.1	4.92
1983	1265	430	562	261	9.8	2.2	4.89
1984	1305	455	567	270	10.8	2.8	4.99
1985	1327	475	574	265	11.0	2.8	5.03
1986	1344	464	595	271	11.2	2.7	5.05
1987	1393	480	612	286	11.4	3.1	5.19
1988	1474	520	639	301	11.1	3.5	5.44
1989	1491	526	639	311	11.1	3.3	5.44
1990	1461	523	616	308	11.1	3.4	5.28
1991	1458	518	604	322	10.8	3.3	5.22

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EASTERN EUROPE

Trends

Linear growth averaging 31.4 million tons of carbon per year characterized the first 38 years of CO₂ emissions in Eastern Europe. From 1989–90, CO₂ emissions from Eastern Europe fell to mid-1980s levels. In 1991, emissions dropped dramatically due to the depressed economy of the former USSR and the mild winters they have experienced the past several years. A small fraction of the decline is due to the unification of Germany and an artifact of our regional definitions (see figure below). Prior to 1991, the region labelled "Eastern Europe" included East Germany or the German Democratic Republic. Beginning in 1991, energy statistics were compiled and reported for unified German which has been included in the region, "Western Europe," which had always contained West Germany or the Federal Republic of Germany. Per capita emissions have large variability across the region but are generally high and average 3.0 tons of carbon per person per year. Albania, emitting 0.5 ton of carbon per person per year, is the only nation in the region with per capita emissions below the global average. The region includes Albania, Bulgaria, Czechoslovakia, Hungary, Poland, Romania, and the former USSR. The former USSR represents 74.6% of the total population and 82.4% of CO₂ emissions in 1991. Coal has been the traditional fuel for the region and contributed 85% of the total CO₂ emissions in 1950. Most recently, use of gas fuels has increased dramatically; in 1991 gas contributed 30% of CO₂ emissions while the coal contribution was down to 37%.

CO₂ emissions from Eastern Europe, with the Germany Democratic Republic from 1950–90 and without for the entire period of record.

CITE AS: Marland, G., R.J. Andres, and T.A. Boden. 1994. Global, regional, and national CO₂ emissions. pp. 505–584. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Carbon Dioxide Emissions
Global, regional, and national CO₂ emissions

G. Marland, R.J. Andres, and T.A. Boden (continued)

EASTERN EUROPE

CO₂ emissions from Eastern Europe.

Per capita CO₂ emission estimates for Eastern Europe.

CITE AS: Marland, G., R.J. Andres, and T.A. Boden. 1994. Global, regional, and national CO₂ emissions. pp. 505-584. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Carbon Dioxide Emissions

Global, regional, and national CO₂ emissions

G. Marland, R.J. Andres, and T.A. Boden (continued)

EASTERN EUROPE

Regional CO₂ Emission Estimates

Year	Emissions for Eastern Europe (million metric tons of carbon)						Per capita emissions (metric tons of carbon)
	Total	Solid	Liquid	Gas	Cement	Gas flaring	
1950	293	250	36	5	2.5	0.0	1.09
1951	319	271	39	6	2.9	0.0	1.17
1952	342	288	45	6	3.3	0.0	1.23
1953	367	306	50	7	3.8	0.0	1.30
1954	396	329	56	7	4.2	0.0	1.38
1955	438	361	64	8	4.9	0.0	1.51
1956	473	383	74	10	5.3	0.0	1.60
1957	512	407	84	15	6.1	0.0	1.71
1958	540	419	93	21	6.9	0.0	1.78
1959	565	430	102	25	8.0	0.0	1.83
1960	591	440	111	31	9.3	0.0	1.89
1961	615	445	121	39	10.3	0.0	1.94
1962	648	453	136	48	11.3	0.1	2.02
1963	691	472	149	58	11.9	0.1	2.12
1964	733	489	162	69	12.9	0.1	2.23
1965	763	496	174	79	14.2	0.1	2.29
1966	797	506	187	88	15.5	0.1	2.37
1967	824	506	205	97	16.6	0.1	2.43
1968	852	509	220	105	17.2	0.1	2.49
1969	893	523	239	114	17.6	0.1	2.59
1970	907	535	244	109	18.7	0.1	2.61
1971	952	544	261	122	19.8	6.0	2.71
1972	994	555	284	128	20.6	5.7	2.81
1973	1030	558	307	136	21.9	6.8	2.89
1974	1065	560	328	147	23.2	7.5	2.96
1975	1118	578	347	161	24.6	8.3	3.08
1976	1165	594	359	178	25.5	9.2	3.18
1977	1205	605	375	189	26.4	10.0	3.27
1978	1246	610	401	197	26.8	10.7	3.35
1979	1254	613	401	208	26.0	5.8	3.35
1980	1295	639	405	219	26.3	5.9	3.43
1981	1266	592	409	233	25.8	5.9	3.33
1982	1292	603	413	245	25.5	5.7	3.37
1983	1309	603	413	261	26.0	5.6	3.39
1984	1325	610	407	276	26.3	5.6	3.40
1985	1410	668	412	299	25.8	5.9	3.60
1986	1416	682	410	292	26.9	5.2	3.58
1987	1465	687	416	330	27.3	4.8	3.68
1988	1485	685	409	353	27.8	10.5	3.71
1989	1450	654	406	351	27.8	10.2	3.60
1990	1331	552	388	358	26.2	6.8	3.28
1991	1186	434	371	352	23.0	6.3	3.03

CITE AS: Marland, G., R.J. Andres, and T.A. Boden. 1994. Global, regional, and national CO₂ emissions. pp. 505-584. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

WESTERN EUROPE

Trends

Western Europe experienced a 10.7% growth in CO₂ emissions during 1991; however, this growth results almost entirely from the inclusion of unified Germany in this region (see figure below). The region is comprised of 22 political entities, 5 of which (Germany, United Kingdom, Italy, France, and Spain) are among the top 20 national CO₂ emitters. These five nations contribute 93% of the region's total CO₂ emissions. Per capita emissions range from the high of 7.5 tons of carbon per person per year in Luxembourg to the low of 0.6 ton of carbon per year in Gibraltar, but for most countries the value lies between 1.5 and 3.5 tons of carbon per year. Gas fuels have become increasingly important since about 1970 and now contribute 16% of total CO₂ emissions.

CO₂ emissions for Western Europe, with unified Germany for only 1991 (total) and a calculated unified Germany from 1950–90 (total plus the CO₂ emissions from the German Democratic Republic).

CITE AS: Marland, G., R.J. Andres, and T.A. Boden. 1994. Global, regional, and national CO₂ emissions. pp. 505–584. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

WESTERN EUROPE

CO₂ emissions from Western Europe.

Per capita CO₂ emission estimates for Western Europe.

CITE AS: Marland, G., R.J. Andres, and T.A. Boden. 1994. Global, regional, and national CO₂ emissions. pp. 505-584. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Carbon Dioxide Emissions
Global, regional, and national CO₂ emissions

G. Marland, R.J. Andres, and T.A. Boden (continued)

WESTERN EUROPE

Regional CO₂ Emission Estimates

Year	Emissions for Western Europe (million metric tons of carbon)						Per capita emissions (metric tons of carbon)
	Total	Solid	Liquid	Gas	Cement	Gas flaring	
1950	383	336	40	1	6.7	0.0	1.26
1951	427	369	50	1	7.4	0.0	1.40
1952	429	367	53	1	7.9	0.0	1.40
1953	427	358	58	2	8.8	0.0	1.38
1954	449	369	68	2	9.4	0.0	1.44
1955	483	390	80	3	10.4	0.0	1.54
1956	509	404	91	3	10.9	0.0	1.61
1957	514	401	98	4	11.1	0.0	1.61
1958	499	374	110	4	11.4	0.0	1.55
1959	499	356	125	5	12.7	0.0	1.54
1960	537	372	145	6	13.5	0.0	1.64
1961	551	369	161	7	14.8	0.0	1.67
1962	583	373	187	8	15.7	0.0	1.75
1963	627	386	216	8	16.4	0.0	1.86
1964	646	372	246	9	18.7	0.0	1.90
1965	661	358	274	11	18.9	0.0	1.93
1966	672	336	305	12	19.9	0.0	1.94
1967	680	319	326	15	20.6	0.0	1.95
1968	721	318	359	22	21.8	0.1	2.06
1969	766	322	393	28	23.1	0.4	2.17
1970	792	305	423	39	24.2	0.8	2.23
1971	807	285	443	52	25.1	2.5	2.26
1972	828	259	474	66	26.6	2.8	2.31
1973	873	266	500	76	27.7	3.0	2.42
1974	847	262	469	86	26.9	3.1	2.33
1975	808	246	441	92	25.7	4.4	2.21
1976	866	263	473	98	26.4	4.6	2.36
1977	844	249	463	101	27.0	4.0	2.29
1978	869	253	476	108	27.9	4.1	2.35
1979	915	276	489	115	28.3	6.2	2.47
1980	881	276	458	114	28.2	5.2	2.37
1981	836	279	413	113	27.3	4.9	2.24
1982	802	274	390	107	26.6	5.1	2.14
1983	788	274	371	111	26.6	4.7	2.10
1984	784	263	374	118	25.0	4.6	2.08
1985	805	286	368	123	24.2	4.2	2.13
1986	798	275	377	117	24.3	4.5	2.11
1987	797	275	373	122	24.3	3.9	2.10
1988	792	265	375	122	25.7	4.9	2.08
1989	818	277	378	133	27.0	2.2	2.14
1990	829	279	378	139	27.1	6.0	2.16
1991	918	333	400	149	28.1	7.9	2.28

CITE AS: Marland, G., R.J. Andres, and T.A. Boden. 1994. Global, regional, and national CO₂ emissions. pp. 505-584. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

CENTRALLY PLANNED ASIA

Trends

Centrally Planned Asia (CPA) includes Vietnam, North Korea (officially Democratic People's Republic of Korea), and Mongolia, but regional statistics are dominated by the Peoples Republic of China. China currently contributes 92.6% of the region's population and 90.3% of the regional total for CO₂ emissions. In 1950 China produced >98% of the region's CO₂ emissions from fossil fuel burning. Growth in CO₂ emissions has been virtually continuous since 1950 as the CPA contribution rose from 1.4% of the world total in 1950 to 12.8% in 1991. The CO₂ emissions have more than doubled since 1973, when growth in many western nations essentially ceased.

CO₂ emissions from Centrally Planned Asia.

Per capita CO₂ emission estimates for Centrally Planned Asia.

CITE AS: Marland, G., R.J. Andres, and T.A. Boden. 1994. Global, regional, and national CO₂ emissions. pp. 505-584. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Global, regional, and national CO₂ emissions

G. Marland, R.J. Andres, and T.A. Boden (continued)

CENTRALLY PLANNED ASIA

Regional CO₂ Emission Estimates

Year	Emissions for Centrally Planned Asia (million metric tons of carbon)						Per capita emissions (metric tons of carbon)
	Total	Solid	Liquid	Gas	Cement	Gas flaring	
1950	22	22	0	0	0.1	0.0	0.04
1951	29	28	1	0	0.2	0.0	0.05
1952	36	35	1	0	0.4	0.0	0.06
1953	38	37	1	0	0.6	0.0	0.06
1954	47	45	1	0	0.7	0.0	0.07
1955	56	53	2	0	0.7	0.0	0.09
1956	63	59	3	0	1.0	0.0	0.10
1957	75	71	3	0	1.1	0.0	0.11
1958	151	145	4	0	1.5	0.0	0.23
1959	207	199	6	0	2.0	0.0	0.30
1960	224	214	7	1	2.2	0.0	0.32
1961	162	153	7	1	1.5	0.0	0.23
1962	133	124	7	1	1.5	0.0	0.18
1963	132	123	7	1	1.8	0.0	0.18
1964	134	122	9	1	1.9	0.0	0.18
1965	147	134	11	1	2.0	0.0	0.19
1966	163	145	16	1	2.0	0.0	0.21
1967	141	122	16	1	1.6	0.0	0.17
1968	153	132	18	1	1.7	0.0	0.18
1969	185	158	24	1	1.9	0.0	0.22
1970	240	205	31	2	2.0	0.0	0.27
1971	277	234	37	2	3.9	0.2	0.31
1972	287	238	42	3	3.9	0.3	0.31
1973	300	244	48	3	4.3	0.3	0.32
1974	305	244	53	4	4.3	0.4	0.32
1975	351	282	59	5	5.2	0.5	0.36
1976	363	284	66	5	7.8	0.5	0.37
1977	403	316	71	6	8.6	0.6	0.40
1978	446	352	76	7	10.0	0.7	0.44
1979	456	360	75	8	11.3	0.8	0.44
1980	447	353	74	7	12.1	0.8	0.42
1981	444	354	70	7	12.6	0.7	0.42
1982	473	382	71	6	14.0	0.7	0.44
1983	500	404	73	6	16.0	0.7	0.45
1984	542	443	74	7	17.7	0.9	0.49
1985	588	483	78	7	20.7	0.0	0.52
1986	620	506	84	7	24.0	0.0	0.54
1987	665	541	90	7	26.7	0.0	0.57
1988	716	582	96	7	30.4	0.1	0.60
1989	729	591	100	8	30.7	0.2	0.60
1990	735	597	99	8	30.3	0.3	0.60
1991	769	618	106	8	36.0	0.4	0.62

CITE AS: Marland, G., R.J. Andres, and T.A. Boden. 1994. Global, regional, and national CO₂ emissions. pp. 505-584. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

FAR EAST

Trends

Emissions of CO₂ from the Far East were 16 times greater in 1991 than in 1950, the culmination of 41 years of growth averaging 7.0% per year. This reflects the growth that has taken place not only in countries like India and South Korea (officially the Republic of Korea), but also in Indonesia, Taiwan, Thailand, Pakistan, Malaysia, the Philippines, and other less populous nations. India and South Korea are responsible for 58.3% of the region's CO₂ emissions, with the above mentioned six countries contributing another 35%. Per capita emissions in the region are as low as 0.01 ton of carbon per person per year in Cambodia and Nepal and as high as 5.8 in Brunei and 4.1 in Singapore. In 8 of the 21 countries in the Far East, the per capita emission rates are <0.1 ton of carbon per person per year. Only five countries have rates that exceed 1.0. That total emissions have increased by a factor of 16 while per capita emissions have increased by a factor of 7 shows that population growth has been an important factor in the Far East. Coal is the major source of CO₂ in the region. Nearly 83% of the coal is used in India and South Korea. In contrast, 58% of the emissions from liquid fuels are from countries other than India and South Korea. Unlike for the developed countries, emissions from the Far East show no break in slope in the middle or late 1970s.

Carbon Dioxide Emissions

Global, regional, and national CO₂ emissions

G. Marland, R.J. Andres, and T.A. Boden (continued)

FAR EAST

CO₂ emissions from the Far East.

Per capita CO₂ emission estimates for the Far East.

CITE AS: Marland, G., R.J. Andres, and T.A. Boden. 1994. Global, regional, and national CO₂ emissions. pp. 505-584. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Carbon Dioxide Emissions

Global, regional, and national CO₂ emissions

G. Marland, R.J. Andres, and T.A. Boden (continued)

FAR EAST

Regional CO₂ Emission Estimates

Year	Emissions for the Far East (million metric tons of carbon)						Per capita emissions (metric tons of carbon)
	Total	Solid	Liquid	Gas	Cement	Gas flaring	
1950	28	20	7	0	0.5	0.0	0.04
1951	31	21	8	1	0.7	0.0	0.05
1952	34	23	10	1	0.7	0.0	0.05
1953	35	23	10	1	0.8	0.0	0.05
1954	38	24	12	1	0.9	0.0	0.05
1955	43	25	16	1	1.0	0.0	0.06
1956	45	26	16	1	1.1	0.0	0.06
1957	47	28	16	1	1.2	0.0	0.06
1958	50	30	17	1	1.4	0.0	0.07
1959	53	31	18	2	1.6	0.0	0.07
1960	57	35	19	2	1.8	0.0	0.07
1961	62	37	21	2	2.0	0.0	0.08
1962	68	41	23	2	2.2	0.0	0.08
1963	74	44	25	2	2.3	0.0	0.09
1964	75	43	27	2	2.6	0.1	0.08
1965	82	47	29	3	2.9	0.2	0.09
1966	86	47	33	3	3.2	0.2	0.09
1967	92	48	36	3	3.5	0.4	0.10
1968	102	49	45	4	4.0	0.4	0.10
1969	107	48	50	4	4.5	0.3	0.11
1970	118	49	58	3	4.7	4.0	0.12
1971	125	50	63	3	5.3	4.0	0.12
1972	134	52	68	4	5.6	4.9	0.13
1973	144	54	75	4	6.0	5.2	0.13
1974	148	56	75	5	6.1	5.4	0.13
1975	158	61	79	6	6.8	5.0	0.14
1976	175	64	91	6	7.9	5.5	0.15
1977	201	78	99	7	8.7	7.8	0.17
1978	214	78	110	8	9.3	8.9	0.17
1979	227	83	117	8	9.6	8.8	0.18
1980	235	90	119	9	10.0	7.8	0.18
1981	242	95	119	9	10.8	7.7	0.19
1982	253	102	121	11	11.5	8.1	0.19
1983	275	114	128	12	13.0	8.8	0.20
1984	282	121	124	14	13.4	10.0	0.20
1985	302	137	126	15	13.9	9.5	0.21
1986	319	146	131	18	15.1	9.3	0.22
1987	335	156	133	20	16.1	9.6	0.23
1988	367	169	146	24	17.8	10.2	0.24
1989	400	180	162	28	19.7	11.0	0.26
1990	425	184	179	30	21.1	11.0	0.27
1991	453	195	192	32	22.0	11.2	0.28

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Global, regional, and national CO₂ emissions

G. Marland, R.J. Andres, and T.A. Boden (continued)

OCEANIA

Trends

Oceania consists of nineteen countries, including Japan, Australia, New Zealand, and a number of less populous nations of the Pacific region. Only Japan and Australia are represented in the list of top 20 CO₂-emitting countries, and together they contribute almost 98% of the regional sum. The pattern of CO₂ emissions bears many similarities with those in North America and Western Europe: that is, strong growth up until 1973 and a leveling off thereafter. Emissions have crept upward since 1973 but in an irregular and halting pattern. Japan's slowly decreasing reliance on liquid fuels strongly affects the regional sums.

CO₂ emissions from Oceania. Per capita CO₂ emission estimates for Oceania.

CITE AS: Marland, G., R.J. Andres, and T.A. Boden. 1994. Global, regional, and national CO₂ emissions. pp. 505-584. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

OCEANIA

Regional CO₂ Emission Estimates

Year	Emissions for Oceania (million metric tons of carbon)						Per capita emissions (metric tons of carbon)
	Total	Solid	Liquid	Gas	Cement	Gas flaring	
1950	46	40	5	0	0.8	0.0	0.48
1951	53	45	7	0	1.1	0.0	0.54
1952	55	46	8	0	1.2	0.0	0.55
1953	59	48	10	0	1.4	0.0	0.58
1954	61	47	12	0	1.8	0.0	0.59
1955	61	46	14	0	1.8	0.0	0.59
1956	67	49	16	0	2.1	0.0	0.64
1957	75	54	19	0	2.5	0.0	0.71
1958	74	51	20	0	2.4	0.0	0.69
1959	79	52	24	0	2.8	0.0	0.73
1960	92	57	31	0	3.5	0.0	0.84
1961	106	63	39	1	3.8	0.0	0.95
1962	110	61	44	1	4.4	0.0	0.98
1963	121	62	53	1	4.6	0.0	1.06
1964	133	65	62	1	5.1	0.0	1.16
1965	144	67	71	1	5.1	0.0	1.24
1966	153	68	77	1	5.8	0.0	1.30
1967	174	72	94	1	6.5	0.0	1.46
1968	196	78	110	1	7.2	0.0	1.63
1969	223	84	130	1	7.7	0.0	1.83
1970	247	85	151	3	8.5	0.0	2.00
1971	256	79	165	3	8.9	0.0	2.04
1972	275	78	183	4	9.9	0.0	2.16
1973	301	83	203	5	11.5	0.0	2.33
1974	296	88	190	6	10.8	0.0	2.26
1975	286	84	185	7	9.8	0.0	2.16
1976	294	83	191	9	10.2	0.1	2.19
1977	310	84	204	10	10.8	0.1	2.28
1978	309	77	206	14	12.4	0.1	2.25
1979	319	82	208	16	12.8	0.1	2.31
1980	317	92	194	18	12.8	0.1	2.27
1981	315	99	184	19	12.5	0.0	2.24
1982	312	100	179	21	11.9	0.1	2.20
1983	304	96	174	22	11.8	0.1	2.12
1984	331	108	183	28	11.6	0.0	2.29
1985	323	114	166	31	10.9	0.0	2.22
1986	318	110	166	32	10.6	0.0	2.17
1987	320	112	165	33	10.7	0.0	2.17
1988	344	120	179	34	11.5	0.0	2.32
1989	360	123	189	36	11.8	0.0	2.41
1990	376	125	200	39	12.5	0.0	2.50
1991	378	130	195	40	13.2	0.0	2.50

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MIDDLE EAST**Trends**

The Middle East, as represented here, is 15 nations that may contribute a large fraction of the world's oil but through their own energy consumption produce only 6% of global CO₂ emissions from fossil fuels and cement. The Middle East, due to the CO₂ emitted during the Kuwaiti oil field fires, exhibited a dramatic singularity of CO₂ emissions for 1991. The 1991 Kuwaiti oil field fires resulted in 130 million metric tons of carbon being emitted to the atmosphere, more than the total CO₂ emissions of the 8th largest national emitter, Canada. The three major fuel consumers discharge 62% of the region's CO₂: Iran, 60.7 million metric tons of carbon in 1991; Saudi Arabia, 58.7 million metric tons of carbon; and Turkey, 38.9 million metric tons of carbon. Gas flaring has been a major source of regional emissions, and in a few years during the early 1970s, before infrastructure was available for gas use and reinjection, flaring accounted for almost half of the total CO₂ emissions. Growth has been nearly continuous since 1950, although it started from a very low base. Per capita emissions underwent rapid growth until 1973 but have changed little since then. Qatar has the highest national per capita CO₂ emission rate in the world, 12.2 metric tons of carbon per person.

CITE AS: Marland, G., R.J. Andres, and T.A. Boden. 1994. Global, regional, and national CO₂ emissions. pp. 505-584. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

MIDDLE EAST

CO₂ emissions from the Middle East.

Per capita CO₂ emission estimates for the Middle East.

CITE AS: Marland, G., R.J. Andres, and T.A. Boden. 1994. Global, regional, and national CO₂ emissions. pp. 505–584. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Global, regional, and national CO₂ emissions

G. Marland, R.J. Andres, and T.A. Boden (continued)

MIDDLE EAST

Regional CO₂ Emission Estimates

Year	Emissions for the Middle East (million metric tons of carbon)						Per capita emissions (metric tons of carbon)
	Total	Solid	Liquid	Gas	Cement	Gas flaring	
1950	5	2	2	0	0.2	0.0	0.08
1951	7	2	5	0	0.2	0.0	0.11
1952	6	2	4	0	0.2	0.0	0.09
1953	8	3	4	0	0.2	0.0	0.12
1954	9	3	6	0	0.3	0.0	0.13
1955	14	3	7	0	0.4	3.2	0.19
1956	16	3	9	0	0.4	3.5	0.22
1957	17	3	10	1	0.5	2.4	0.22
1958	19	3	11	1	1.0	2.7	0.24
1959	20	3	12	1	0.7	3.1	0.25
1960	25	3	16	1	0.8	3.5	0.30
1961	26	3	17	1	0.9	3.9	0.31
1962	30	3	20	2	0.9	4.3	0.35
1963	34	4	21	2	1.0	6.4	0.38
1964	40	4	20	2	1.1	12.1	0.44
1965	48	4	23	2	1.2	16.4	0.51
1966	55	5	27	3	1.4	19.0	0.57
1967	56	4	23	3	1.4	24.3	0.56
1968	65	4	29	4	1.7	25.3	0.64
1969	74	5	28	7	2.0	32.6	0.70
1970	74	5	27	8	2.1	31.5	0.68
1971	88	5	33	8	2.4	39.4	0.79
1972	95	6	33	8	2.7	44.9	0.83
1973	112	6	40	10	2.7	54.2	0.95
1974	117	6	43	11	3.0	53.0	0.96
1975	114	7	47	12	3.6	45.7	0.91
1976	134	7	56	12	4.0	55.3	1.04
1977	138	7	64	11	4.4	51.6	1.04
1978	140	7	66	11	5.8	50.5	1.03
1979	149	8	78	16	5.5	42.3	1.06
1980	139	8	74	15	5.4	36.9	0.96
1981	137	9	80	15	6.2	27.6	0.91
1982	142	11	88	12	6.9	24.7	0.91
1983	151	13	98	13	7.0	20.1	0.94
1984	160	15	102	22	8.2	12.5	0.96
1985	176	18	109	29	8.7	11.8	1.02
1986	189	21	113	36	8.9	10.2	1.06
1987	190	21	112	38	9.4	8.4	1.03
1988	198	17	120	43	9.7	8.1	1.04
1989	215	20	129	48	10.4	7.1	1.10
1990	229	21	134	51	10.3	12.4	1.14
1991	358	22	253	54	10.0	19.2	1.84

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DEVELOPING AMERICA

Trends

The region "Developing America," as represented here, comprises nearly 50 political entities, including Greenland, Bermuda, and the island nations of the Caribbean, in addition to all of Central and South America. Two of the countries appear in the inventory of the top 20 highest CO₂-emitting countries. Mexico and Brazil account for 53% of the regional total. Other countries emitting >10 million tons of carbon per year are Venezuela (33.2), Argentina (31.6), and Colombia (15.7). This is a region of great diversity, but the collective trend is of growth in CO₂ emissions until at least 1974. Liquid fuels account for 68% of the regional emissions, and the post-1974 trend continues upward but is clearly affected by global oil markets. Coal burning is a notably small contributor in this region, accounting for only 9% of CO₂ emissions; most occurs in Brazil, Mexico, and Colombia. Per capita emissions of CO₂ doubled between 1950 and 1973 but have been virtually constant since then. Per capita emissions are high in many of the Caribbean islands, often >2.0 metric tons of carbon per person per year; only three of the larger mainland nations have lower per capita rates of CO₂ emissions: Venezuela (1.7 metric tons of carbon per person per year), Mexico (1.1), and Argentina (1.0).

Global, regional, and national CO₂ emissions

G. Marland, R.J. Andres, and T.A. Boden (continued)

DEVELOPING AMERICA

CO₂ emissions from Developing America. *Per capita CO₂ emission estimates for Developing America.*

CITE AS: Marland, G., R.J. Andres, and T.A. Boden. 1994. Global, regional, and national CO₂ emissions. pp. 505-584. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

DEVELOPING AMERICA

Regional CO₂ Emission Estimates

Year	Emissions for Developing America (million metric tons of carbon)						Per capita emissions (metric tons of carbon)
	Total	Solid	Liquid	Gas	Cement	Gas flaring	
1950	45	6	29	1	1.1	8.3	0.27
1951	53	7	33	2	1.2	10.1	0.31
1952	55	6	35	2	1.3	10.8	0.32
1953	55	6	36	2	1.4	10.0	0.31
1954	60	6	39	3	1.5	10.6	0.33
1955	66	6	44	3	1.7	11.3	0.35
1956	72	6	48	3	1.9	12.4	0.37
1957	78	6	52	4	2.1	13.6	0.39
1958	76	6	51	4	2.2	12.8	0.37
1959	83	6	57	5	2.3	12.7	0.39
1960	84	7	57	6	2.4	11.7	0.39
1961	86	7	59	7	2.6	10.8	0.39
1962	92	7	62	8	2.7	11.5	0.40
1963	92	7	62	9	2.8	10.9	0.39
1964	99	7	67	10	3.1	11.7	0.41
1965	102	7	68	11	3.3	11.7	0.41
1966	108	8	72	12	3.5	12.1	0.42
1967	117	8	78	14	3.7	13.3	0.45
1968	125	9	86	14	4.2	13.0	0.46
1969	138	9	96	14	4.4	13.8	0.50
1970	144	9	98	16	4.9	16.0	0.51
1971	152	9	107	17	5.2	14.7	0.52
1972	158	9	112	18	5.8	13.4	0.53
1973	172	10	122	20	6.4	13.4	0.56
1974	182	11	132	21	6.8	11.6	0.58
1975	181	11	133	21	7.2	8.8	0.57
1976	198	11	148	21	7.7	10.1	0.60
1977	202	13	150	23	8.1	8.4	0.60
1978	219	14	162	25	8.7	9.1	0.64
1979	232	15	170	29	9.4	8.6	0.66
1980	243	16	177	32	10.3	8.6	0.68
1981	242	15	176	32	10.4	8.5	0.66
1982	255	16	177	42	10.3	10.4	0.68
1983	241	17	165	41	9.1	9.1	0.63
1984	240	19	165	38	9.3	8.7	0.61
1985	242	21	164	39	9.7	8.4	0.61
1986	249	22	170	39	10.6	7.6	0.61
1987	261	22	178	41	11.5	7.9	0.63
1988	266	23	181	43	11.7	7.6	0.63
1989	270	24	185	43	11.4	6.2	0.62
1990	274	23	186	46	11.4	7.2	0.62
1991	287	25	194	49	12.0	6.5	0.64

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AFRICA

Trends

Africa's CO₂ emissions are low in both absolute and per capita terms. Total emissions have increased by a factor of 7 since 1950 and have increased at a linear rate of ~5 million tons of carbon per year since 1963. Although per capita emissions in 1991 were 2.3 times those in 1950, they were still only 5.4% of the comparable value for North America. Solid and liquid fuels contribute about equally, and gas fuels account for only 9%. To the extent that we can rely on gas-flaring data, 1987 was the first year in which gas use exceeded gas flaring. A small number of nations are largely responsible for the regional emissions from fossil fuels and cement; South Africa accounts for 41% of the continental total, and another 40% of the CO₂ comes from Egypt, Nigeria, Algeria, and Libya combined. These are the only five countries on the continent with annual CO₂ emissions in excess of 10 million metric tons of carbon. Only three other countries have per capita CO₂ emissions >1.0 metric ton of carbon per year: Libya (2.5), South Africa (2.0), and Gabon (1.4). In 29 of the 49 African nations, per capita emissions are <0.1 metric ton of carbon per person per year.

CITE AS: Marland, G., R.J. Andres, and T.A. Boden. 1994. Global, regional, and national CO₂ emissions. pp. 505-584. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

AFRICA

CO₂ emissions from Africa.

Per capita CO₂ emission estimates for Africa.

CITE AS: Marland, G., R.J. Andres, and T.A. Boden. 1994. Global, regional, and national CO₂ emissions. pp. 505-584. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Carbon Dioxide Emissions
Global, regional, and national CO₂ emissions

G. Marland, R.J. Andres, and T.A. Boden (continued)

AFRICA

Regional CO₂ Emission Estimates

Year	Emissions for Africa (million metric tons of carbon)						Per capita emissions (metric tons of carbon)
	Total	Solid	Liquid	Gas	Cement	Gas flaring	
1950	26	19	7	0	0.6	0.0	0.12
1951	28	20	7	0	0.6	0.0	0.12
1952	30	22	8	0	0.7	0.0	0.13
1953	31	22	8	0	0.7	0.0	0.13
1954	32	22	9	0	0.8	0.0	0.13
1955	36	25	9	0	1.0	0.0	0.14
1956	37	26	10	0	1.0	0.0	0.15
1957	39	27	11	0	1.0	0.0	0.15
1958	41	28	11	0	1.1	0.0	0.15
1959	41	28	12	0	1.2	0.0	0.15
1960	43	29	13	0	1.2	0.0	0.15
1961	45	29	14	0	1.2	0.0	0.16
1962	46	29	15	0	1.2	0.0	0.16
1963	48	30	17	0	1.3	0.3	0.16
1964	53	32	19	0	1.5	0.5	0.17
1965	59	34	21	1	1.6	1.4	0.19
1966	61	34	23	1	1.6	1.4	0.19
1967	65	35	22	1	1.7	5.7	0.19
1968	71	36	24	1	1.9	8.1	0.21
1969	76	37	26	1	2.2	10.5	0.21
1970	82	39	26	0	2.4	15.0	0.23
1971	90	41	30	0	2.6	15.3	0.24
1972	95	42	31	1	2.8	17.6	0.25
1973	102	42	34	1	2.9	21.8	0.26
1974	105	43	35	1	3.1	22.2	0.26
1975	105	44	38	2	3.0	17.6	0.25
1976	114	47	41	2	3.1	21.2	0.27
1977	116	47	43	4	3.3	19.5	0.26
1978	124	47	44	9	3.5	19.6	0.27
1979	133	52	48	5	3.8	23.9	0.29
1980	141	54	52	9	4.3	20.8	0.29
1981	143	60	57	8	4.7	14.3	0.29
1982	141	59	58	7	5.0	12.3	0.28
1983	149	63	61	8	5.5	11.3	0.28
1984	157	68	64	7	5.7	12.0	0.29
1985	160	69	63	10	5.7	12.1	0.29
1986	167	73	64	12	5.4	13.0	0.29
1987	166	75	63	13	5.9	10.5	0.28
1988	173	75	67	14	6.4	10.5	0.29
1989	174	74	67	15	6.2	12.6	0.28
1990	180	74	69	16	7.0	14.7	0.28
1991	184	75	70	17	6.9	14.8	0.28

CITE AS: Marland, G., R.J. Andres, and T.A. Boden. 1994. Global, regional, and national CO₂ emissions. pp. 505-584. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

UNITED STATES

Trends

The United States continues to be the largest single source of fossil fuel-related CO₂ emissions despite slight declines in U.S. emissions during the past 2 years. In fact, U.S. emissions are approximately 38% higher than those of the world's second largest emitter, the former USSR. Emissions in 1991 were nearly twice those of 1950, although the U.S. share of global emissions declined from 44% to 22% over the same interval because of higher growth rates in other countries. In 1989, CO₂ emissions from the United States reached an all-time high of 1370 million metric tons of carbon and have remained near this level during the past 2 years (~1346 million metric tons of carbon for both 1990 and 1991). This recent stabilization ended a 7-year pattern of increasing emissions after the low in 1982. Gone are the effects of the oil price shocks in the late 1970s, which had a major impact on U.S. emissions during the early 1980s. Per capita values remain well below the 1973 high, roughly equivalent to late 1960s levels and only 17% higher than the 1950 value. In 1991, 41% of the emissions were from petroleum products; the coal share increased only slowly over the last two decades.

Global, regional, and national CO₂ emissions

G. Marland, R.J. Andres, and T.A. Boden (continued)

UNITED STATES

CO₂ emissions from the United States. *Per capita CO₂ emission estimates for the United States.*

CITE AS: Marland, G., R.J. Andres, and T.A. Boden. 1994. Global, regional, and national CO₂ emissions. pp. 505-584. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Global, regional, and national CO₂ emissions

G. Marland, R.J. Andres, and T.A. Boden (continued)

UNITED STATES

National CO₂ Emission Estimates

Year	Emissions for the United States (million metric tons of carbon)						Per capita emissions (metric tons of carbon)	Bunkers ^a
	Total	Solid	Liquid	Gas	Cement	Gas flaring		
1950	696.1	347.1	244.8	87.1	5.3	11.8	4.57	8.1
1951	716.7	334.5	262.2	102.7	5.7	11.7	4.63	10.3
1952	697.9	296.6	273.2	109.9	5.8	12.5	4.44	10.8
1953	714.5	294.3	286.6	115.5	6.1	11.9	4.46	11.0
1954	680.5	252.2	290.2	121.2	6.3	10.6	4.18	10.1
1955	746.0	283.3	313.3	130.8	7.2	11.4	4.50	10.8
1956	781.9	295.0	328.5	138.1	7.6	12.7	4.63	11.4
1957	775.1	282.7	325.8	147.6	7.1	11.9	4.51	13.0
1958	750.8	245.3	333.0	155.8	7.5	9.3	4.29	11.5
1959	781.4	251.5	343.5	169.9	8.1	8.4	4.40	11.6
1960	799.5	253.4	349.8	180.4	7.6	8.3	4.43	11.7
1961	801.9	245.0	354.1	187.4	7.7	7.7	4.37	11.9
1962	831.5	254.2	364.3	198.7	8.0	6.3	4.46	11.3
1963	875.6	272.5	378.8	210.3	8.4	5.6	4.63	10.4
1964	912.9	289.7	389.7	219.8	8.8	5.0	4.76	10.8
1965	948.3	301.1	405.6	228.0	8.9	4.7	4.88	10.6
1966	999.7	312.7	425.9	246.4	9.1	5.5	5.08	11.7
1967	1039.2	321.1	443.6	258.5	8.8	7.2	5.23	13.2
1968	1081.0	314.8	471.9	277.4	9.4	7.6	5.38	14.2
1969	1132.0	319.7	497.4	297.8	9.5	7.7	5.58	12.4
1970	1165.5	322.4	514.8	312.1	9.0	7.2	5.68	13.3
1971	1173.2	305.7	530.5	323.3	9.7	4.2	5.66	12.8
1972	1227.3	310.4	575.5	327.6	10.2	3.6	5.86	12.6
1973	1275.4	334.0	605.4	321.7	10.6	3.6	6.03	14.6
1974	1231.1	330.1	580.7	307.9	10.0	2.4	5.76	14.5
1975	1179.0	317.6	565.1	286.0	8.4	1.9	5.46	14.7
1976	1262.7	351.6	608.9	291.3	9.0	2.0	5.78	16.8
1977	1270.5	355.6	642.7	260.5	9.7	2.0	5.76	20.6
1978	1293.9	361.2	655.5	264.7	10.4	2.2	5.80	23.9
1979	1303.8	378.7	637.5	274.8	10.4	2.4	5.78	27.5
1980	1261.8	394.6	583.5	272.5	9.3	1.8	5.54	30.5
1981	1213.3	403.0	535.8	264.2	8.8	1.4	5.28	27.8
1982	1152.4	390.1	507.8	245.4	7.8	1.4	4.97	23.3
1983	1157.8	405.5	508.5	233.8	8.7	1.4	4.94	21.4
1984	1194.2	427.8	513.8	241.5	9.6	1.6	5.05	21.7
1985	1217.6	448.0	523.7	234.9	9.6	1.4	5.11	15.4
1986	1237.4	439.6	544.4	242.2	9.7	1.4	5.14	15.0
1987	1283.4	454.2	561.4	256.4	9.6	1.8	5.28	14.9
1988	1357.1	491.7	585.8	268.0	9.5	2.1	5.54	16.1
1989	1369.9	497.9	584.2	276.2	9.5	2.1	5.53	16.8
1990	1346.8	498.6	562.7	273.7	9.5	2.2	5.39	19.6
1991	1346.0	492.3	555.1	287.2	9.3	2.0	5.33	18.4

^aBunkers refer to emissions, expressed in million metric tons of carbon, resulting from fuels consumed by ships and aircraft engaged in international transportation. Emissions from bunker fuels are shown with the country where the fuel loading occurred but are not included in the national total.

CITE AS: Marland, G., R.J. Andres, and T.A. Boden. 1994. Global, regional, and national CO₂ emissions. pp. 505-584. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

FORMER USSR

Trends

CO₂ emissions from the former USSR dropped almost 4% from 1990 to 1991, continuing a trend that began in 1989. Recent declines are the result of social and economic turmoil in the USSR and the newly independent republics. Prior to 1989, emissions had grown virtually unchecked since 1950 at a rate of 4.8% annually. Despite recent declines, the former USSR's share has increased since 1950 from 12% to 16% of total global emissions. Growth during the late 1980s was stimulated largely by the rapid exploitation of huge natural gas resources. In 1991, emissions from natural gas consumption accounted for 33% of Soviet emissions. Contributions from coal burning, on the other hand, have shrunk, from 80% in 1950 to 31% in 1991. Petroleum consumption over the past 15 years has been relatively static. Gas-flaring data for the former USSR are poor and partly estimated and should be considered qualitative only, but gas flaring contributes only a small fraction of total emissions.

FORMER USSR

CO₂ emissions from the former USSR.

Per capita CO₂ emission estimates for the former USSR.

CITE AS: Marland, G., R.J. Andres, and T.A. Boden. 1994. Global, regional, and national CO₂ emissions. pp. 505-584. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Carbon Dioxide Emissions

Global, regional, and national CO₂ emissions

G. Marland, R.J. Andres, and T.A. Boden (continued)

FORMER USSR

National CO₂ Emission Estimates

Year	Emissions for the former USSR (million metric tons of carbon)						Per capita emissions (metric tons of carbon)	Bunkers ^a
	Total	Solid	Liquid	Gas	Cement	Gas flaring		
1950	185.8	148.6	32.7	3.1	1.4	0.0	1.03	NA
1951	201.4	161.1	35.2	3.4	1.7	0.0	1.10	NA
1952	215.7	170.6	39.7	3.4	1.9	0.0	1.16	NA
1953	228.1	178.4	43.9	3.7	2.2	0.0	1.21	NA
1954	249.1	193.8	48.7	4.0	2.6	0.0	1.29	NA
1955	282.5	217.9	56.7	4.8	3.1	0.0	1.44	NA
1956	309.8	234.1	65.8	6.5	3.4	0.0	1.55	NA
1957	338.9	250.4	74.4	10.1	3.9	0.0	1.67	NA
1958	361.7	258.9	83.2	15.0	4.5	0.0	1.75	NA
1959	380.3	264.9	91.0	19.2	5.3	0.0	1.80	NA
1960	396.0	266.0	99.4	24.4	6.2	0.0	1.85	NA
1961	408.4	262.1	107.7	31.6	6.9	0.0	1.87	NA
1962	428.7	261.1	120.5	39.4	7.8	0.0	1.94	NA
1963	459.5	271.0	132.0	48.2	8.3	0.0	2.04	NA
1964	488.6	279.5	141.6	58.7	8.8	0.0	2.14	NA
1965	518.5	289.5	151.1	68.0	9.8	0.0	2.25	NA
1966	547.5	299.5	161.6	75.4	10.9	0.0	2.34	NA
1967	572.5	302.2	176.2	82.6	11.5	0.0	2.43	NA
1968	588.7	299.4	187.9	89.5	11.9	0.0	2.47	NA
1969	613.1	303.8	201.3	95.8	12.2	0.0	2.55	NA
1970	628.2	323.3	203.2	88.8	13.0	0.0	2.59	NA
1971	665.4	330.1	215.3	100.5	13.6	5.9	2.71	NA
1972	700.0	340.1	234.4	105.7	14.2	5.7	2.83	NA
1973	728.6	343.8	251.4	111.7	14.9	6.8	2.92	NA
1974	757.8	344.9	271.4	118.4	15.7	7.4	3.01	NA
1975	795.9	355.3	286.4	129.3	16.6	8.2	3.13	NA
1976	827.4	365.4	293.7	142.2	16.9	9.2	3.22	NA
1977	855.2	371.4	304.0	152.6	17.3	9.9	3.30	NA
1978	882.6	369.5	325.0	160.1	17.3	10.6	3.38	NA
1979	888.4	370.2	325.2	170.5	16.7	5.8	3.37	NA
1980	923.0	390.4	331.8	178.0	17.0	5.8	3.48	NA
1981	908.1	354.1	339.8	191.1	17.3	5.8	3.39	NA
1982	929.1	359.3	344.8	202.4	16.8	5.7	3.44	NA
1983	944.1	357.1	346.4	217.5	17.4	5.6	3.46	NA
1984	954.6	355.5	340.1	235.7	17.7	5.6	3.47	NA
1985	1033.4	405.4	345.4	258.9	17.8	5.9	3.72	NA
1986	1033.8	416.9	343.3	250.1	18.4	5.2	3.69	NA
1987	1077.4	418.0	347.6	288.2	18.7	4.8	3.81	NA
1988	1109.2	422.9	345.7	311.1	19.0	10.5	3.89	NA
1989	1082.2	402.0	341.5	309.3	19.1	10.2	3.77	NA
1990	1013.0	338.5	330.7	318.3	18.7	6.8	3.50	NA
1991	977.4	301.8	332.0	320.1	17.3	6.3	3.36	NA

^aBunkers refer to emissions, expressed in million metric tons of carbon, resulting from fuels consumed by ships and aircraft engaged in international transportation. Emissions from bunker fuels are shown with the country where the fuel loading occurred but are not included in the national total. NA = not available.

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PEOPLES REPUBLIC OF CHINA

Trends

China's emissions of CO₂ have grown phenomenally since 1950, when China stood tenth among nations. Growth from 1967 to 1991 has been fairly regular, with an average annual growth of 24.0 million metric tons per year (with a minor offset in 1980–81). Per capita emissions increased by a factor of 15 since 1950; combined with a doubling of the population, total CO₂ emissions in 1991 were 32 times the 1950 level. Growth has occurred largely in the use of coal, which accounted for 99% of the total in 1950 and 80% in 1991. Liquid fuels now contribute 14% of emissions and have grown appreciably during the past 4 years. The anomalous peak for 1958–61 is common in Chinese data. These years are part of the period "The Great Leap Forward," and whether the anomaly represents a real event in CO₂ emissions or a data residual is not clear. China is the world's largest hydraulic cement producer: in 1991 China accounted for an estimated 273 million short tons, or roughly 21% of the world's supply. Emissions from cement production account for 4.9% of China's 1991 total CO₂ emissions.

Carbon Dioxide Emissions
Global, regional, and national CO₂ emissions

G. Marland, R.J. Andres, and T.A. Boden (continued)

PEOPLES REPUBLIC OF CHINA

CO₂ emissions from the Peoples Republic of China.

Per capita CO₂ emission estimates for the Peoples Republic of China.

CITE AS: Marland, G., R.J. Andres, and T.A. Boden. 1994. Global, regional, and national CO₂ emissions. pp. 505-584. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Carbon Dioxide Emissions

Global, regional, and national CO₂ emissions

G. Marland, R.J. Andres, and T.A. Boden (continued)

PEOPLES REPUBLIC OF CHINA

National CO₂ Emission Estimates

Year	Emissions for the Peoples Republic of China (million metric tons of carbon)						Per capita emissions (metric tons of carbon)	Bunkers ^a
	Total	Solid	Liquid	Gas	Cement	Gas flaring		
1950	21.7	21.4	0.2	0.0	0.1	0.0	0.04	NA
1951	28.1	27.6	0.3	0.0	0.2	0.0	0.05	NA
1952	35.4	34.6	0.4	0.0	0.4	0.0	0.06	NA
1953	37.0	36.0	0.5	0.0	0.5	0.0	0.06	NA
1954	44.5	43.0	0.9	0.0	0.6	0.0	0.08	NA
1955	52.7	50.6	1.5	0.0	0.6	0.0	0.09	NA
1956	59.7	56.6	2.2	0.0	0.9	0.0	0.10	NA
1957	70.7	67.3	2.5	0.0	0.9	0.0	0.11	NA
1958	145.0	140.3	3.4	0.1	1.3	0.0	0.23	NA
1959	199.0	192.0	5.2	0.2	1.7	0.0	0.31	NA
1960	215.3	206.6	6.3	0.5	1.8	0.0	0.33	NA
1961	152.2	144.3	6.1	0.8	1.1	0.0	0.23	NA
1962	121.4	113.7	5.9	0.6	1.1	0.0	0.18	NA
1963	120.4	112.1	6.4	0.5	1.4	0.0	0.18	NA
1964	120.4	110.9	7.6	0.6	1.4	0.0	0.17	NA
1965	131.2	119.6	9.6	0.6	1.5	0.0	0.18	NA
1966	144.1	129.7	12.2	0.7	1.5	0.0	0.20	NA
1967	119.4	105.9	11.6	0.8	1.1	0.0	0.16	NA
1968	129.2	114.0	13.3	0.7	1.2	0.0	0.17	NA
1969	159.0	138.4	18.2	1.0	1.4	0.0	0.20	NA
1970	211.6	183.9	24.9	1.5	1.4	0.0	0.26	NA
1971	240.5	203.3	31.8	2.0	3.1	0.2	0.29	NA
1972	255.5	212.8	36.8	2.5	3.1	0.3	0.30	NA
1973	265.7	216.4	42.4	3.1	3.4	0.3	0.30	NA
1974	271.0	214.3	48.9	3.9	3.4	0.4	0.30	NA
1975	314.3	250.3	54.7	4.6	4.1	0.5	0.34	NA
1976	328.2	251.4	64.3	5.3	6.7	0.5	0.35	NA
1977	366.2	282.3	69.4	6.3	7.6	0.6	0.39	NA
1978	407.4	317.2	73.4	7.2	8.9	0.7	0.43	NA
1979	416.2	325.4	72.3	7.6	10.1	0.8	0.43	NA
1980	406.4	316.6	70.7	7.5	10.9	0.8	0.42	NA
1981	402.6	317.5	66.3	6.7	11.4	0.7	0.41	NA
1982	431.5	345.1	66.8	6.3	12.8	0.7	0.43	NA
1983	455.2	365.0	68.4	6.4	14.7	0.7	0.45	NA
1984	494.8	400.9	70.0	6.6	16.5	0.9	0.48	NA
1985	536.7	437.0	73.5	6.8	19.4	0.0	0.51	NA
1986	564.4	456.8	78.4	7.2	22.0	0.0	0.53	NA
1987	602.5	487.3	83.5	7.3	24.4	0.0	0.56	NA
1988	646.0	520.8	89.3	7.5	28.5	0.0	0.59	NA
1989	657.1	528.0	93.1	7.9	28.1	0.0	0.59	NA
1990	660.7	533.0	92.1	8.0	27.6	0.0	0.58	NA
1991	694.2	552.4	99.7	8.4	33.7	0.0	0.60	NA

^aBunkers refer to emissions, expressed in million metric tons of carbon, resulting from fuels consumed by ships and aircraft engaged in international transportation. Emissions from bunker fuels are shown with the country where the fuel loading occurred but are not included in the national total. NA = not available.

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Carbon Dioxide Emissions

Global, regional, and national CO₂ emissions

G. Marland, R.J. Andres, and T.A. Boden (continued)

JAPAN

Trends

The history of CO₂ emissions from Japan is remarkable for the abrupt change that occurred in 1973. With postwar growth at 9.9% per year from 1950 to 1973, total emissions have been virtually constant since 1973, although there are signs of renewed growth and the two years of highest emissions were 1990 and 1991. Rising consumption of liquid petroleum products halted in 1973, and constant CO₂ emissions reflect the increasing contributions of coal and natural gas as the petroleum share shrank from 71% in 1973 to 57% in 1991. Japan is the world's largest consumer of liquified natural gas, and it imported over 39 billion cubic meters in 1987. Per capita emissions have returned to levels comparable to the 1973 maximum although they are nearly eight times larger than the very low value that prevailed in 1950.

CO₂ emissions from Japan.

Per capita CO₂ emission estimates for Japan.

CITE AS: Marland, G., R.J. Andres, and T.A. Boden. 1994. Global, regional, and national CO₂ emissions. pp. 505-584. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Carbon Dioxide Emissions

Global, regional, and national CO₂ emissions

G. Marland, R.J. Andres, and T.A. Boden (continued)

JAPAN

National CO₂ Emission Estimates

Year	Emissions for Japan (million metric tons of carbon)						Per capita emissions (metric tons of carbon)	Bunkers ^a
	Total	Solid	Liquid	Gas	Cement	Gas flaring		
1950	28.3	26.4	1.2	0.0	0.6	0.0	0.34	NA
1951	34.0	30.6	2.5	0.0	0.9	0.0	0.40	0.7
1952	35.9	31.4	3.5	0.0	1.0	0.0	0.42	0.7
1953	40.2	32.9	6.0	0.1	1.2	0.0	0.46	0.5
1954	39.3	31.2	6.5	0.1	1.5	0.0	0.44	0.6
1955	39.1	30.1	7.5	0.1	1.4	0.0	0.43	1.2
1956	44.2	33.5	8.8	0.1	1.8	0.0	0.49	1.8
1957	51.8	37.5	12.0	0.2	2.1	0.0	0.57	1.9
1958	49.8	34.9	12.6	0.3	2.0	0.0	0.54	1.6
1959	53.0	34.7	15.6	0.3	2.3	0.0	0.57	2.3
1960	63.9	38.4	22.0	0.4	3.1	0.0	0.68	3.6
1961	77.7	44.4	29.4	0.6	3.4	0.0	0.82	5.0
1962	80.4	42.6	33.2	0.7	3.9	0.0	0.84	5.8
1963	89.2	42.9	41.2	1.0	4.1	0.0	0.92	7.0
1964	98.5	44.2	48.7	1.1	4.5	0.0	1.01	8.4
1965	106.0	45.8	54.8	1.0	4.4	0.0	1.07	7.3
1966	115.0	47.1	61.7	1.0	5.2	0.0	1.15	9.4
1967	134.2	50.1	77.1	1.1	5.8	0.0	1.33	9.2
1968	154.0	55.3	91.2	1.2	6.5	0.0	1.51	7.9
1969	179.0	61.0	109.7	1.3	7.0	0.0	1.74	9.4
1970	202.5	63.3	129.3	2.1	7.8	0.0	1.94	7.1
1971	209.5	57.0	142.2	2.2	8.1	0.0	1.98	10.0
1972	224.9	55.3	158.4	2.2	9.0	0.0	2.10	11.4
1973	250.7	59.3	177.8	2.9	10.6	0.0	2.31	14.9
1974	244.1	63.3	166.9	3.9	9.9	0.0	2.22	18.0
1975	233.7	58.9	161.2	4.7	8.9	0.0	2.10	15.9
1976	239.3	57.6	166.7	5.6	9.3	0.0	2.12	11.6
1977	251.6	56.6	178.3	6.7	9.9	0.0	2.21	9.3
1978	250.7	49.9	179.8	9.4	11.5	0.0	2.18	9.4
1979	260.2	54.7	182.3	11.2	11.9	0.0	2.25	9.2
1980	254.9	62.8	167.0	13.1	12.0	0.0	2.18	8.5
1981	249.9	68.9	156.2	13.3	11.5	0.0	2.12	9.4
1982	244.6	68.5	151.5	13.6	11.0	0.0	2.06	6.7
1983	239.9	65.2	149.1	14.6	11.0	0.0	2.01	4.6
1984	264.3	76.9	157.1	19.6	10.7	0.0	2.20	3.2
1985	254.2	80.5	142.8	21.0	9.9	0.0	2.10	3.1
1986	248.9	76.3	140.7	22.2	9.7	0.0	2.05	5.7
1987	246.9	75.2	139.4	22.6	9.7	0.0	2.02	5.1
1988	269.8	83.0	152.8	23.5	10.5	0.0	2.20	4.5
1989	281.3	83.0	162.2	25.3	10.8	0.0	2.29	4.7
1990	294.7	84.1	172.2	27.0	11.5	0.0	2.39	5.0
1991	297.8	87.6	169.1	29.0	12.1	0.0	2.40	5.8

^aBunkers refer to emissions, expressed in million metric tons of carbon, resulting from fuels consumed by ships and aircraft engaged in international transportation. Emissions from bunker fuels are shown with the country where the fuel loading occurred but are not included in the national total. NA = not available.

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GERMANY

Trends

Emissions of CO₂ from unified Germany dropped slightly in 1991 to 264.6 million metric tons of carbon, marking the fifth consecutive year that total emissions have decreased for Germany. This continues a general declining trend that has prevailed since 1979. The 1991 per capita emission estimate of 3.31 tons of carbon per person is comparable to early 1960s levels and 12.7% lower than the record value of 1979. Although the largest fraction of emissions (52%) is from burning of solid fuels, the use of coal has been in general decline since 1950, at which time 97.3% of the total emissions were from coal burning. Natural gas burning first contributed over 1% in 1968 and is now 14% of the total. The year 1991 marked the first year that the United Nations has published energy statistics for unified Germany. Through 1990 statistics are still published for the former German Democratic Republic (GDR) and Federal Republic of Germany (FRG). We have combined the statistics here to generate a 1950–91 time series for unified Germany. CO₂ emission time series for GDR and FRG that cover the period 1950–90 are presented on pages 548–549. Future issues of *Trends* will offer CO₂ emissions time series for unified Germany only.

CITE AS: Marland, G., R.J. Andres, and T.A. Boden. 1994. Global, regional, and national CO₂ emissions. pp. 505–584. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

GERMANY

CO₂ emissions from Germany.

Per capita CO₂ emission estimates for Germany.

CITE AS: Marland, G., R.J. Andres, and T.A. Boden. 1994. Global, regional, and national CO₂ emissions. pp. 505-584. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Carbon Dioxide Emissions
Global, regional, and national CO₂ emissions

G. Marland, R.J. Andres, and T.A. Boden (continued)

GERMANY

National CO₂ Emission Estimates

Year	Emissions for Germany (million metric tons of carbon)						Per capita emissions (metric tons of carbon)	Bunkers ^a
	Total	Solid	Liquid	Gas	Cement	Gas flaring		
1950	138.4	134.6	2.1	0.0	1.7	0.0	2.02	1.4
1951	156.4	151.5	3.0	0.0	1.9	0.0	2.28	1.7
1952	165.7	160.1	3.6	0.0	2.1	0.0	2.40	1.8
1953	169.0	161.8	4.7	0.1	2.5	0.0	2.43	1.5
1954	178.8	169.4	6.7	0.1	2.6	0.0	2.56	1.7
1955	196.1	184.9	8.2	0.2	2.9	0.0	2.79	2.1
1956	207.8	193.8	10.6	0.3	3.1	0.0	2.94	2.4
1957	210.9	195.1	12.4	0.3	3.1	0.0	2.96	2.2
1958	204.9	186.4	15.1	0.3	3.2	0.0	2.86	1.9
1959	204.7	181.4	19.2	0.3	3.7	0.0	2.84	2.0
1960	220.6	191.4	24.8	0.4	4.1	0.0	3.03	2.3
1961	226.1	192.4	28.9	0.4	4.4	0.0	3.08	2.4
1962	239.2	197.9	36.2	0.5	4.6	0.0	3.23	2.6
1963	256.2	205.9	44.8	0.7	4.7	0.0	3.43	2.6
1964	262.5	204.2	51.9	1.0	5.4	0.0	3.48	3.1
1965	260.1	193.7	59.4	1.5	5.5	0.0	3.42	3.4
1966	257.7	183.6	66.7	1.8	5.6	0.0	3.37	3.8
1967	253.6	176.5	69.5	2.4	5.3	0.0	3.30	3.4
1968	266.7	177.9	79.3	3.9	5.6	0.0	3.46	3.7
1969	285.0	185.1	88.5	5.6	5.8	0.0	3.68	4.0
1970	274.7	163.1	97.2	8.1	6.3	0.0	3.53	4.8
1971	277.6	158.9	101.0	11.0	6.7	0.0	3.56	5.0
1972	278.6	149.4	107.7	14.3	7.1	0.0	3.56	5.3
1973	289.3	151.7	112.4	18.4	6.9	0.0	3.69	5.2
1974	282.1	152.7	100.2	23.0	6.3	0.0	3.59	4.7
1975	266.2	139.0	97.2	24.1	6.0	0.0	3.38	4.3
1976	289.2	149.9	107.5	25.4	6.4	0.0	3.68	4.4
1977	278.8	139.2	106.9	26.5	6.2	0.0	3.54	4.6
1978	285.5	141.1	109.2	28.6	6.5	0.0	3.63	4.5
1979	297.6	148.1	111.9	30.8	6.7	0.0	3.79	4.6
1980	291.6	148.6	105.3	31.4	6.3	0.0	3.72	4.6
1981	277.6	150.3	91.7	29.7	5.9	0.0	3.55	4.9
1982	268.6	148.3	86.8	27.8	5.7	0.0	3.44	4.4
1983	266.9	149.1	83.3	28.7	5.7	0.0	3.43	4.3
1984	273.0	154.1	83.8	29.6	5.5	0.0	3.51	4.2
1985	274.9	156.0	84.8	29.0	5.1	0.0	3.54	5.0
1986	276.1	154.5	88.9	27.5	5.2	0.0	3.56	6.0
1987	271.9	150.8	85.9	29.7	5.1	0.4	3.50	5.4
1988	271.8	148.8	87.9	29.6	5.3	0.3	3.50	5.1
1989	267.2	147.1	81.5	32.9	5.5	0.2	3.44	5.0
1990	265.9	142.3	84.1	33.7	5.5	0.3	3.43	5.0
1991	264.6	138.5	84.0	36.1	5.7	0.3	3.31	NA

^aBunkers refer to emissions, expressed in million metric tons of carbon, resulting from fuels consumed by ships and aircraft engaged in international transportation. Emissions from bunker fuels are shown with the country where the fuel loading occurred but are not included in the national total. NA = not available.

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Carbon Dioxide Emissions

Global, regional, and national CO₂ emissions

G. Marland, R.J. Andres, and T.A. Boden (continued)

FORMER GERMAN DEMOCRATIC REPUBLIC

National CO₂ Emission Estimates

Year	Emissions for the Former German Democratic Republic (million metric tons of carbon)						Per capita emissions (metric tons of carbon)	Bunkers ^a
	Total	Solid	Liquid	Gas	Cement	Gas flaring		
1950	43.5	43.3	0.0	0.0	0.2	0.0	2.36	NA
1951	47.6	47.2	0.2	0.0	0.2	0.0	2.59	NA
1952	50.4	49.7	0.4	0.0	0.3	0.0	2.75	NA
1953	55.8	55.1	0.4	0.0	0.3	0.0	3.07	NA
1954	58.7	57.8	0.6	0.0	0.4	0.0	3.25	NA
1955	63.2	62.4	0.4	0.0	0.4	0.0	3.52	NA
1956	64.8	63.7	0.7	0.0	0.4	0.0	3.64	NA
1957	67.0	65.6	0.8	0.0	0.5	0.0	3.80	NA
1958	68.2	67.0	0.7	0.0	0.5	0.0	3.90	NA
1959	68.8	67.5	0.7	0.0	0.6	0.0	3.97	NA
1960	71.9	70.3	0.9	0.0	0.7	0.0	4.17	NA
1961	75.7	73.8	1.1	0.0	0.7	0.0	4.41	NA
1962	79.3	77.1	1.4	0.0	0.7	0.0	4.64	NA
1963	81.6	79.0	1.8	0.0	0.7	0.0	4.78	NA
1964	84.1	80.8	2.5	0.0	0.8	0.0	4.94	NA
1965	82.6	78.7	3.0	0.0	0.8	0.0	4.85	NA
1966	83.1	78.2	3.9	0.0	0.9	0.0	4.88	NA
1967	80.8	75.6	4.2	0.0	1.0	0.0	4.74	NA
1968	81.8	75.6	5.1	0.1	1.0	0.0	4.80	NA
1969	85.6	78.2	6.3	0.1	1.0	0.0	5.02	NA
1970	73.8	65.0	7.4	0.3	1.1	0.0	4.33	NA
1971	75.1	65.7	7.8	0.5	1.2	0.0	4.41	NA
1972	74.5	62.6	9.8	0.9	1.2	0.0	4.38	NA
1973	75.6	62.1	10.5	1.6	1.3	0.0	4.46	NA
1974	75.6	61.1	10.5	2.7	1.4	0.0	4.48	NA
1975	75.9	60.7	11.1	2.8	1.4	0.0	4.51	NA
1976	77.9	61.3	12.0	3.0	1.5	0.0	4.63	NA
1977	79.9	62.0	13.2	3.0	1.6	0.0	4.76	NA
1978	80.7	62.2	14.0	2.9	1.7	0.0	4.82	NA
1979	82.4	62.9	14.9	3.0	1.7	0.0	4.92	NA
1980	83.7	63.1	15.3	3.6	1.7	0.0	5.00	NA
1981	84.0	63.2	15.1	4.0	1.7	0.0	5.02	NA
1982	84.1	64.2	14.5	3.9	1.6	0.0	5.03	NA
1983	83.5	64.3	13.4	4.2	1.6	0.0	5.00	NA
1984	86.0	67.1	13.2	4.2	1.6	0.0	5.15	NA
1985	90.2	71.4	13.4	3.9	1.6	0.0	5.42	NA
1986	91.1	72.1	13.1	4.3	1.6	0.0	5.50	NA
1987	91.0	72.3	12.8	4.3	1.7	0.0	5.52	NA
1988	88.9	70.2	12.8	4.2	1.7	0.0	5.42	NA
1989	88.0	68.8	13.5	4.1	1.7	0.0	5.40	NA
1990	82.0	63.2	13.7	3.7	1.4	0.0	5.05	NA

^aBunkers refer to emissions, expressed in million metric tons of carbon, resulting from fuels consumed by ships and aircraft engaged in international transportation. Emissions from bunker fuels are shown with the country where the fuel loading occurred but are not included in the national total. NA = not available.

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Global, regional, and national CO₂ emissions

G. Marland, R.J. Andres, and T.A. Boden (continued)

PRE-1991 FEDERAL REPUBLIC OF GERMANY

National CO₂ Emission Estimates

Year	Emissions for the Pre-1991 Federal Republic of Germany (million metric tons of carbon)						Per capita emissions (metric tons of carbon)	Bunkers ^a
	Total	Solid	Liquid	Gas	Cement	Gas flaring		
1950	94.9	91.3	2.0	0.0	1.5	0.0	1.90	1.4
1951	108.8	104.3	2.8	0.0	1.7	0.0	2.16	1.7
1952	115.4	110.4	3.2	0.0	1.8	0.0	2.27	1.8
1953	113.2	106.7	4.3	0.1	2.1	0.0	2.21	1.5
1954	120.1	111.7	6.1	0.1	2.3	0.0	2.32	1.7
1955	132.9	122.5	7.7	0.2	2.5	0.0	2.54	2.1
1956	143.0	130.2	9.9	0.3	2.6	0.0	2.70	2.4
1957	143.9	129.5	11.6	0.2	2.6	0.0	2.69	2.2
1958	136.7	119.5	14.3	0.3	2.7	0.0	2.53	1.9
1959	135.9	113.9	18.5	0.3	3.2	0.0	2.48	2.0
1960	148.6	121.1	23.8	0.3	3.4	0.0	2.68	2.3
1961	150.5	118.6	27.8	0.4	3.7	0.0	2.68	2.4
1962	159.9	120.8	34.8	0.5	3.9	0.0	2.81	2.6
1963	174.6	126.9	43.1	0.7	4.0	0.0	3.03	2.6
1964	178.3	123.4	49.4	1.0	4.6	0.0	3.05	3.1
1965	177.5	115.0	56.4	1.5	4.6	0.0	3.01	3.4
1966	174.6	105.4	62.8	1.8	4.7	0.0	2.94	3.8
1967	172.8	100.9	65.3	2.4	4.3	0.0	2.89	3.4
1968	184.9	102.3	74.2	3.9	4.5	0.0	3.07	3.7
1969	199.4	106.9	82.2	5.5	4.8	0.0	3.30	4.0
1970	200.8	98.0	89.8	7.8	5.2	0.0	3.31	4.8
1971	202.5	93.2	93.2	10.4	5.6	0.0	3.32	5.0
1972	204.1	86.9	97.9	13.5	5.9	0.0	3.33	5.3
1973	213.8	89.6	101.8	16.8	5.6	0.0	3.48	5.2
1974	206.5	91.6	89.7	20.3	4.9	0.0	3.35	4.7
1975	190.3	78.3	86.1	21.3	4.6	0.0	3.08	4.3
1976	211.4	88.6	95.5	22.4	4.8	0.0	3.42	4.4
1977	198.9	77.2	93.7	23.5	4.5	0.0	3.22	4.6
1978	204.7	79.0	95.2	25.8	4.8	0.0	3.31	4.5
1979	215.1	85.2	97.0	27.8	5.0	0.0	3.49	4.6
1980	207.9	85.5	90.0	27.8	4.6	0.0	3.38	4.6
1981	193.6	87.1	76.6	25.7	4.3	0.0	3.15	4.9
1982	184.5	84.1	72.3	23.9	4.1	0.0	3.01	4.4
1983	183.4	84.8	70.0	24.5	4.1	0.0	3.00	4.3
1984	187.0	87.0	70.6	25.5	3.9	0.0	3.06	4.2
1985	184.6	84.6	71.4	25.2	3.5	0.0	3.03	5.0
1986	185.0	82.4	75.8	23.2	3.6	0.0	3.03	6.0
1987	180.9	78.5	73.1	25.4	3.4	0.4	2.96	5.4
1988	182.9	78.6	75.0	25.3	3.6	0.3	2.99	5.1
1989	179.2	78.3	68.0	28.8	3.9	0.2	2.92	5.0
1990	183.9	79.0	70.4	30.0	4.1	0.3	3.00	5.0

^aBunkers refer to emissions, expressed in million metric tons of carbon, resulting from fuels consumed by ships and aircraft engaged in international transportation. Emissions from bunker fuels are shown with the country where the fuel loading occurred but are not included in the national total.

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INDIA

Trends

India has recently experienced dramatic growth in CO₂ emissions, which have increased 5.9% per year since 1950 as India has climbed from 13th to 6th place as a national contributor. Total emissions increased by 10.4 times over this interval, and per capita emissions increased almost 4 times. Emissions in India continue to result largely from coal burning. Coal contributed 87% of the emissions in 1950 and 71% in 1991; at the same time, the oil fraction increased from 11% to 22%. Indian emissions data reveal little impact from the oil price increases that affected emissions in the United States and western Europe so dramatically in the late 1970s and early 1980s. Per capita emissions in 1991 were ~4% of the U.S. value.

CO₂ emissions from India. Per capita CO₂ emission estimates for India.

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Carbon Dioxide Emissions
Global, regional, and national CO₂ emissions

G. Marland, R.J. Andres, and T.A. Boden (continued)

INDIA

National CO₂ Emission Estimates

Year	Emissions for India (million metric tons of carbon)						Per capita emissions (metric tons of carbon)	Bunkers ^a
	Total	Solid	Liquid	Gas	Cement	Gas flaring		
1950	18.4	16.0	2.0	0.0	0.4	0.0	0.05	0.2
1951	19.2	16.6	2.1	0.0	0.4	0.0	0.05	0.2
1952	20.3	17.7	2.1	0.0	0.5	0.0	0.05	0.3
1953	20.6	18.0	2.1	0.0	0.5	0.0	0.05	0.2
1954	21.7	18.5	2.6	0.0	0.6	0.0	0.06	0.3
1955	23.5	19.4	3.5	0.0	0.6	0.0	0.06	0.3
1956	24.4	19.9	3.8	0.0	0.7	0.0	0.06	0.3
1957	27.3	22.2	4.3	0.0	0.8	0.0	0.07	0.5
1958	28.6	23.1	4.6	0.0	0.8	0.0	0.07	0.4
1959	30.2	24.3	5.0	0.0	0.9	0.0	0.07	0.4
1960	33.2	26.8	5.3	0.0	1.1	0.0	0.08	0.4
1961	35.9	29.0	5.8	0.0	1.1	0.0	0.08	0.4
1962	39.5	31.5	6.8	0.0	1.2	0.0	0.09	0.4
1963	42.4	33.7	7.4	0.0	1.3	0.0	0.09	0.4
1964	41.4	32.3	7.7	0.0	1.3	0.1	0.09	0.5
1965	45.6	35.5	8.4	0.1	1.4	0.2	0.09	0.5
1966	47.2	35.7	9.7	0.1	1.5	0.2	0.09	0.5
1967	47.4	36.3	8.9	0.1	1.6	0.4	0.09	0.6
1968	51.5	37.7	11.5	0.2	1.6	0.4	0.10	0.6
1969	52.4	37.6	12.4	0.3	1.8	0.3	0.10	0.5
1970	53.3	37.7	13.1	0.3	1.8	0.4	0.10	0.5
1971	56.2	38.7	14.7	0.3	2.0	0.4	0.10	0.5
1972	59.4	41.0	15.6	0.3	2.1	0.3	0.10	0.4
1973	61.1	42.0	16.4	0.3	2.0	0.4	0.10	0.5
1974	63.6	44.4	16.4	0.4	1.9	0.5	0.10	0.4
1975	69.1	49.2	16.7	0.5	2.2	0.5	0.11	0.5
1976	72.2	51.5	17.1	0.6	2.5	0.5	0.11	0.5
1977	86.5	64.2	18.4	0.7	2.6	0.6	0.13	0.6
1978	87.0	62.9	20.2	0.7	2.7	0.5	0.13	0.6
1979	90.8	64.8	22.2	0.8	2.5	0.6	0.13	0.6
1980	95.5	69.7	22.4	0.7	2.4	0.3	0.14	0.7
1981	102.7	74.0	24.1	0.8	2.8	0.9	0.15	0.5
1982	109.2	78.4	25.5	1.2	3.1	1.0	0.15	0.4
1983	118.5	85.7	26.7	1.4	3.4	1.2	0.16	0.5
1984	122.5	86.8	28.6	1.7	3.9	1.4	0.16	0.6
1985	134.3	94.8	31.4	2.0	4.5	1.6	0.18	0.5
1986	143.6	101.5	32.9	2.8	5.0	1.4	0.18	0.6
1987	152.1	108.5	33.7	3.2	5.0	1.7	0.19	0.7
1988	163.8	117.4	35.3	3.5	5.5	2.0	0.20	0.9
1989	178.5	126.0	39.3	4.2	6.3	2.6	0.22	0.8
1990	184.2	130.1	39.6	5.2	6.7	2.7	0.22	0.7
1991	192.0	135.5	41.4	5.3	6.8	3.0	0.22	0.7

^aBunkers refer to emissions, expressed in million metric tons of carbon, resulting from fuels consumed by ships and aircraft engaged in international transportation. Emissions from bunker fuels are shown with the country where the fuel loading occurred but are not included in the national total.

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UNITED KINGDOM

Trends

Carbon dioxide emissions in the United Kingdom have been virtually constant for the last 7 years and have remained well below the 1973 and 1979 peaks. Emissions declined 18% from 1979 to 1984. After at least 23 years of increases in emissions from liquid fuels and generally declining emissions from coal burning, emissions from both fuels began to decline simultaneously in 1974. Emissions from natural gas grew rapidly in the late 1960s and early 1970s before leveling off in the mid-1980s. Natural-gas burning now accounts for nearly 17% of total emissions of CO₂. Total emissions were only 14% higher in 1991 than in 1950; the increase was by far the smallest increase among the top 20 nations. During the 41-year interval, the United Kingdom dropped from third to seventh in rank among CO₂-emitting nations.

CO₂ emissions from the United Kingdom.

Per capita CO₂ emission estimates for the United Kingdom.

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Global, regional, and national CO₂ emissions

G. Marland, R.J. Andres, and T.A. Boden (continued)

UNITED KINGDOM

National CO₂ Emission Estimates

Year	Emissions for the United Kingdom (million metric tons of carbon)						Per capita emissions (metric tons of carbon)	Bunkers ^a
	Total	Solid	Liquid	Gas	Cement	Gas flaring		
1950	138.0	125.3	11.4	0.0	1.3	0.0	2.72	5.2
1951	150.3	134.2	14.6	0.0	1.4	0.0	2.96	5.8
1952	145.7	129.7	14.5	0.0	1.5	0.0	2.86	6.0
1953	148.9	132.1	15.3	0.0	1.6	0.0	2.92	5.8
1954	152.4	133.6	17.1	0.0	1.7	0.0	2.98	6.1
1955	159.0	138.0	19.2	0.0	1.7	0.0	3.10	6.2
1956	158.2	136.6	19.8	0.0	1.8	0.0	3.07	5.6
1957	157.2	133.2	22.3	0.0	1.7	0.0	3.04	4.7
1958	153.2	126.7	24.9	0.0	1.6	0.0	2.95	4.8
1959	150.5	117.5	31.2	0.0	1.7	0.0	2.88	4.8
1960	160.8	123.7	35.2	0.0	1.8	0.0	3.06	5.2
1961	162.0	122.3	37.7	0.0	2.0	0.0	3.06	4.9
1962	163.2	120.7	40.5	0.1	1.9	0.0	3.06	4.6
1963	166.1	121.3	42.8	0.1	1.9	0.0	3.09	4.5
1964	167.3	117.7	47.2	0.1	2.3	0.0	3.09	4.5
1965	171.2	116.6	51.8	0.5	2.3	0.0	3.14	4.8
1966	170.0	111.4	55.9	0.5	2.3	0.0	3.10	4.6
1967	162.8	101.7	57.9	0.8	2.4	0.0	2.95	4.8
1968	166.8	102.2	60.3	1.7	2.4	0.1	3.01	5.1
1969	172.8	101.6	65.0	3.3	2.4	0.4	3.11	5.4
1970	175.4	97.4	68.6	6.3	2.3	0.8	3.14	6.2
1971	176.1	91.6	71.0	10.2	2.4	0.9	3.15	6.5
1972	172.2	77.8	76.5	14.4	2.5	1.1	3.07	6.3
1973	178.1	81.7	76.8	15.6	2.7	1.3	3.17	6.7
1974	167.2	72.7	72.0	18.6	2.4	1.5	2.97	6.0
1975	164.1	76.3	64.4	19.5	2.3	1.6	2.91	5.0
1976	163.0	75.9	63.1	20.2	2.1	1.6	2.89	5.2
1977	164.6	74.9	64.3	21.6	2.1	1.7	2.91	4.6
1978	165.7	73.5	65.4	22.2	2.2	2.3	2.93	4.7
1979	175.6	78.7	66.9	24.3	2.2	3.4	3.11	4.8
1980	160.6	74.4	57.8	24.1	2.0	2.2	2.84	4.5
1981	151.5	72.3	50.9	24.5	1.7	2.2	2.68	4.0
1982	151.5	69.6	52.6	25.5	1.8	2.0	2.68	4.4
1983	151.2	70.2	50.7	26.5	1.8	2.0	2.67	4.1
1984	143.9	48.5	64.5	27.2	1.8	1.8	2.54	4.4
1985	153.3	64.7	55.9	29.5	1.8	1.4	2.70	4.5
1986	155.9	68.1	55.4	29.5	1.8	1.0	2.74	4.7
1987	157.0	71.0	53.6	29.3	1.9	1.1	2.75	4.6
1988	157.0	68.1	56.7	28.9	2.2	1.1	2.74	4.9
1989	159.3	69.8	57.5	28.6	2.3	1.1	2.77	5.5
1990	156.5	66.3	57.9	29.4	1.9	1.1	2.72	5.7
1991	157.5	68.6	59.0	27.2	1.6	1.1	2.73	5.2

^aBunkers refer to emissions, expressed in million metric tons of carbon, resulting from fuels consumed by ships and aircraft engaged in international transportation. Emissions from bunker fuels are shown with the country where the fuel loading occurred but are not included in the national total.

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CANADA

Trends

Driven by a 6.5% per year increase in emissions from liquid fuels, total CO₂ emissions from Canada increased by a factor of 2.4 from 1950 to 1974. Continuing growth until 1980 was maintained by continuing expansion of natural gas consumption and an upturn in coal consumption. The post-1980 drop was comparable to that observed in the United States, and the pattern from 1980 to 1987 was erratic but essentially at a constant level. During the last two years, emissions have decreased 7% after peaking in 1989 at 120.7 million metric tons of carbon. Emissions from coal burning comprised 63% of the total in 1950 but declined in both absolute and relative terms until 1974. Since emissions from liquid fuels turned down in 1974, emissions from coal have turned back up, growing at an average rate of almost 4% per year. In 1991, coal contributed 23% of total emissions, barely half of the liquid fuel contribution and less than natural gas. Per capita CO₂ emissions from Canada peaked in 1979 at 4.9 metric tons of carbon per capita, a value exceeded only by the United States among the major CO₂-emitting nations.

Carbon Dioxide Emissions
Global, regional, and national CO₂ emissions

G. Marland, R.J. Andres, and T.A. Boden (continued)

CANADA

CO₂ emissions from Canada.

Per capita CO₂ emission estimates for Canada.

CITE AS: Marland, G., R.J. Andres, and T.A. Boden. 1994. Global, regional, and national CO₂ emissions. pp. 505-584. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Carbon Dioxide Emissions

Global, regional, and national CO₂ emissions

G. Marland, R.J. Andres, and T.A. Boden (continued)

CANADA

National CO₂ Emission Estimates

Year	Emissions for Canada (million metric tons of carbon)						Per capita emissions (metric tons of carbon)	Bunkers ^a
	Total	Solid	Liquid	Gas	Cement	Gas flaring		
1950	42.3	26.6	14.3	1.0	0.4	0.0	3.08	1.2
1951	44.6	26.7	16.5	1.1	0.4	0.0	3.16	1.3
1952	43.7	24.7	17.4	1.2	0.4	0.0	3.02	1.4
1953	44.0	22.8	19.1	1.3	0.5	0.3	2.96	1.5
1954	44.7	22.0	20.5	1.6	0.5	0.0	2.92	1.3
1955	46.4	19.9	23.4	2.0	0.5	0.6	2.95	1.5
1956	52.0	21.6	26.5	2.3	0.6	0.9	3.21	1.5
1957	50.0	17.9	27.3	3.0	0.7	1.1	3.01	1.8
1958	49.8	15.7	28.5	3.7	0.8	1.1	2.92	1.5
1959	50.5	14.7	29.4	4.7	0.8	0.9	2.88	1.8
1960	52.7	13.6	31.6	5.9	0.7	0.9	2.94	1.9
1961	53.0	12.5	32.4	6.3	0.8	1.1	2.90	1.9
1962	56.6	12.9	34.5	7.1	0.8	1.3	3.03	2.0
1963	57.7	12.8	36.6	6.1	0.9	1.2	3.03	2.2
1964	64.9	14.3	39.2	9.3	1.0	1.2	3.36	2.2
1965	68.9	14.9	41.4	10.4	1.0	1.1	3.50	2.5
1966	70.1	14.4	41.9	11.6	1.1	1.2	3.50	2.7
1967	77.0	15.7	46.8	12.3	1.0	1.1	3.78	2.7
1968	81.7	16.6	48.9	14.0	1.0	1.2	3.95	3.0
1969	83.7	16.2	49.3	15.9	1.0	1.2	3.98	3.1
1970	90.6	16.1	55.1	17.1	1.0	1.3	4.25	2.8
1971	93.5	15.3	57.4	18.4	1.1	1.2	4.32	2.6
1972	101.2	17.0	60.9	20.9	1.2	1.2	4.62	2.9
1973	101.7	14.2	62.6	22.3	1.4	1.2	4.58	3.2
1974	103.1	13.2	64.7	22.8	1.4	1.0	4.59	2.9
1975	105.8	16.7	63.5	23.4	1.4	0.7	4.65	2.4
1976	106.8	16.1	64.6	24.1	1.3	0.7	4.64	2.3
1977	109.7	17.7	65.0	25.1	1.3	0.6	4.71	2.3
1978	111.6	18.3	65.6	25.6	1.4	0.7	4.74	2.6
1979	117.2	19.6	68.9	26.3	1.6	0.8	4.92	2.0
1980	117.4	21.3	67.4	26.4	1.4	0.9	4.88	1.9
1981	113.8	22.1	63.7	25.8	1.4	0.8	4.68	1.3
1982	109.1	23.3	57.6	26.2	1.1	0.8	4.45	1.1
1983	107.4	24.9	53.7	27.0	1.1	0.8	4.35	1.0
1984	111.1	27.2	52.7	28.8	1.2	1.2	4.45	0.9
1985	109.4	26.8	49.8	30.1	1.4	1.4	4.35	0.8
1986	106.8	24.8	50.2	29.0	1.4	1.3	4.20	0.8
1987	109.7	26.1	51.0	29.6	1.7	1.3	4.27	1.0
1988	116.9	27.9	53.4	32.5	1.6	1.4	4.50	1.1
1989	120.7	27.9	55.0	35.0	1.6	1.3	4.59	1.3
1990	114.3	24.6	52.8	34.1	1.6	1.2	4.29	1.3
1991	112.1	25.8	48.6	34.9	1.5	1.2	4.15	1.2

^aBunkers refer to emissions, expressed in million metric tons of carbon, resulting from fuels consumed by ships and aircraft engaged in international transportation. Emissions from bunker fuels are shown with the country where the fuel loading occurred but are not included in the national total.

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Carbon Dioxide Emissions

Global, regional, and national CO₂ emissions

G. Marland, R.J. Andres, and T.A. Boden (continued)

ITALY

Trends

As occurred in many industrialized nations, CO₂ emissions from Italy rose steeply from 1950 until the growth was abruptly terminated in 1974. Since 1974, emissions from liquid fuels have vacillated but generally declined, dropping from 75% to 58% of a static but varying total. Emissions have now risen for five successive years, and 1991 marks a new high. Significant increases in natural gas consumption have compensated for the drop in oil consumption. Coal usage was virtually constant from 1950 to 1974, and it has stabilized, though at a higher level, since 1984. Per capita CO₂ emissions grew rapidly from 1950 to 1974, increasing by a factor of nearly 8, but have been nearly constant since 1974.

CO₂ emissions from Italy.

Per capita CO₂ emission estimates for Italy.

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Carbon Dioxide Emissions

Global, regional, and national CO₂ emissions

G. Marland, R.J. Andres, and T.A. Boden (continued)

ITALY

National CO₂ Emission Estimates

Year	Emissions for Italy (million metric tons of carbon)						Per capita emissions (metric tons of carbon)	Bunkers ^a
	Total	Solid	Liquid	Gas	Cement	Gas flaring		
1950	11.4	6.8	3.7	0.3	0.7	0.0	0.24	NA
1951	13.4	7.6	4.5	0.5	0.8	0.0	0.28	NA
1952	13.9	7.2	5.1	0.7	0.9	0.0	0.29	NA
1953	15.4	7.4	5.8	1.2	1.1	0.0	0.32	NA
1954	17.9	7.7	7.4	1.5	1.2	0.0	0.37	NA
1955	20.1	8.0	8.8	1.9	1.4	0.0	0.41	NA
1956	22.9	8.6	10.6	2.3	1.5	0.0	0.47	NA
1957	23.9	8.2	11.5	2.6	1.6	0.0	0.49	NA
1958	24.1	7.4	12.2	2.6	1.7	0.0	0.49	NA
1959	25.8	7.2	13.6	3.1	2.0	0.0	0.52	NA
1960	30.1	7.7	17.0	3.3	2.2	0.0	0.60	NA
1961	34.2	8.3	20.0	3.5	2.5	0.0	0.68	NA
1962	40.2	8.8	25.1	3.7	2.7	0.0	0.79	NA
1963	45.2	9.0	29.5	3.7	3.0	0.0	0.88	NA
1964	48.3	7.7	33.6	3.9	3.1	0.0	0.93	NA
1965	51.8	8.4	36.6	4.0	2.8	0.0	0.99	NA
1966	58.3	8.7	42.2	4.3	3.0	0.0	1.11	NA
1967	64.8	9.7	46.8	4.7	3.6	0.0	1.23	NA
1968	69.2	9.0	50.7	5.5	4.0	0.0	1.30	NA
1969	74.4	9.1	55.0	6.1	4.3	0.0	1.39	NA
1970	78.0	9.1	58.4	6.0	4.5	0.0	1.45	NA
1971	80.9	8.5	61.3	6.8	4.3	0.0	1.49	NA
1972	84.9	8.0	64.4	7.9	4.6	0.0	1.56	NA
1973	92.0	8.1	70.0	8.9	4.9	0.0	1.68	NA
1974	93.5	8.7	69.9	10.0	4.9	0.0	1.70	NA
1975	88.6	8.4	64.1	11.4	4.7	0.0	1.60	NA
1976	96.2	8.5	68.9	13.8	4.9	0.0	1.73	NA
1977	93.6	8.6	66.3	13.6	5.2	0.0	1.67	NA
1978	98.0	9.2	69.5	14.2	5.2	0.0	1.75	NA
1979	102.8	10.5	73.1	13.8	5.3	0.0	1.83	NA
1980	101.6	11.7	70.0	14.2	5.7	0.0	1.80	NA
1981	99.8	12.5	67.9	13.7	5.7	0.0	1.76	NA
1982	96.8	13.2	63.8	14.4	5.4	0.0	1.71	NA
1983	93.6	11.6	62.6	14.0	5.3	0.0	1.64	NA
1984	95.7	14.5	59.5	16.6	5.1	0.0	1.68	NA
1985	97.7	15.8	59.8	17.0	5.0	0.0	1.71	NA
1986	95.1	14.2	59.8	16.2	4.9	0.0	1.66	NA
1987	99.3	14.9	61.3	18.0	5.1	0.0	1.73	NA
1988	101.5	14.6	62.6	19.2	5.2	0.0	1.76	NA
1989	106.7	14.3	66.0	21.0	5.4	0.0	1.85	NA
1990	108.1	14.1	63.8	24.8	5.4	0.0	1.87	NA
1991	109.9	13.8	64.0	26.6	5.4	0.0	1.90	NA

^aBunkers refer to emissions, expressed in million metric tons of carbon, resulting from fuels consumed by ships and aircraft engaged in international transportation. Emissions from bunker fuels are shown with the country where the fuel loading occurred but are not included in the national total. NA = not available.

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FRANCE

Trends

The CO₂ emissions history of France is striking in that emissions have declined since 1973 and particularly since 1979. The country's total since 1973 is virtually a reflection of the decrease in liquid fuel use, although a late-1970s bulge in emissions from solid fuels and the continuing increased use of natural gas pushed the 1979 value above the 1973 total. CO₂ emissions in 1950 were 83% from coal, but coal use declined steadily from 1963 to 1975, and even the late-1970s bulge appears to have been a temporary reaction to world oil price increases. By 1991, only 22% of emissions were from coal, and natural gas crept upward toward 17%. France made a major commitment to nuclear power, and nuclear power generation grew rapidly from ca. 1975 until it contributed 76% of total electricity generation in 1987. France is a net exporter of electricity. Extensive use of nuclear power has clearly curtailed fossil fuel-related CO₂ emissions from France; per capita emissions declined steadily from the 1973 and 1977 maxima. CO₂ emissions in 1991 were 25% less than the 1979 maximum.

FRANCE

CO₂ emissions from France.

Per capita CO₂ emission estimates for France.

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Carbon Dioxide Emissions

Global, regional, and national CO₂ emissions

G. Marland, R.J. Andres, and T.A. Boden (continued)

FRANCE

National CO₂ Emission Estimates

Year	Emissions for France (million metric tons of carbon)						Per capita emissions (metric tons of carbon)	Bunkers ^a
	Total	Solid	Liquid	Gas	Cement	Gas flaring		
1950	55.7	46.1	8.6	0.1	1.0	0.0	1.33	1.0
1951	63.0	51.6	10.2	0.2	1.1	0.0	1.50	1.5
1952	62.5	50.2	11.0	0.2	1.2	0.0	1.48	1.6
1953	59.1	46.0	11.7	0.1	1.3	0.0	1.38	1.5
1954	62.3	47.5	13.3	0.2	1.3	0.0	1.45	1.5
1955	65.8	49.5	14.7	0.2	1.4	0.0	1.52	1.6
1956	73.9	55.7	16.5	0.2	1.6	0.0	1.69	1.8
1957	76.4	57.3	17.1	0.3	1.7	0.0	1.73	1.5
1958	73.3	52.7	18.4	0.4	1.8	0.0	1.64	1.8
1959	72.2	49.8	19.8	0.8	1.9	0.0	1.60	1.5
1960	74.8	49.9	21.4	1.6	1.9	0.0	1.64	1.6
1961	77.7	50.1	23.3	2.2	2.1	0.0	1.68	1.8
1962	82.5	51.4	26.2	2.5	2.3	0.0	1.76	2.0
1963	92.2	54.5	32.6	2.6	2.5	0.0	1.94	1.9
1964	95.3	52.5	37.1	2.7	2.9	0.0	1.98	2.0
1965	97.1	49.2	42.1	2.7	3.0	0.0	1.99	2.0
1966	95.7	45.4	44.2	2.9	3.2	0.0	1.94	2.2
1967	102.3	44.7	51.1	3.3	3.3	0.0	2.06	2.6
1968	105.7	42.8	55.6	3.9	3.5	0.0	2.11	2.9
1969	113.6	42.9	62.5	4.5	3.7	0.0	2.25	3.4
1970	116.2	40.3	66.8	5.1	3.9	0.0	2.29	4.3
1971	122.1	36.7	73.9	6.1	3.9	1.5	2.39	4.5
1972	126.8	32.4	81.7	7.2	4.1	1.4	2.46	5.3
1973	135.5	31.9	89.6	8.5	4.2	1.4	2.61	6.1
1974	130.8	31.9	84.3	8.8	4.4	1.3	2.50	5.5
1975	118.2	28.0	75.1	9.8	4.0	1.2	2.24	5.4
1976	132.3	33.0	83.4	10.6	4.0	1.3	2.50	5.9
1977	125.2	32.2	76.8	11.0	3.9	1.3	2.35	6.1
1978	132.2	33.4	81.6	12.0	3.8	1.3	2.47	5.6
1979	136.9	36.3	82.4	13.2	3.9	1.0	2.55	5.9
1980	132.1	36.3	77.7	13.4	4.0	0.8	2.45	5.0
1981	120.5	33.2	69.2	13.7	3.8	0.5	2.23	4.8
1982	114.4	33.2	64.2	13.2	3.6	0.3	2.11	4.2
1983	108.7	30.1	60.8	14.5	3.3	0.0	1.99	3.8
1984	104.7	28.6	58.4	14.6	3.1	0.0	1.91	3.6
1985	103.3	27.8	57.0	15.2	3.2	0.0	1.87	3.9
1986	98.2	23.0	56.7	15.2	3.2	0.0	1.77	3.9
1987	95.4	21.2	56.6	14.4	3.2	0.0	1.71	4.5
1988	87.8	15.3	54.8	14.3	3.4	0.0	1.56	4.7
1989	96.2	20.1	57.7	14.7	3.6	0.0	1.70	4.3
1990	96.6	21.1	56.9	15.1	3.6	0.0	1.70	5.4
1991	102.1	22.1	59.5	17.0	3.5	0.0	1.79	4.7

^aBunkers refer to emissions, expressed in million metric tons of carbon, resulting from fuels consumed by ships and aircraft engaged in international transportation. Emissions from bunker fuels are shown with the country where the fuel loading occurred but are not included in the national total.

CITE AS: Marland, G., R.J. Andres, and T.A. Boden. 1994. Global, regional, and national CO₂ emissions. pp. 505–584. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Global, regional, and national CO₂ emissions

G. Marland, R.J. Andres, and T.A. Boden (continued)

MEXICO

Trends

Carbon dioxide emissions from Mexico grew exponentially at a rate of 7.6% per year from 1950 to 1982. From 1983 to 1988, total emissions declined slightly and leveled off near 80 million metric tons of carbon. From 1989 to 1991, total emissions rose 9.8% and reached an all-time high of 92.8 million metric tons of carbon in 1991. Emissions growth was largely based on increasing oil production; even in 1991, 74% of emissions were from petroleum products, the highest fraction of any of the major CO₂-emitting countries. Per capita emissions also peaked in 1982. The impact of the oil price dislocations of the late 1970s and early 1980s is also reflected in a 72% decrease in emissions from gas flaring after 1982. Consumption of natural gas has become increasingly important in Mexico and now accounts for 15% of CO₂ emissions.

CO₂ emissions from Mexico. Per capita CO₂ emission estimates for Mexico.

CITE AS: Marland, G., R.J. Andres, and T.A. Boden. 1994. Global, regional, and national CO₂ emissions. pp. 505-584. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Global, regional, and national CO₂ emissions

G. Marland, R.J. Andres, and T.A. Boden (continued)

MEXICO

National CO₂ Emission Estimates

Year	Emissions for Mexico (million metric tons of carbon)						Per capita emissions (metric tons of carbon)	Bunkers ^a
	Total	Solid	Liquid	Gas	Cement	Gas flaring		
1950	8.3	0.5	6.5	0.4	0.2	0.7	0.31	NA
1951	9.5	0.6	7.3	0.5	0.2	1.0	0.34	NA
1952	10.2	0.7	7.7	0.5	0.2	1.0	0.35	NA
1953	10.0	0.8	7.5	0.6	0.2	1.0	0.34	NA
1954	9.9	0.7	7.3	0.6	0.2	1.0	0.33	NA
1955	10.8	0.7	7.9	0.6	0.3	1.3	0.35	NA
1956	11.5	0.8	8.5	0.7	0.3	1.2	0.36	NA
1957	13.5	0.8	10.0	0.7	0.3	1.7	0.40	NA
1958	14.8	0.8	10.3	1.3	0.3	2.0	0.43	NA
1959	15.9	0.9	10.9	1.4	0.4	2.4	0.45	NA
1960	17.2	1.0	11.7	1.7	0.4	2.4	0.47	NA
1961	17.8	1.0	12.3	2.2	0.4	2.0	0.47	NA
1962	17.4	1.0	11.5	3.2	0.5	1.2	0.45	NA
1963	18.1	1.1	11.7	3.2	0.5	1.6	0.45	NA
1964	20.3	1.2	12.7	3.7	0.6	2.1	0.49	NA
1965	20.5	1.1	12.9	4.3	0.6	1.6	0.48	NA
1966	22.1	1.2	13.7	4.6	0.7	1.8	0.50	NA
1967	24.6	1.4	15.4	5.4	0.8	1.6	0.54	NA
1968	25.6	1.6	16.2	5.4	0.8	1.6	0.54	NA
1969	27.9	1.7	18.3	5.3	0.9	1.7	0.57	NA
1970	28.9	1.9	17.8	5.6	1.0	2.6	0.57	NA
1971	31.1	2.1	19.7	5.5	1.0	2.8	0.60	NA
1972	32.5	2.2	20.6	6.2	1.2	2.3	0.61	NA
1973	35.3	2.5	22.6	6.9	1.3	2.0	0.64	NA
1974	39.5	3.0	25.1	7.2	1.4	2.7	0.69	NA
1975	40.7	3.1	26.0	7.1	1.6	2.9	0.69	NA
1976	47.5	3.2	32.4	7.1	1.7	3.1	0.78	NA
1977	49.3	3.4	34.5	7.7	1.8	1.9	0.79	NA
1978	57.6	3.9	39.4	9.5	1.9	2.9	0.90	NA
1979	62.5	4.3	42.6	11.2	2.1	2.3	0.96	NA
1980	71.0	4.3	49.4	12.4	2.2	2.7	1.06	NA
1981	77.1	4.6	54.5	12.3	2.4	3.2	1.12	NA
1982	86.9	4.5	54.5	20.6	2.6	4.7	1.23	NA
1983	79.7	5.0	50.9	18.4	2.3	3.1	1.11	NA
1984	77.3	5.1	53.5	14.2	2.5	2.0	1.05	NA
1985	78.4	5.6	53.9	14.4	2.8	1.7	1.04	NA
1986	78.3	5.5	55.7	13.2	2.7	1.1	1.01	NA
1987	81.9	5.7	58.6	13.3	3.0	1.2	1.04	NA
1988	80.7	5.6	58.6	12.7	3.1	0.8	1.00	NA
1989	84.5	5.5	62.8	12.3	3.1	0.7	1.02	NA
1990	88.7	5.5	64.9	13.1	3.3	1.9	1.05	NA
1991	92.8	5.7	68.5	13.6	3.6	1.3	1.07	NA

^aBunkers refer to emissions, expressed in million metric tons of carbon, resulting from fuels consumed by ships and aircraft engaged in international transportation. Emissions from bunker fuels are shown with the country where the fuel loading occurred but are not included in the national total. NA = not available.

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POLAND

Trends

Carbon dioxide emissions from Poland climbed at a remarkably steady rate of 4.8% per year until 1980, when they dropped abruptly (11.6%). CO₂ emissions crept back up throughout the 1980s, and in 1987 they exceeded the previous high in 1980. Since the 1987 high, CO₂ emissions have plummeted 34% to early 1970s levels while per capita emissions have dropped to mid-1960s levels. Emissions are predominantly from coal burning: 97% in 1950 and 82% in 1991. The drop following 1980 is apparent in rates of liquid fuel burning, but it occurred predominantly in coal consumption.

CO₂ emissions from Poland.

Per capita CO₂ emission estimates for Poland.

CITE AS: Marland, G., R.J. Andres, and T.A. Boden. 1994. Global, regional, and national CO₂ emissions. pp. 505-584. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Global, regional, and national CO₂ emissions

G. Marland, R.J. Andres, and T.A. Boden (continued)

POLAND

National CO₂ Emission Estimates

Year	Emissions for Poland (million metric tons of carbon)						Per capita emissions (metric tons of carbon)	Bunkers ^a
	Total	Solid	Liquid	Gas	Cement	Gas flaring		
1950	31.0	30.1	0.4	0.1	0.3	0.0	1.25	NA
1951	33.7	32.7	0.4	0.2	0.4	0.0	1.33	NA
1952	35.3	34.3	0.5	0.2	0.4	0.0	1.37	NA
1953	38.4	37.2	0.6	0.2	0.4	0.0	1.46	NA
1954	40.7	39.2	0.9	0.2	0.5	0.0	1.52	0.2
1955	42.6	40.8	1.0	0.3	0.5	0.0	1.56	0.1
1956	45.9	44.0	1.1	0.3	0.5	0.0	1.65	0.1
1957	49.3	47.2	1.2	0.3	0.6	0.0	1.75	0.1
1958	48.8	46.5	1.3	0.3	0.7	0.0	1.70	0.1
1959	52.3	49.8	1.5	0.3	0.7	0.0	1.80	0.1
1960	55.0	52.1	1.6	0.4	0.9	0.0	1.86	0.1
1961	57.2	53.7	1.9	0.5	1.0	0.0	1.91	0.1
1962	59.7	55.8	2.3	0.6	1.0	0.0	1.96	0.1
1963	63.6	59.4	2.6	0.6	1.0	0.0	2.06	0.1
1964	66.9	61.9	3.1	0.7	1.2	0.0	2.14	0.1
1965	68.0	62.1	3.7	0.9	1.3	0.0	2.16	0.1
1966	69.4	63.0	4.1	1.0	1.4	0.0	2.19	0.1
1967	71.2	64.0	4.4	1.3	1.5	0.0	2.23	0.1
1968	75.8	67.2	5.3	1.7	1.6	0.0	2.36	0.1
1969	80.6	71.0	5.7	2.4	1.6	0.0	2.49	0.1
1970	82.8	71.9	6.2	3.0	1.7	0.0	2.55	0.1
1971	85.2	73.7	6.6	3.1	1.8	0.0	2.60	0.1
1972	89.7	77.3	7.3	3.2	1.9	0.0	2.71	0.1
1973	91.1	77.3	8.3	3.4	2.1	0.0	2.73	0.1
1974	93.9	79.5	8.8	3.5	2.3	0.0	2.79	0.1
1975	101.8	85.3	10.0	4.0	2.5	0.0	2.99	0.1
1976	108.2	90.0	11.0	4.4	2.7	0.0	3.15	0.1
1977	113.6	94.1	12.1	4.5	2.9	0.0	3.28	0.1
1978	117.6	97.7	12.4	4.5	3.0	0.0	3.36	0.1
1979	120.5	99.7	13.3	4.9	2.6	0.0	3.42	0.0
1980	125.4	104.9	13.2	4.9	2.5	0.0	3.53	0.0
1981	110.8	92.6	11.5	4.8	1.9	0.0	3.09	0.0
1982	114.2	96.3	10.8	4.8	2.2	0.0	3.15	0.0
1983	114.4	96.5	10.7	5.0	2.2	0.0	3.13	0.0
1984	119.3	100.9	11.0	5.1	2.3	0.0	3.23	0.0
1985	122.4	104.2	11.3	4.9	2.0	0.0	3.29	0.0
1986	124.4	105.3	11.6	5.3	2.1	0.0	3.32	0.0
1987	127.8	108.6	11.5	5.5	2.2	0.0	3.39	0.0
1988	122.3	103.6	10.9	5.4	2.3	0.0	3.23	1.3
1989	116.1	97.7	10.7	5.3	2.3	0.0	3.05	1.2
1990	95.2	79.0	9.5	5.0	1.7	0.0	2.49	0.4
1991	84.1	68.6	9.5	4.4	1.6	0.0	2.20	0.2

^aBunkers refer to emissions, expressed in million metric tons of carbon, resulting from fuels consumed by ships and aircraft engaged in international transportation. Emissions from bunker fuels are shown with the country where the fuel loading occurred but are not included in the national total. NA = not available.

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Global, regional, and national CO₂ emissions

G. Marland, R.J. Andres, and T.A. Boden (continued)

SOUTH AFRICA

Trends

With a domestic economy powered by coal, South Africa has experienced a 4.6-fold increase in CO₂ emissions since 1950, with 85–90% of emissions from coal. With no natural gas, another 12% is currently from oil consumption, and the remainder is from cement manufacture. The oil price problems so evident in other countries appear to have had only a minor impact on South African CO₂ emissions.

It is appropriate to note that the emissions shown here are by primary fuel. Consequently, when liquid fuels are produced from coal, the emissions will still appear in these tabulations as CO₂ from solid fuels.

CO₂ emissions from South Africa. Per capita CO₂ emission estimates for South Africa.

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Carbon Dioxide Emissions
Global, regional, and national CO₂ emissions

G. Marland, R.J. Andres, and T.A. Boden (continued)

SOUTH AFRICA

National CO₂ Emission Estimates

Year	Emissions for South Africa (million metric tons of carbon)						Per capita emissions (metric tons of carbon)	Bunkers ^a
	Total	Solid	Liquid	Gas	Cement	Gas flaring		
1950	16.6	15.0	1.4	0.0	0.3	0.0	1.21	0.7
1951	17.8	16.0	1.5	0.0	0.3	0.0	1.28	0.6
1952	19.5	17.6	1.6	0.0	0.3	0.0	1.36	0.4
1953	19.5	17.5	1.7	0.0	0.3	0.0	1.33	0.4
1954	20.3	18.1	1.8	0.0	0.3	0.0	1.35	0.4
1955	22.8	20.4	2.1	0.0	0.3	0.0	1.48	0.4
1956	24.0	21.4	2.3	0.0	0.3	0.0	1.52	0.7
1957	24.7	22.1	2.2	0.0	0.3	0.0	1.53	1.1
1958	26.5	23.6	2.5	0.0	0.4	0.0	1.60	0.5
1959	26.0	23.3	2.4	0.0	0.4	0.0	1.53	0.4
1960	26.9	24.1	2.5	0.0	0.4	0.0	1.55	0.4
1961	28.1	24.9	2.8	0.0	0.4	0.0	1.57	0.5
1962	29.0	25.6	3.0	0.0	0.4	0.0	1.58	0.4
1963	30.1	26.6	3.2	0.0	0.4	0.0	1.60	0.5
1964	32.8	28.2	4.2	0.0	0.5	0.0	1.70	0.7
1965	35.2	30.6	4.1	0.0	0.5	0.0	1.78	0.7
1966	35.3	30.0	4.7	0.0	0.5	0.0	1.73	1.0
1967	36.8	31.1	5.2	0.0	0.5	0.0	1.77	2.0
1968	37.9	32.6	4.7	0.0	0.6	0.0	1.78	2.9
1969	39.3	33.2	5.4	0.0	0.7	0.0	1.80	2.6
1970	40.8	34.1	6.0	0.0	0.8	0.0	1.82	2.9
1971	45.9	36.7	8.4	0.0	0.8	0.0	1.99	3.0
1972	46.8	38.0	8.0	0.0	0.8	0.0	1.97	2.9
1973	47.1	37.7	8.5	0.0	0.9	0.0	1.93	2.8
1974	47.9	38.5	8.4	0.0	1.0	0.0	1.91	2.7
1975	50.1	39.5	9.6	0.0	1.0	0.0	1.94	2.5
1976	52.3	41.1	10.3	0.0	1.0	0.0	1.97	1.8
1977	52.8	41.9	9.9	0.0	0.9	0.0	1.93	2.1
1978	53.0	42.3	9.7	0.0	0.9	0.0	1.89	2.3
1979	56.9	46.8	9.2	0.0	0.9	0.0	1.98	2.4
1980	58.2	49.3	7.9	0.0	1.0	0.0	1.97	2.8
1981	64.5	54.4	9.0	0.0	1.1	0.0	2.13	3.1
1982	63.5	53.9	8.6	0.0	1.1	0.0	2.04	3.2
1983	67.6	57.3	9.2	0.0	1.1	0.0	2.12	3.0
1984	72.6	62.4	9.1	0.0	1.1	0.0	2.22	2.8
1985	73.7	63.6	9.1	0.0	1.0	0.0	2.19	2.8
1986	75.7	65.6	9.2	0.0	0.9	0.0	2.20	2.7
1987	76.8	66.6	9.3	0.0	0.9	0.0	2.18	2.7
1988	77.8	67.3	9.4	0.0	1.2	0.0	2.15	2.8
1989	75.9	65.3	9.5	0.0	1.1	0.0	2.05	2.8
1990	75.8	65.7	9.0	0.0	1.1	0.0	2.00	2.8
1991	76.1	66.0	9.1	0.0	1.0	0.0	1.96	2.8

^aBunkers refer to emissions, expressed in million metric tons of carbon, resulting from fuels consumed by ships and aircraft engaged in international transportation. Emissions from bunker fuels are shown with the country where the fuel loading occurred but are not included in the national total.

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SOUTH KOREA

Trends

Even though minor offsets in the growth of CO₂ emissions from South Korea, or the Republic of Korea, may have occurred during the late 1970s, the last 41 years have been dominated by growth that averaged 12.4% per year and totaled over 120 times as much CO₂ in 1991 as in 1950. Per capita emissions have increased by a factor of 55. Initial growth was based on coal, but oil consumption grew rapidly from 1965 to 1979 and was the major source of CO₂ emissions from 1970 until 1983, at which time coal use grew rapidly again. Natural gas became a significant contributor of CO₂ for the first time in 1987, as South Korea increased imports of liquid natural gas. The indication is that emissions from liquid fuels started to increase again after 1985.

CO₂ emissions from South Korea.

Per capita CO₂ emission estimates for South Korea.

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Global, regional, and national CO₂ emissions

G. Marland, R.J. Andres, and T.A. Boden (continued)

SOUTH KOREA

National CO₂ Emission Estimates

Year	Emissions for South Korea (million metric tons of carbon)						Per capita emissions (metric tons of carbon)	Bunkers ^a
	Total	Solid	Liquid	Gas	Cement	Gas flaring		
1950	0.6	0.5	0.1	0.0	0.0	0.0	0.03	NA
1951	0.8	0.7	0.2	0.0	0.0	0.0	0.04	NA
1952	1.0	0.8	0.2	0.0	0.0	0.0	0.05	NA
1953	1.3	1.0	0.3	0.0	0.0	0.0	0.06	NA
1954	1.4	1.1	0.3	0.0	0.0	0.0	0.07	NA
1955	1.8	1.5	0.3	0.0	0.0	0.0	0.08	NA
1956	2.1	1.7	0.4	0.0	0.0	0.0	0.09	NA
1957	2.3	1.8	0.4	0.0	0.0	0.0	0.10	NA
1958	2.5	2.0	0.5	0.0	0.0	0.0	0.11	NA
1959	3.1	2.5	0.6	0.0	0.0	0.0	0.13	NA
1960	3.5	2.8	0.6	0.0	0.1	0.0	0.14	NA
1961	4.0	3.3	0.6	0.0	0.1	0.0	0.15	NA
1962	4.8	3.8	0.8	0.0	0.1	0.0	0.18	NA
1963	5.8	4.6	1.1	0.0	0.1	0.0	0.21	NA
1964	6.1	5.1	0.9	0.0	0.2	0.0	0.22	NA
1965	6.9	5.4	1.2	0.0	0.2	0.0	0.24	NA
1966	8.3	6.2	1.8	0.0	0.3	0.0	0.28	NA
1967	9.7	6.5	2.9	0.0	0.3	0.0	0.32	NA
1968	10.2	5.5	4.2	0.0	0.5	0.0	0.33	NA
1969	11.7	5.5	5.5	0.0	0.7	0.0	0.37	NA
1970	14.2	6.4	7.0	0.0	0.8	0.0	0.45	NA
1971	15.4	6.5	7.9	0.0	0.9	0.0	0.47	NA
1972	16.0	6.8	8.4	0.0	0.9	0.0	0.48	NA
1973	19.1	7.9	10.0	0.0	1.1	0.0	0.56	NA
1974	19.4	8.2	10.0	0.0	1.2	0.0	0.56	NA
1975	20.8	8.5	11.0	0.0	1.4	0.0	0.59	NA
1976	23.9	9.3	12.9	0.0	1.6	0.0	0.67	NA
1977	27.0	10.2	14.9	0.0	1.9	0.0	0.74	NA
1978	29.3	10.4	16.9	0.0	2.1	0.0	0.79	NA
1979	34.1	12.6	19.3	0.0	2.2	0.0	0.91	NA
1980	34.3	13.4	18.8	0.0	2.1	0.0	0.90	NA
1981	35.4	14.5	18.8	0.0	2.1	0.0	0.92	NA
1982	36.3	15.4	18.5	0.0	2.4	0.0	0.92	NA
1983	38.5	16.6	19.0	0.0	2.9	0.0	0.97	NA
1984	41.9	20.4	18.7	0.0	2.8	0.0	1.04	NA
1985	46.4	25.0	18.6	0.0	2.8	0.0	1.14	NA
1986	47.1	24.5	19.3	0.0	3.2	0.0	1.14	NA
1987	49.5	24.9	20.0	1.2	3.5	0.0	1.18	NA
1988	56.9	27.0	24.5	1.5	3.9	0.0	1.34	NA
1989	60.3	26.5	28.2	1.5	4.1	0.0	1.41	NA
1990	65.9	25.7	33.9	1.7	4.6	0.0	1.52	NA
1991	72.2	26.4	39.3	2.0	4.6	0.0	1.65	NA

^aBunkers refer to emissions, expressed in million metric tons of carbon, resulting from fuels consumed by ships and aircraft engaged in international transportation. Emissions from bunker fuels are shown with the country where the fuel loading occurred but are not included in the national total. NA = not available.

CITE AS: Marland, G., R.J. Andres, and T.A. Boden. 1994. Global, regional, and national CO₂ emissions. pp. 505-584. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

AUSTRALIA

Trends

Australian CO₂ emissions have increased by a factor of 4.8 since 1950, reflecting a 2.3-fold increase resulting from growing per capita emissions and a 2.1-fold increase in population. Emissions from both solid and liquid fuels have grown, although emissions from liquid fuels have been nearly constant since 1981, and a steep growth in gas consumption has occurred since 1969. Total emissions have grown at an almost linear rate of 1.38 million metric tons of carbon per year. Coal remains the major contributor, at 57% of the total. A small drop in emissions in 1983 is the only indication of the global trauma in oil prices that marks the post-1973 period.

CO₂ emissions from Australia.

Per capita CO₂ emission estimates for Australia.

CITE AS: Marland, G., R.J. Andres, and T.A. Boden. 1994. Global, regional, and national CO₂ emissions. pp. 505-584. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Carbon Dioxide Emissions
Global, regional, and national CO₂ emissions

G. Marland, R.J. Andres, and T.A. Boden (continued)

AUSTRALIA

National CO₂ Emission Estimates

Year	Emissions for Australia (million metric tons of carbon)						Per capita emissions (metric tons of carbon)	Bunkers ^a
	Total	Solid	Liquid	Gas	Cement	Gas flaring		
1950	15.0	12.1	2.7	0.0	0.2	0.0	1.82	0.8
1951	16.2	12.6	3.4	0.0	0.2	0.0	1.92	0.8
1952	16.5	12.9	3.4	0.0	0.2	0.0	1.91	0.8
1953	16.3	13.2	2.8	0.0	0.2	0.0	1.84	0.7
1954	18.6	14.0	4.3	0.0	0.3	0.0	2.06	0.7
1955	19.3	14.0	5.0	0.0	0.3	0.0	2.09	1.0
1956	20.0	14.0	5.7	0.0	0.3	0.0	2.11	1.1
1957	20.4	14.1	5.9	0.0	0.3	0.0	2.11	1.2
1958	21.2	14.4	6.5	0.0	0.3	0.0	2.15	1.1
1959	22.9	15.5	7.0	0.0	0.4	0.0	2.26	1.1
1960	24.1	16.1	7.6	0.0	0.4	0.0	2.33	1.2
1961	24.7	16.4	7.9	0.0	0.4	0.0	2.35	1.2
1962	25.9	16.8	8.7	0.0	0.4	0.0	2.41	1.1
1963	27.5	17.4	9.7	0.0	0.4	0.0	2.51	1.3
1964	29.7	18.3	10.9	0.0	0.5	0.0	2.66	1.4
1965	33.0	19.4	13.1	0.0	0.5	0.0	2.90	1.5
1966	32.8	19.5	12.8	0.0	0.5	0.0	2.82	1.7
1967	35.2	20.5	14.1	0.0	0.5	0.0	2.97	1.9
1968	36.7	20.9	15.3	0.0	0.5	0.0	3.03	2.2
1969	38.8	21.3	16.8	0.1	0.6	0.0	3.15	2.1
1970	38.9	20.3	17.2	0.8	0.6	0.0	3.10	2.2
1971	40.0	20.3	18.0	1.1	0.6	0.0	3.13	2.4
1972	41.2	21.2	17.8	1.6	0.7	0.0	3.18	2.3
1973	43.8	21.8	19.6	1.8	0.7	0.0	3.32	2.6
1974	44.2	23.3	18.1	2.1	0.7	0.0	3.29	2.7
1975	45.2	23.7	18.5	2.3	0.7	0.0	3.32	2.4
1976	47.0	24.2	19.5	2.5	0.7	0.0	3.40	1.8
1977	50.7	26.2	20.7	3.0	0.7	0.0	3.61	1.9
1978	51.5	25.7	21.4	3.8	0.7	0.0	3.61	2.0
1979	52.4	26.5	21.1	4.2	0.7	0.0	3.62	1.7
1980	55.3	28.1	21.7	4.8	0.7	0.0	3.77	1.6
1981	58.4	28.9	23.1	5.6	0.8	0.0	3.92	1.6
1982	59.5	29.6	22.9	6.1	0.8	0.0	3.94	1.4
1983	56.7	29.2	20.7	6.2	0.7	0.0	3.71	1.4
1984	59.4	30.2	21.9	6.6	0.7	0.0	3.83	1.3
1985	60.9	32.6	19.3	8.2	0.8	0.0	3.86	1.0
1986	60.9	32.2	20.3	7.7	0.8	0.0	3.81	1.2
1987	64.7	35.1	20.8	7.9	0.8	0.0	3.97	1.2
1988	65.8	35.9	20.9	8.1	0.9	0.0	3.98	1.4
1989	69.8	38.7	21.9	8.3	0.9	0.0	4.15	1.6
1990	72.5	39.8	22.6	9.2	0.9	0.0	4.25	1.7
1991	71.5	40.8	20.9	8.8	0.9	0.0	4.12	1.7

^aBunkers refer to emissions, expressed in million metric tons of carbon, resulting from fuels consumed by ships and aircraft engaged in international transportation. Emissions from bunker fuels are shown with the country where the fuel loading occurred but are not included in the national total.

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NORTH KOREA

Trends

The total CO₂ emissions for North Korea, or the Democratic People's Republic of Korea, have averaged 15.2% growth per year over the 41-year record. Since 1950, total emissions from North Korea have grown by a factor of 332 to 66.4 million metric tons of carbon for 1991. Coal consumption accounted for over 91% of the 1991 CO₂ emission total. With no natural gas, another 5.6% currently comes from liquid petroleum consumption, and the remainder is from cement manufacture. Recent estimates of per capita emissions from North Korea are ~2.6 times the global average.

CO₂ emissions from North Korea.

Per capita CO₂ emission estimates for North Korea.

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Global, regional, and national CO₂ emissions

G. Marland, R.J. Andres, and T.A. Boden (continued)

NORTH KOREA

National CO₂ Emission Estimates

Year	Emissions for North Korea (million metric tons of carbon)						Per capita emissions (metric tons of carbon)	Bunkers ^a
	Total	Solid	Liquid	Gas	Cement	Gas flaring		
1950	0.2	0.1	0.1	0.0	0.0	0.0	0.02	NA
1951	0.3	0.1	0.1	0.0	0.0	0.0	0.03	NA
1952	0.2	0.1	0.1	0.0	0.0	0.0	0.03	NA
1953	0.5	0.3	0.1	0.0	0.0	0.0	0.05	NA
1954	1.3	1.1	0.1	0.0	0.1	0.0	0.15	NA
1955	2.0	1.8	0.1	0.0	0.0	0.0	0.22	NA
1956	2.5	2.2	0.1	0.0	0.1	0.0	0.26	NA
1957	3.1	2.8	0.1	0.0	0.1	0.0	0.32	NA
1958	4.3	3.9	0.2	0.0	0.2	0.0	0.43	NA
1959	5.4	5.0	0.2	0.0	0.3	0.0	0.52	NA
1960	6.5	6.0	0.2	0.0	0.3	0.0	0.60	NA
1961	7.2	6.7	0.2	0.0	0.3	0.0	0.65	NA
1962	8.4	7.8	0.3	0.0	0.3	0.0	0.74	NA
1963	9.0	8.3	0.3	0.0	0.3	0.0	0.77	NA
1964	9.8	9.1	0.3	0.0	0.4	0.0	0.81	NA
1965	12.2	11.5	0.3	0.0	0.3	0.0	0.98	NA
1966	13.1	12.4	0.3	0.0	0.3	0.0	1.02	NA
1967	14.4	13.7	0.3	0.0	0.4	0.0	1.09	NA
1968	16.3	15.4	0.6	0.0	0.4	0.0	1.19	NA
1969	17.6	16.6	0.6	0.0	0.4	0.0	1.24	NA
1970	20.2	18.9	0.7	0.0	0.5	0.0	1.38	NA
1971	29.5	28.3	0.6	0.0	0.7	0.0	1.96	NA
1972	24.6	23.3	0.6	0.0	0.7	0.0	1.59	NA
1973	26.7	25.3	0.6	0.0	0.8	0.0	1.69	NA
1974	27.9	26.2	0.8	0.0	0.8	0.0	1.72	NA
1975	29.5	27.6	1.0	0.0	1.0	0.0	1.78	NA
1976	30.2	28.3	0.9	0.0	1.0	0.0	1.79	NA
1977	31.2	29.3	1.0	0.0	1.0	0.0	1.81	NA
1978	32.6	30.1	1.5	0.0	1.0	0.0	1.85	NA
1979	33.1	30.3	1.7	0.0	1.1	0.0	1.85	NA
1980	34.3	31.2	2.0	0.0	1.1	0.0	1.88	NA
1981	34.4	31.2	2.1	0.0	1.1	0.0	1.85	NA
1982	35.1	31.8	2.2	0.0	1.1	0.0	1.86	NA
1983	37.6	34.3	2.3	0.0	1.1	0.0	1.96	NA
1984	40.5	37.0	2.4	0.0	1.1	0.0	2.07	NA
1985	43.4	39.8	2.6	0.0	1.1	0.0	2.18	NA
1986	47.2	43.0	3.1	0.0	1.1	0.0	2.33	NA
1987	52.9	47.5	4.1	0.0	1.2	0.0	2.57	NA
1988	60.5	55.1	3.9	0.0	1.6	0.0	2.89	NA
1989	64.2	58.1	3.9	0.0	2.2	0.0	3.01	NA
1990	65.2	59.3	3.7	0.0	2.2	0.0	3.00	NA
1991	66.4	60.5	3.7	0.0	2.2	0.0	2.99	NA

^aBunkers refer to emissions, expressed in million metric tons of carbon, resulting from fuels consumed by ships and aircraft engaged in international transportation. Emissions from bunker fuels are shown with the country where the fuel loading occurred but are not included in the national total. NA = not available.

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IRAN

Trends

Iran has shown remarkable growth in total CO₂ emissions since 1955, averaging 7.6% per year. In 1991 total emissions reached an all-time high of 60.7 million metric tons of carbon. Crude oil and petroleum products account for the majority of the emissions, almost 65% in 1991. The CO₂ emissions time series for Iran, as for other countries in the Middle East, shows sizeable emissions from gas flaring in the late 1960s and 1970s and a decline in these emissions during the 1980s and 1990s. This downturn reflects changes in oil field practices, improvements in oil field facilities, and increasing use of gas fuels. Emissions from gas fuels have grown 60-fold since 1955 and now account for 20% of Iran's total CO₂ emissions. From a per capita standpoint, Iran is near the global average at ~1 metric ton of carbon per person. Energy statistics for Iran in the early 1950s and the corresponding CO₂ emissions estimates should be used with caution (see Footnote *b* on page 576).

Carbon Dioxide Emissions
Global, regional, and national CO₂ emissions

G. Marland, R.J. Andres, and T.A. Boden (continued)

IRAN

CO₂ emissions from Iran.

Per capita CO₂ emission estimates for Iran.

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Carbon Dioxide Emissions

Global, regional, and national CO₂ emissions

G. Marland, R.J. Andres, and T.A. Boden (continued)

IRAN

National CO₂ Emission Estimates

Year	Emissions for Iran (million metric tons of carbon)						Per capita emissions (metric tons of carbon)	Bunkers ^a
	Total	Solid	Liquid	Gas	Cement	Gas flaring		
1950 ^b	-1.5	0.1	-1.6	0.0	0.0	0.0	-0.09	NA
1951	1.9	0.1	1.8	0.0	0.0	0.0	0.11	NA
1952	1.1	0.1	1.0	0.0	0.0	0.0	0.06	NA
1953	1.0	0.1	0.9	0.0	0.0	0.0	0.06	NA
1954	0.3	0.2	0.1	0.0	0.0	0.0	0.02	NA
1955	4.3	0.2	0.8	0.2	0.0	3.2	0.23	NA
1956	6.2	0.1	2.3	0.2	0.0	3.5	0.32	NA
1957	6.0	0.1	3.0	0.4	0.0	2.4	0.30	NA
1958	6.9	0.1	3.6	0.4	0.1	2.7	0.34	NA
1959	7.0	0.2	3.2	0.5	0.1	3.1	0.33	NA
1960	10.2	0.2	6.0	0.5	0.1	3.5	0.47	NA
1961	10.0	0.1	5.3	0.5	0.1	3.9	0.45	NA
1962	10.2	0.1	5.1	0.6	0.1	4.3	0.45	NA
1963	11.3	0.2	5.5	0.6	0.1	4.9	0.48	NA
1964	13.0	0.2	6.4	0.6	0.1	5.6	0.54	NA
1965	14.7	0.2	6.7	0.6	0.1	7.0	0.59	NA
1966	17.5	0.2	7.2	0.7	0.2	9.2	0.69	NA
1967	18.5	0.2	7.5	0.8	0.2	9.8	0.71	NA
1968	22.5	0.2	10.0	0.8	0.3	11.2	0.84	NA
1969	22.7	0.4	7.8	2.5	0.3	11.7	0.82	NA
1970	24.0	0.4	7.8	5.6	0.4	9.8	0.84	NA
1971	26.6	0.4	9.5	4.9	0.4	11.3	0.91	NA
1972	27.6	0.7	9.0	4.8	0.5	12.7	0.91	NA
1973	33.8	0.8	12.3	5.2	0.5	14.9	1.08	NA
1974	37.8	0.9	14.8	6.6	0.6	14.8	1.17	NA
1975	36.0	0.8	15.8	6.2	0.7	12.5	1.08	NA
1976	41.2	0.7	18.6	6.2	0.8	14.8	1.20	NA
1977	42.6	0.7	21.3	5.6	1.0	14.0	1.20	NA
1978	42.3	0.7	21.2	5.1	1.6	13.6	1.16	NA
1979	43.0	0.7	26.2	6.6	1.2	8.3	1.14	NA
1980	31.7	0.7	21.3	3.6	1.1	5.0	0.81	NA
1981	29.4	0.6	20.4	3.3	1.1	4.0	0.72	NA
1982	36.0	0.9	22.9	3.4	1.3	7.5	0.84	NA
1983	36.9	0.8	23.6	4.4	1.4	6.7	0.82	NA
1984	38.0	0.9	25.1	6.9	1.6	3.4	0.81	NA
1985	40.3	1.0	27.3	7.5	1.7	2.8	0.82	NA
1986	37.5	1.0	24.2	7.8	1.7	2.8	0.74	NA
1987	40.0	1.1	26.4	8.4	1.7	2.5	0.76	NA
1988	44.5	1.1	29.2	10.5	1.7	2.1	0.81	NA
1989	48.8	1.1	33.6	11.6	1.7	0.8	0.86	NA
1990	58.0	1.3	37.1	11.9	1.8	6.0	0.99	NA
1991	60.7	1.4	39.4	12.1	2.0	5.8	1.01	NA

^aNA = not available.

^bDomestic fuel consumption is calculated as the difference between production plus imports and exports plus changes in stocks. When both production and exports are very large and very similar, a small error in either estimate can make it appear that domestic consumption was negative.

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Global, regional, and national CO₂ emissions

G. Marland, R.J. Andres, and T.A. Boden (continued)

SPAIN

Trends

Spain has recovered from an early-1980s emissions lull to record five consecutive years of growth, including an all-time high of 60 million metric tons of carbon in 1991. Spain experienced a drop in CO₂ emissions from liquid fuels during the period 1980–86. Emissions from coal grew from 1978 until 1985, balancing some of the loss in liquid fuel burning. Liquid fuels have been the dominant source of CO₂ from Spain since 1966, contributing 52% of emissions in 1991 after a high of 69.6% in 1974. Coal was the dominant CO₂ source before 1966 and still contributed as much as 36% in 1991. Per capita emissions remain low, in contrast with those of most other Western European nations, at a rate of 1.54 metric tons of carbon per capita per year, a value that has changed little since 1974.

CO₂ emissions from Spain. Per capita CO₂ emission estimates for Spain.

CITE AS: Marland, G., R.J. Andres, and T.A. Boden. 1994. Global, regional, and national CO₂ emissions. pp. 505–584. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Carbon Dioxide Emissions

Global, regional, and national CO₂ emissions

G. Marland, R.J. Andres, and T.A. Boden (continued)

SPAIN

National CO₂ Emission Estimates

Year	Emissions for Spain (million metric tons of carbon)						Per capita emissions (metric tons of carbon)	Bunkers ^a
	Total	Solid	Liquid	Gas	Cement	Gas flaring		
1950	9.1	7.3	1.4	0.0	0.3	0.0	0.32	1.5
1951	9.1	7.3	1.5	0.0	0.4	0.0	0.32	1.6
1952	10.3	8.0	1.9	0.0	0.4	0.0	0.36	1.8
1953	10.7	8.3	2.0	0.0	0.4	0.0	0.37	1.9
1954	10.9	8.3	2.1	0.0	0.5	0.0	0.38	2.0
1955	11.1	8.2	2.3	0.0	0.6	0.0	0.38	2.2
1956	11.6	8.1	2.8	0.0	0.6	0.0	0.40	2.4
1957	13.8	9.2	3.9	0.0	0.7	0.0	0.46	3.4
1958	15.3	10.0	4.7	0.0	0.7	0.0	0.51	2.7
1959	14.3	9.0	4.5	0.0	0.8	0.0	0.47	2.6
1960	13.4	8.8	3.9	0.0	0.8	0.0	0.44	2.8
1961	14.7	9.2	4.6	0.0	0.9	0.0	0.48	3.0
1962	16.5	9.5	6.0	0.0	1.0	0.0	0.53	2.9
1963	16.1	9.5	5.6	0.0	1.1	0.0	0.51	3.1
1964	17.6	9.0	7.5	0.0	1.2	0.0	0.56	3.2
1965	19.5	9.5	8.7	0.0	1.3	0.0	0.61	3.3
1966	21.3	8.8	10.8	0.0	1.6	0.0	0.66	3.5
1967	23.7	8.8	13.0	0.0	1.8	0.0	0.72	4.1
1968	26.6	9.0	15.5	0.0	2.0	0.0	0.80	4.7
1969	26.5	9.0	15.2	0.0	2.2	0.0	0.79	4.7
1970	30.2	10.0	17.9	0.0	2.3	0.0	0.89	2.3
1971	33.4	9.6	21.2	0.2	2.3	0.0	0.98	2.3
1972	37.6	9.9	24.5	0.4	2.7	0.0	1.09	2.6
1973	40.0	9.6	26.8	0.6	3.0	0.0	1.15	2.5
1974	45.1	10.1	31.4	0.6	3.0	0.0	1.28	2.5
1975	46.6	11.3	31.3	0.7	3.3	0.0	1.31	1.7
1976	50.6	11.1	35.1	0.9	3.4	0.0	1.41	1.8
1977	49.8	12.2	33.0	0.8	3.8	0.0	1.37	1.8
1978	49.4	11.2	33.2	0.8	4.1	0.0	1.34	1.7
1979	53.0	13.1	35.2	1.0	3.8	0.0	1.42	2.4
1980	54.6	13.5	36.2	1.1	3.8	0.0	1.45	2.1
1981	54.5	16.0	33.4	1.2	3.9	0.0	1.44	2.0
1982	54.5	18.9	30.2	1.3	4.0	0.0	1.43	2.3
1983	53.2	19.0	28.7	1.3	4.2	0.0	1.39	2.5
1984	49.8	19.1	25.9	1.3	3.5	0.0	1.30	2.8
1985	51.8	21.8	25.2	1.5	3.3	0.0	1.35	3.0
1986	47.3	18.0	24.6	1.4	3.3	0.0	1.23	3.4
1987	48.6	17.9	26.1	1.5	3.1	0.0	1.26	4.1
1988	49.9	16.0	28.4	2.0	3.3	0.0	1.28	3.6
1989	56.9	21.2	29.3	2.7	3.7	0.0	1.46	3.7
1990	57.8	20.6	30.2	3.1	3.8	0.0	1.48	4.3
1991	60.0	21.6	31.1	3.5	3.8	0.0	1.54	4.6

^aBunkers refer to emissions, expressed in million metric tons of carbon, resulting from fuels consumed by ships and aircraft engaged in international transportation. Emissions from bunker fuels are shown with the country where the fuel loading occurred but are not included in the national total.

CITE AS: Marland, G., R.J. Andres, and T.A. Boden. 1994. Global, regional, and national CO₂ emissions. pp. 505-584. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Global, regional, and national CO₂ emissions

G. Marland, R.J. Andres, and T.A. Boden (continued)

BRAZIL**Trends**

Total CO₂ emissions from Brazil grew rapidly from 1950 to 1979 (almost tenfold) but dropped sharply during 1980–84. Emissions have increased steadily since 1984 and reached an all-time high in 1991. Historically, emissions have come largely from consumption of liquid fuels, but since 1973, when 86% of emissions were from liquid fuels, emissions from solid fuels have played an increasing role. In 1991, emissions were 71.1% from liquids and 18.5% from solids. Emissions from gas fuels have remained small (3.4% in 1991) but have gradually increased since 1965. Until 1974, more gas was flared than used.

CO₂ emissions from Brazil. *Per capita CO₂ emission estimates for Brazil.*

CITE AS: Marland, G., R.J. Andres, and T.A. Boden. 1994. Global, regional, and national CO₂ emissions. pp. 505–584. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Carbon Dioxide Emissions

Global, regional, and national CO₂ emissions

G. Marland, R.J. Andres, and T.A. Boden (continued)

BRAZIL

National CO₂ Emission Estimates

Year	Emissions for Brazil (million metric tons of carbon)						Per capita emissions (metric tons of carbon)	Bunkers ^a
	Total	Solid	Liquid	Gas	Cement	Gas flaring		
1950	5.4	1.8	3.4	0.0	0.2	0.0	0.10	NA
1951	5.9	1.7	4.0	0.0	0.2	0.0	0.11	NA
1952	6.8	1.7	4.9	0.0	0.2	0.0	0.12	NA
1953	6.9	1.6	5.1	0.0	0.3	0.0	0.12	NA
1954	8.1	1.6	6.2	0.0	0.3	0.0	0.13	NA
1955	9.3	1.6	7.3	0.0	0.4	0.0	0.15	NA
1956	10.0	1.4	8.1	0.0	0.4	0.0	0.16	NA
1957	9.8	1.4	7.9	0.0	0.5	0.0	0.15	NA
1958	10.7	1.1	9.0	0.0	0.5	0.1	0.16	NA
1959	10.7	1.1	8.9	0.0	0.5	0.1	0.15	NA
1960	12.8	1.4	10.6	0.0	0.6	0.1	0.18	NA
1961	13.4	1.3	11.3	0.0	0.6	0.2	0.18	NA
1962	14.7	1.6	12.2	0.0	0.7	0.1	0.19	NA
1963	15.2	1.5	12.8	0.0	0.7	0.1	0.19	NA
1964	15.5	1.7	12.8	0.0	0.8	0.2	0.19	NA
1965	15.4	1.9	12.5	0.1	0.8	0.2	0.18	NA
1966	17.6	2.3	14.2	0.1	0.8	0.2	0.20	NA
1967	18.1	2.2	14.7	0.1	0.9	0.2	0.20	NA
1968	21.1	2.4	17.5	0.1	1.0	0.3	0.23	NA
1969	23.0	2.6	18.9	0.1	1.1	0.3	0.25	NA
1970	23.7	2.6	19.3	0.0	1.2	0.5	0.25	NA
1971	25.7	2.5	21.4	0.1	1.3	0.4	0.26	NA
1972	28.8	2.6	24.2	0.1	1.5	0.3	0.29	NA
1973	32.9	2.5	28.2	0.1	1.8	0.3	0.32	NA
1974	35.9	3.0	30.5	0.2	2.0	0.2	0.34	NA
1975	38.2	3.4	32.0	0.2	2.4	0.2	0.35	NA
1976	41.8	3.2	35.5	0.2	2.6	0.2	0.38	NA
1977	43.9	4.1	36.3	0.3	2.9	0.2	0.39	NA
1978	47.5	4.9	38.9	0.4	3.0	0.3	0.41	NA
1979	50.5	5.1	41.2	0.4	3.4	0.3	0.43	NA
1980	50.1	5.5	40.0	0.5	3.7	0.4	0.41	NA
1981	45.9	5.4	36.1	0.5	3.5	0.5	0.37	NA
1982	46.3	6.1	35.5	0.7	3.5	0.6	0.36	NA
1983	44.5	6.6	33.3	0.9	2.8	0.8	0.34	NA
1984	44.5	7.9	31.8	1.1	2.7	1.0	0.34	NA
1985	47.7	9.6	32.9	1.4	2.8	0.9	0.35	NA
1986	52.6	9.7	37.1	1.6	3.4	0.7	0.38	NA
1987	54.2	10.1	38.2	1.8	3.5	0.6	0.38	NA
1988	55.1	10.5	38.6	1.9	3.4	0.6	0.38	NA
1989	56.4	10.6	39.8	2.0	3.5	0.6	0.39	NA
1990	55.1	9.4	39.4	2.0	3.5	0.7	0.37	NA
1991	58.8	10.9	41.8	2.0	3.5	0.7	0.39	NA

^aBunkers refer to emissions, expressed in million metric tons of carbon, resulting from fuels consumed by ships and aircraft engaged in international transportation. Emissions from bunker fuels are shown with the country where the fuel loading occurred but are not included in the national total. NA = not available.

CITE AS: Marland, G., R.J. Andres, and T.A. Boden. 1994. Global, regional, and national CO₂ emissions. pp. 505–584. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

SAUDI ARABIA

Trends

Saudi Arabia was the world's twentieth largest CO₂ emitter in 1991, with approximately 59 million metric tons of carbon. Until 1966, Saudi Arabia had negligible CO₂ emissions. Since 1966, Saudi Arabia has averaged 15.2% growth annually in CO₂ emissions, with a temporary drop in 1975 and a spike in 1986. Saudi Arabia is the world's third largest oil producer and the bulk of CO₂ emissions (57% in 1991) are from oil consumption. Use of natural gas has become increasingly important in recent years and now accounts for 33% of total CO₂ emissions. A striking feature of the time series for Saudi Arabia is the emissions resulting from flaring gas in the oil fields. In 1974, gas flaring accounted for 84% of Saudi Arabia's total emissions. As new technologies were incorporated into the oil fields and it became possible to use or reinject these gases, emissions from gas flaring fell sharply and now account for only 7% of total emissions. Per capita emissions have grown by a factor of almost 9 since 1950; at 3.81 metric tons of carbon per person, they are well above the global average. Energy statistics for Saudi Arabia in the early 1950s and the corresponding CO₂ emission estimates should be used with caution (see Footnote *b* on page 583).

CITE AS: Marland, G., R.J. Andres, and T.A. Boden. 1994. Global, regional, and national CO₂ emissions. pp. 505-584. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

SAUDI ARABIA

CO₂ emissions from Saudi Arabia.

Per capita CO₂ emission estimates for Saudi Arabia.

CITE AS: Marland, G., R.J. Andres, and T.A. Boden. 1994. Global, regional, and national CO₂ emissions. pp. 505-584. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Carbon Dioxide Emissions
Global, regional, and national CO₂ emissions

G. Marland, R.J. Andres, and T.A. Boden (continued)

SAUDI ARABIA

National CO₂ Emission Estimates

Year	Emissions for Saudi Arabia (million metric tons of carbon)						Per capita emissions (metric tons of carbon)	Bunkers ^a
	Total	Solid	Liquid	Gas	Cement	Gas flaring		
1950	1.4	0.0	1.4	0.0	0.0	0.0	0.44	NA
1951 ^b	-0.1	0.0	-0.1	0.0	0.0	0.0	-0.03	NA
1952	0.0	0.0	0.0	0.0	0.0	0.0	0.00	NA
1953	0.1	0.0	0.1	0.0	0.0	0.0	0.04	NA
1954	0.3	0.0	0.3	0.0	0.0	0.0	0.10	NA
1955	0.6	0.0	0.6	0.0	0.0	0.0	0.16	NA
1956	0.4	0.0	0.4	0.0	0.0	0.0	0.12	NA
1957	0.6	0.0	0.6	0.0	0.0	0.0	0.15	NA
1958	0.9	0.0	0.5	0.0	0.4	0.0	0.24	NA
1959	0.5	0.0	0.5	0.0	0.0	0.0	0.13	NA
1960	0.7	0.0	0.7	0.0	0.0	0.0	0.18	NA
1961	1.0	0.0	1.0	0.0	0.0	0.0	0.23	NA
1962	1.7	0.0	1.7	0.0	0.0	0.0	0.39	NA
1963	1.9	0.0	1.9	0.0	0.0	0.0	0.42	NA
1964	1.9	0.0	1.5	0.3	0.0	0.0	0.41	NA
1965	1.2	0.0	0.6	0.5	0.0	0.0	0.24	NA
1966	1.7	0.0	1.1	0.6	0.0	0.0	0.35	NA
1967	7.0	0.0	1.2	0.6	0.0	5.1	1.36	NA
1968	7.9	0.0	1.5	0.9	0.1	5.5	1.49	NA
1969	9.6	0.0	2.2	0.9	0.1	6.4	1.74	NA
1970	9.8	0.0	2.0	0.0	0.1	7.8	1.71	NA
1971	14.2	0.0	3.6	0.0	0.1	10.4	2.36	NA
1972	16.7	0.0	2.2	0.1	0.1	14.2	2.66	NA
1973	22.9	0.0	2.5	0.3	0.1	19.9	3.48	NA
1974	24.3	0.0	3.3	0.3	0.1	20.5	3.51	NA
1975	20.4	0.0	4.7	0.3	0.2	15.3	2.82	NA
1976	25.2	0.0	5.1	0.3	0.2	19.6	3.31	NA
1977	27.5	0.0	7.4	0.3	0.2	19.6	3.44	NA
1978	27.8	0.0	10.1	0.3	0.2	17.1	3.30	NA
1979	33.5	0.0	15.1	0.3	0.3	17.8	3.78	NA
1980	35.7	0.0	15.4	0.7	0.4	19.3	3.81	NA
1981	36.3	0.0	18.4	0.5	0.6	16.7	3.65	NA
1982	36.3	0.0	23.4	0.7	1.0	11.2	3.44	NA
1983	37.6	0.0	29.3	0.3	1.1	7.0	3.37	NA
1984	39.0	0.0	28.8	7.1	1.0	2.2	3.31	NA
1985	44.2	0.0	32.9	8.6	1.1	1.6	3.57	NA
1986	52.5	0.0	37.8	12.1	1.3	1.3	4.06	NA
1987	46.0	0.0	31.6	12.2	1.2	1.0	3.43	NA
1988	47.7	0.0	30.8	13.7	1.5	1.7	3.43	NA
1989	51.0	0.0	33.4	14.0	1.6	2.0	3.55	NA
1990	58.6	0.0	37.0	17.3	1.6	2.7	3.94	NA
1991	58.7	0.0	33.5	19.5	1.6	4.0	3.81	NA

^aBunkers refer to emissions, expressed in million metric tons of carbon, resulting from fuels consumed by ships and aircraft engaged in international transportation. Emissions from bunker fuels are shown with the country where the fuel loading occurred but are not included in the national total. NA = not available.

^bDomestic fuel consumption is calculated as the difference between production plus imports and exports plus changes in stocks. When both production and exports are very large and very similar, a small error in either estimate can make it appear that domestic consumption was negative.

CITE AS: Marland, G., R.J. Andres, and T.A. Boden. 1994. Global, regional, and national CO₂ emissions. pp. 505-584. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

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Introduction

TEMPERATURE

During the past 20 years, much attention has been given to the potential climatic effects of increasing concentrations of atmospheric greenhouse gases. These potential climatic effects could have far-reaching environmental, economic, and social consequences. Much of the work performed to date has involved (1) climate modeling or empirical analyses attempting to attribute climatic changes to various astronomical and atmospheric factors and (2) assembly and examination of new geological, historical, and instrumental data. From these studies, researchers have gained not only important new insights into the possible climatic response to the increasing concentrations of carbon dioxide (CO₂) and other trace gases, but also a better understanding of the overall climate system's sensitivity to both human and natural perturbations.

To isolate the "greenhouse signal" (the part of climate change indicative of increased concentrations of greenhouse gases) researchers must have long-term observational records to identify the climate changes that have already occurred. These observational records also must have sufficient spatial coverage. Although local and regional variations in temperature are important in assessing the impacts of climate and climate change on society, large-scale averages are most likely to indicate detectable changes in climate that result from changes in atmospheric concentrations of trace gases. Fortunately, many climatic variables (e.g., surface air temperature) have been measured at a large number of meteorological stations for the past century, mostly at land locations in the Northern Hemisphere. Researchers have compiled and analyzed several time series of global average surface air temperatures largely using land-based data and data from a few fixed-position weather ships. Previous attempts to determine large-scale tropospheric and stratospheric temperatures have typically used radiosonde and rocketsonde data. Recently, short global temperature series have been compiled from satellite data, and long-term climates, spanning the full glacial-interglacial cycle, have been reconstructed from ice cores from the Antarctic ice sheets. Ice-core data provide access to climate information including an estimate of temperature changes at the atmospheric level where the snow formed and at the surface. Despite the possible limitations of these individual temperature records, they collectively provide a good indication of global warming trends. Indeed, many of the series show warming trends in the troposphere, particularly during the 1980s, yet whether these trends result from a buildup of greenhouse gases or are due to other factors (e.g., greater frequency of El Niño/Southern Oscillation (ENSO) events in the Pacific Ocean) remains unclear (see figure on following page).

The following pages provide nine records of surface air temperature anomalies. Their spatial coverage ranges from the globe to an individual Antarctic site and from the Earth's surface to the lower stratosphere. Their temporal coverage ranges from monthly to annual records. The first record is the Vostok ice-core temperature record which is followed by three records of global and hemispheric temperature anomalies derived from surface stations and a single record derived from satellite data. Next, two records are presented that contain annual and seasonal temperature anomalies for the Earth's surface, the troposphere, the tropopause, and low stratosphere. For these vertical profiles, global anomaly estimates are provided first, followed by northern zonal averages, southern zonal averages, and

Global annual temperature anomalies from Spencer and Christy (A), Angell (B), Vinnikov et al. (C), Wilson and Hansen (D), and Jones et al. (E).

hemispheric averages. Finally, national and regional estimates are provided for the United States and Canada. For the United States, seasonal and annual temperature anomalies are provided for 23 subregions. For Canada, seasonal and annual temperature anomalies are provided for 11 subregions.

Since the publication of *Trends '91*, the influence of the 1991 Mt. Pinatubo eruption is now being seen in the temperature records for 1991–92. This issue of *Trends* offers greater temporal and spatial coverage along with recent updates to previously published temperature records. The addition of the temperature record derived from the Vostok ice core offers a 165-kyr record that documents the Last Glacial Period. For two records published in previous issues of *Trends*—global and hemispheric temperature anomalies of Spencer and Christy and of Vinnikov et al.—seasonal and monthly averages have been included, respectively. The addition of records from Oort et al., who present global and hemispheric temperature anomalies derived from rawinsonde records, complements Angell's records derived from radiosonde data. Inclusion of the Canadian national and regional temperature departures aids those researchers addressing regional climate issues in North America. All of these temperature records have been frequently referenced in studies addressing potential greenhouse gas-induced climate changes.

All of the data presented in this section were made available to CDIAC by the principal investigator(s) listed at the beginning of the data records. We urge readers to credit the principal investigators and their organizations when using these data. The proper citation for each record is listed at the bottom of each page. Users are cautioned to pay close attention to table footnotes concerning the nature of each data record and are encouraged to contact the principal investigators before applying the data in specific model or research exercises.

Temperature

Vostok isotopic temperature record

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Period of Record

164,400 BP–present

Methods

Because isotopic fractions of the heavier oxygen-18 (^{18}O) and deuterium (D) in snowfall are temperature dependent and a strong spatial correlation exists between the annual mean temperature and the mean isotopic ratio ($\delta^{18}\text{O}$ or δD) of precipitation, it is possible to derive ice-core climate records. This record presented by Jouzel et al. (1987) was the first ice core record to span a full glacial-interglacial cycle. The record was based on an ice core drilled at Vostok, the Russian station in central east Antarctica. The 2083-m ice core from Vostok, Antarctica, was obtained during a series of drillings in the early 1970s and 1980 and was the result of collaboration between French and former-Soviet scientists.

Vostok
Antarctica
78°28' S, 106°48' E
3488 m above MSL

CITE AS: Jouzel, J., C. Lorius, J.R. Petit, N.I. Barkov, and V.M. Kotlyakov. 1994. Vostok isotopic temperature record. pp. 590–602. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Vostok isotopic temperature record

J. Jouzel, C. Lorius, J.R. Petit, N.I. Barkov, and V.M. Kotlyakov (continued)

The first isotopic analysis of the Vostok ice core was described in Lorius et al. (1985). Sampling of ice for ^{18}O and deuterium was done in the field during the 1982–83 austral summer by cutting a continuous slice from the length of ice after careful cleaning. Sampling was performed on 1.5- to 2-m increments of ice. Samples were sent in solid form to Grenoble and then melted before isotopic analysis in Saclay. Two independent series of samples were obtained. For the discontinuous series, duplicated to check reproducibility, one sample was taken at each 25-m interval from the surface down to the bottom of the core. For the continuous series, samples were collected between 1406 and 2083 m. Oxygen-18 and deuterium determinations were simultaneously performed on all the samples and the ^{18}O results were discussed in Lorius et al. (1985).

The 165-kyr Vostok temperature record presented here was reconstructed from the continuous deuterium profile measured along the core. The samples were analyzed for their ^{18}O and δD contents. The new samples were taken along 1-m ice increments (instead of 2 m) and processed as described in Lorius et al. (1985). The sample analyses of Jouzel et al. (1987) created data on an almost continuous basis on the 2083-m core below 138 m. According to Jouzel et al. (1987), the total ice recovery was about 85%; only one long (8-m) series during the Younger Dryas was missing. These temperature estimates are based on both experimental and theoretical arguments. One of the fundamental arguments used in deriving this temperature record is that the deuterium content distribution is well documented over East Antarctica and over a large range of temperatures (-20° to -55°C); thus, there is a linear relationship between the average annual surface temperature and the snow deuterium content. The slope of this δD /surface temperature relationship was found by Jouzel et al. (1987) to be 6% per $^{\circ}\text{C}$. Details on the methodology are presented in Jouzel et al. (1987) and Lorius et al. (1985).

CITE AS: Jouzel, J., C. Lorius, J.R. Petit, N.I. Barkov, and V.M. Kotlyakov. 1994. Vostok isotopic temperature record. pp. 590–602. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

VOSTOK ISOTOPE TEMPERATURE RECORD

Trends

Jouzel et al. (1987) concluded that this continuous deuterium record along the Vostok ice core record documents the Last Glacial Period and confirms that the warmest part of the Last Interglacial Period was about 2°C warmer than the Holocene. One of the prominent features of this record is the large approximately 100 kyr glacial-interglacial signal with an amplitude of approximately 11°C. A more recent ice-core record from Vostok now extends back to the penultimate glacial period (~140–200 kyr ago) and the end of the preceding interglacial (Jouzel et al. 1993). This newer record shows that East Antarctica was colder and drier during glacial periods than during the Holocene and reveal direct correlations of carbon dioxide and methane concentrations with temperature (Jouzel et al. 1993).

Variation with time of the Vostok isotope temperature record in °C as a difference from the modern surface-temperature value of -55.5°C.

CITE AS: Jouzel, J., C. Lorius, J.R. Petit, N.I. Barkov, and V.M. Kotlyakov. 1994. Vostok isotopic temperature record. pp. 590–602. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Vostok isotopic temperature record

J. Jouzel, C. Lorius, J.R. Petit, N.I. Barkov, and V.M. Kotlyakov (continued)

VOSTOK ISOTOPE TEMPERATURE RECORD

Vostok Isotope Temperature Record^a

Years BP	Temperature variation (°C)	Years BP	Temperature variation (°C)	Years BP	Temperature variation (°C)	Years BP	Temperature variation (°C)
0	-0.067126	5000	0.137859	10000	-0.768110	15000	-7.687860
100	-0.076050	5100	0.121142	10100	-1.067350	15100	-7.836070
200	-0.084918	5200	0.100434	10200	-1.382040	15200	-7.969020
300	-0.093724	5300	0.077542	10300	-1.697520	15300	-8.088950
400	-0.103570	5400	0.054123	10400	-2.002750	15400	-8.195320
500	-0.115790	5500	0.031926	10500	-2.274270	15500	-8.290050
600	-0.129140	5600	0.012810	10600	-2.501020	15600	-8.373190
700	-0.142570	5700	-0.000990	10700	-2.680630	15700	-8.446780
800	-0.155840	5800	-0.007933	10800	-2.821330	15800	-8.511140
900	-0.169370	5900	-0.008103	10900	-2.928770	15900	-8.564900
1000	-0.183320	6000	-0.000893	11000	-3.007150	16000	-8.613420
1100	-0.197200	6100	0.014827	11100	-3.059620	16100	-8.657900
1200	-0.209770	6200	0.038354	11200	-3.090980	16200	-8.693310
1300	-0.219490	6300	0.069318	11300	-3.099040	16300	-8.722460
1400	-0.225690	6400	0.105169	11400	-3.106580	16400	-8.746110
1500	-0.226560	6500	0.144557	11500	-3.097350	16500	-8.764820
1600	-0.221010	6600	0.185837	11600	-3.081800	16600	-8.778710
1700	-0.209370	6700	0.227105	11700	-3.063160	16700	-8.788960
1800	-0.193590	6800	0.267378	11800	-3.045250	16800	-8.796160
1900	-0.176120	6900	0.306496	11900	-3.029990	16900	-8.800730
2000	-0.158800	7000	0.344790	12000	-3.021380	17000	-8.804050
2100	-0.143390	7100	0.381702	12100	-3.022940	17100	-8.806740
2200	-0.130550	7200	0.415852	12200	-3.038560	17200	-8.807600
2300	-0.118917	7300	0.448623	12300	-3.071790	17300	-8.806800
2400	-0.107373	7400	0.479449	12400	-3.144030	17400	-8.803390
2500	-0.094665	7500	0.509053	12500	-3.243590	17500	-8.797140
2600	-0.079782	7600	0.537847	12600	-3.343160	17600	-8.788180
2700	-0.062663	7700	0.565816	12700	-3.442730	17700	-8.776980
2800	-0.043862	7800	0.592574	12800	-3.542290	17800	-8.764980
2900	-0.024871	7900	0.618369	12900	-3.661270	17900	-8.752820
3000	-0.006904	8000	0.643126	13000	-3.812890	18000	-8.741430
3100	0.009104	8100	0.666174	13100	-3.975480	18100	-8.730780
3200	0.022604	8200	0.686558	13200	-4.148560	18200	-8.721290
3300	0.033449	8300	0.703703	13300	-4.331000	18300	-8.713840
3400	0.042074	8400	0.717062	13400	-4.518220	18400	-8.707890
3500	0.050228	8500	0.725375	13500	-4.711310	18500	-8.703160
3600	0.059697	8600	0.728013	13600	-4.908470	18600	-8.702030
3700	0.071340	8700	0.724823	13700	-5.109130	18700	-8.703720
3800	0.085552	8800	0.714751	13800	-5.312760	18800	-8.709940
3900	0.100474	8900	0.695975	13900	-5.518790	18900	-8.718980
4000	0.115396	9000	0.666550	14000	-5.726910	19000	-8.733710
4100	0.128568	9100	0.624060	14100	-5.936230	19100	-8.748440
4200	0.139466	9200	0.566250	14200	-6.146890	19200	-8.769710
4300	0.148708	9300	0.488424	14300	-6.357430	19300	-8.796470
4400	0.156683	9400	0.394710	14400	-6.566680	19400	-8.827140
4500	0.162995	9500	0.278108	14500	-6.772710	19500	-8.861000
4600	0.166482	9600	0.133384	14600	-6.973490	19600	-8.895830
4700	0.166409	9700	-0.042795	14700	-7.166960	19700	-8.931440
4800	0.161371	9800	-0.251763	14800	-7.347420	19800	-8.966380
4900	0.152639	9900	-0.494219	14900	-7.525050	19900	-8.999370

Temperature

Vostok isotopic temperature record

J. Jouzel, C. Lorius, J.R. Petit, N.I. Barkov, and V.M. Kotlyakov (continued)

VOSTOK ISOTOPE TEMPERATURE RECORD

Vostok Isotope Temperature Record (continued)^a

Years BP	Temperature variation (°C)	Years BP	Temperature variation (°C)	Years BP	Temperature variation (°C)	Years BP	Temperature variation (°C)
20000	-9.029700	25000	-8.624670	30000	-7.654520	35000	-7.177340
20100	-9.052730	25100	-8.627950	30100	-7.649090	35100	-7.174630
20200	-9.075020	25200	-8.627610	30200	-7.643400	35200	-7.170360
20300	-9.097300	25300	-8.622370	30300	-7.635070	35300	-7.164860
20400	-9.117980	25400	-8.615770	30400	-7.622240	35400	-7.158190
20500	-9.131580	25500	-8.605290	30500	-7.602890	35500	-7.149990
20600	-9.139500	25600	-8.592930	30600	-7.575970	35600	-7.139330
20700	-9.145140	25700	-8.580570	30700	-7.539770	35700	-7.125550
20800	-9.143930	25800	-8.567130	30800	-7.500610	35800	-7.107930
20900	-9.136490	25900	-8.554270	30900	-7.446510	35900	-7.085550
21000	-9.121280	26000	-8.541470	31000	-7.385500	36000	-7.058920
21100	-9.097570	26100	-8.528660	31100	-7.315410	36100	-7.028250
21200	-9.073860	26200	-8.515860	31200	-7.234730	36200	-6.996060
21300	-9.044460	26300	-8.503050	31300	-7.146060	36300	-6.963870
21400	-9.005160	26400	-8.491930	31400	-7.051010	36400	-6.931680
21500	-8.964110	26500	-8.485170	31500	-6.951320	36500	-6.900800
21600	-8.921130	26600	-8.478410	31600	-6.848690	36600	-6.873390
21700	-8.872680	26700	-8.471640	31700	-6.745750	36700	-6.849250
21800	-8.821600	26800	-8.464880	31800	-6.644780	36800	-6.828940
21900	-8.767640	26900	-8.457980	31900	-6.548040	36900	-6.811970
22000	-8.713280	27000	-8.448020	32000	-6.458140	37000	-6.798220
22100	-8.659340	27100	-8.434910	32100	-6.378020	37100	-6.786350
22200	-8.606170	27200	-8.419550	32200	-6.308980	37200	-6.775250
22300	-8.555840	27300	-8.401660	32300	-6.252750	37300	-6.762900
22400	-8.509520	27400	-8.381000	32400	-6.220130	37400	-6.746580
22500	-8.465720	27500	-8.358790	32500	-6.191010	37500	-6.724400
22600	-8.427510	27600	-8.336370	32600	-6.173820	37600	-6.694640
22700	-8.389310	27700	-8.314330	32700	-6.172420	37700	-6.655070
22800	-8.351100	27800	-8.292550	32800	-6.187970	37800	-6.608680
22900	-8.319190	27900	-8.269460	32900	-6.218360	37900	-6.555000
23000	-8.291770	28000	-8.246190	33000	-6.261520	38000	-6.491590
23100	-8.268650	28100	-8.222910	33100	-6.318760	38100	-6.421430
23200	-8.251520	28200	-8.199640	33200	-6.381240	38200	-6.345990
23300	-8.241020	28300	-8.173860	33300	-6.455530	38300	-6.266700
23400	-8.238290	28400	-8.145160	33400	-6.535630	38400	-6.185600
23500	-8.245420	28500	-8.113230	33500	-6.619000	38500	-6.105600
23600	-8.256620	28600	-8.078340	33600	-6.702690	38600	-6.026300
23700	-8.276120	28700	-8.040110	33700	-6.782670	38700	-5.953620
23800	-8.301750	28800	-7.999660	33800	-6.857540	38800	-5.886470
23900	-8.332760	28900	-7.956380	33900	-6.924390	38900	-5.829050
24000	-8.367000	29000	-7.912680	34000	-6.981940	39000	-5.783920
24100	-8.402810	29100	-7.868660	34100	-7.029810	39100	-5.750610
24200	-8.438780	29200	-7.826300	34200	-7.068210	39200	-5.729560
24300	-8.473680	29300	-7.787190	34300	-7.101750	39300	-5.722660
24400	-8.507390	29400	-7.753320	34400	-7.127070	39400	-5.727910
24500	-8.537320	29500	-7.724900	34500	-7.141240	39500	-5.744090
24600	-8.564030	29600	-7.701800	34600	-7.155420	39600	-5.771620
24700	-8.584300	29700	-7.683800	34700	-7.169600	39700	-5.809190
24800	-8.601060	29800	-7.670560	34800	-7.176930	39800	-5.854690
24900	-8.616570	29900	-7.661300	34900	-7.178400	39900	-5.907430

Vostok isotopic temperature record

J. Jouzel, C. Lorius, J.R. Petit, N.I. Barkov, and V.M. Kotlyakov (continued)

VOSTOK ISOTOPE TEMPERATURE RECORD

Vostok Isotope Temperature Record (continued)^a

Years BP	Temperature variation (°C)	Years BP	Temperature variation (°C)	Years BP	Temperature variation (°C)	Years BP	Temperature variation (°C)
40000	-5.966820	45000	-6.862780	50000	-6.606350	55000	-5.677520
40100	-6.031850	45100	-6.814850	50100	-6.628020	55100	-5.758360
40200	-6.099270	45200	-6.766330	50200	-6.645330	55200	-5.836250
40300	-6.171640	45300	-6.716850	50300	-6.657870	55300	-5.910950
40400	-6.247480	45400	-6.666880	50400	-6.665900	55400	-5.980660
40500	-6.325790	45500	-6.616270	50500	-6.663720	55500	-6.046690
40600	-6.407090	45600	-6.564860	50600	-6.660250	55600	-6.109340
40700	-6.490810	45700	-6.512150	50700	-6.648980	55700	-6.168170
40800	-6.576060	45800	-6.458650	50800	-6.626070	55800	-6.226100
40900	-6.662360	45900	-6.404970	50900	-6.593390	55900	-6.284030
41000	-6.748230	46000	-6.351580	51000	-6.551400	56000	-6.341130
41100	-6.832250	46100	-6.299130	51100	-6.498820	56100	-6.397510
41200	-6.913080	46200	-6.246980	51200	-6.436580	56200	-6.453970
41300	-6.989260	46300	-6.196150	51300	-6.365480	56300	-6.510880
41400	-7.060670	46400	-6.146880	51400	-6.284890	56400	-6.568500
41500	-7.126710	46500	-6.099560	51500	-6.197340	56500	-6.626950
41600	-7.186260	46600	-6.055150	51600	-6.104020	56600	-6.685930
41700	-7.240560	46700	-6.014480	51700	-6.007290	56700	-6.745060
41800	-7.289990	46800	-5.976280	51800	-5.908030	56800	-6.803720
41900	-7.334620	46900	-5.942630	51900	-5.807110	56900	-6.861010
42000	-7.376010	47000	-5.913330	52000	-5.705550	57000	-6.916260
42100	-7.414700	47100	-5.886280	52100	-5.604410	57100	-6.969200
42200	-7.448260	47200	-5.863140	52200	-5.504920	57200	-7.020130
42300	-7.479590	47300	-5.843990	52300	-5.408590	57300	-7.069330
42400	-7.505320	47400	-5.827450	52400	-5.315990	57400	-7.117340
42500	-7.527240	47500	-5.814300	52500	-5.228330	57500	-7.164040
42600	-7.541130	47600	-5.805730	52600	-5.146950	57600	-7.209130
42700	-7.550770	47700	-5.801750	52700	-5.069760	57700	-7.253010
42800	-7.553130	47800	-5.803840	52800	-5.000580	57800	-7.295450
42900	-7.549430	47900	-5.814980	52900	-4.940230	57900	-7.335990
43000	-7.541020	48000	-5.832070	53000	-4.888960	58000	-7.373890
43100	-7.527960	48100	-5.856680	53100	-4.848470	58100	-7.407560
43200	-7.509270	48200	-5.886970	53200	-4.820600	58200	-7.435850
43300	-7.485840	48300	-5.919260	53300	-4.804360	58300	-7.457910
43400	-7.458010	48400	-5.954950	53400	-4.800010	58400	-7.473150
43500	-7.426000	48500	-5.993570	53500	-4.807420	58500	-7.481240
43600	-7.391440	48600	-6.034980	53600	-4.827250	58600	-7.482320
43700	-7.355280	48700	-6.077760	53700	-4.852500	58700	-7.478600
43800	-7.318360	48800	-6.123650	53800	-4.885070	58800	-7.474870
43900	-7.281370	48900	-6.171610	53900	-4.923990	58900	-7.471140
44000	-7.244670	49000	-6.221530	54000	-4.967820	59000	-7.467940
44100	-7.208760	49100	-6.272720	54100	-5.016790	59100	-7.469010
44200	-7.173540	49200	-6.323490	54200	-5.070510	59200	-7.476070
44300	-7.138970	49300	-6.372070	54300	-5.129410	59300	-7.490460
44400	-7.104180	49400	-6.417270	54400	-5.194620	59400	-7.513080
44500	-7.068550	49500	-6.458680	54500	-5.265680	59500	-7.548490
44600	-7.031440	49600	-6.495290	54600	-5.342290	59600	-7.583910
44700	-6.992690	49700	-6.525660	54700	-5.423840	59700	-7.627880
44800	-6.951620	49800	-6.556020	54800	-5.508350	59800	-7.677840
44900	-6.908270	49900	-6.582200	54900	-5.593490	59900	-7.731840

Temperature

Vostok isotopic temperature record

J. Jouzel, C. Lorius, J.R. Petit, N.I. Barkov, and V.M. Kotlyakov (continued)

VOSTOK ISOTOPE TEMPERATURE RECORD

Vostok Isotope Temperature Record (continued)^a

Years BP	Temperature variation (°C)	Years BP	Temperature variation (°C)	Years BP	Temperature variation (°C)	Years BP	Temperature variation (°C)
60000	-7.787750	65000	-7.577890	70000	-6.517180	75000	-5.876240
60100	-7.843820	65100	-7.555960	70100	-6.428470	75100	-5.802000
60200	-7.898850	65200	-7.525870	70200	-6.339840	75200	-5.727160
60300	-7.951630	65300	-7.492750	70300	-6.252300	75300	-5.651210
60400	-8.001130	65400	-7.448000	70400	-6.167250	75400	-5.573720
60500	-8.045830	65500	-7.393120	70500	-6.085900	75500	-5.494400
60600	-8.085410	65600	-7.328320	70600	-6.007380	75600	-5.412190
60700	-8.119500	65700	-7.254340	70700	-5.934680	75700	-5.326090
60800	-8.148290	65800	-7.166780	70800	-5.868110	75800	-5.234860
60900	-8.172340	65900	-7.077920	70900	-5.812430	75900	-5.142210
61000	-8.192130	66000	-6.989060	71000	-5.760780	76000	-5.047240
61100	-8.208640	66100	-6.900200	71100	-5.723540	76100	-4.951490
61200	-8.221540	66200	-6.811340	71200	-5.698750	76200	-4.855770
61300	-8.232170	66300	-6.725590	71300	-5.686880	76300	-4.760680
61400	-8.240010	66400	-6.645090	71400	-5.688570	76400	-4.666610
61500	-8.244840	66500	-6.573140	71500	-5.704720	76500	-4.574080
61600	-8.247000	66600	-6.511620	71600	-5.734000	76600	-4.483810
61700	-8.246930	66700	-6.461930	71700	-5.776070	76700	-4.398270
61800	-8.245570	66800	-6.425190	71800	-5.829810	76800	-4.317590
61900	-8.243650	66900	-6.402060	71900	-5.897190	76900	-4.236910
62000	-8.242290	67000	-6.392770	72000	-5.968380	77000	-4.163230
62100	-8.241970	67100	-6.397710	72100	-6.049520	77100	-4.095050
62200	-8.242730	67200	-6.415810	72200	-6.137280	77200	-4.031900
62300	-8.244420	67300	-6.445600	72300	-6.227290	77300	-3.974050
62400	-8.246800	67400	-6.484980	72400	-6.317680	77400	-3.922540
62500	-8.249500	67500	-6.532740	72500	-6.407390	77500	-3.877310
62600	-8.252110	67600	-6.587100	72600	-6.492470	77600	-3.838320
62700	-8.253420	67700	-6.646160	72700	-6.570550	77700	-3.805580
62800	-8.254330	67800	-6.707660	72800	-6.638920	77800	-3.779670
62900	-8.251700	67900	-6.769420	72900	-6.694920	77900	-3.758780
63000	-8.245320	68000	-6.830060	73000	-6.739450	78000	-3.740190
63100	-8.234240	68100	-6.889470	73100	-6.772590	78100	-3.722660
63200	-8.217610	68200	-6.946090	73200	-6.794240	78200	-3.704930
63300	-8.194980	68300	-6.999320	73300	-6.802770	78300	-3.687020
63400	-8.166330	68400	-7.047670	73400	-6.799230	78400	-3.668490
63500	-8.131780	68500	-7.089760	73500	-6.784690	78500	-3.650070
63600	-8.091210	68600	-7.123830	73600	-6.760210	78600	-3.632880
63700	-8.045130	68700	-7.144950	73700	-6.727090	78700	-3.617240
63800	-7.994980	68800	-7.161720	73800	-6.685870	78800	-3.603190
63900	-7.942620	68900	-7.161180	73900	-6.637090	78900	-3.590670
64000	-7.888280	69000	-7.147250	74000	-6.584110	79000	-3.578440
64100	-7.833940	69100	-7.126240	74100	-6.525730	79100	-3.566740
64200	-7.782310	69200	-7.090700	74200	-6.461620	79200	-3.555450
64300	-7.736170	69300	-7.044300	74300	-6.393570	79300	-3.544690
64400	-7.697930	69400	-6.987580	74400	-6.321420	79400	-3.534000
64500	-7.667930	69500	-6.921930	74500	-6.247610	79500	-3.522510
64600	-7.645080	69600	-6.849570	74600	-6.173260	79600	-3.509140
64700	-7.627180	69700	-6.771880	74700	-6.098450	79700	-3.492760
64800	-7.611620	69800	-6.690110	74800	-6.024210	79800	-3.472050
64900	-7.595850	69900	-6.604950	74900	-5.950260	79900	-3.441530

Vostok isotopic temperature record

J. Jouzel, C. Lorius, J.R. Petit, N.I. Barkov, and V.M. Kotlyakov (continued)

VOSTOK ISOTOPE TEMPERATURE RECORD

Vostok Isotope Temperature Record (continued)^a

Years BP	Temperature variation (°C)	Years BP	Temperature variation (°C)	Years BP	Temperature variation (°C)	Years BP	Temperature variation (°C)
80000	-3.409190	85000	-4.960020	90000	-4.915180	95000	-4.855890
80100	-3.376860	85100	-5.014910	90100	-4.898100	95100	-4.833690
80200	-3.338370	85200	-5.070260	90200	-4.879310	95200	-4.809280
80300	-3.296170	85300	-5.126930	90300	-4.859630	95300	-4.781090
80400	-3.252850	85400	-5.185560	90400	-4.840050	95400	-4.749820
80500	-3.210160	85500	-5.245700	90500	-4.822050	95500	-4.715080
80600	-3.169450	85600	-5.307930	90600	-4.807690	95600	-4.678330
80700	-3.131550	85700	-5.371040	90700	-4.797060	95700	-4.640700
80800	-3.096850	85800	-5.434150	90800	-4.789570	95800	-4.602930
80900	-3.066480	85900	-5.496190	90900	-4.784070	95900	-4.565160
81000	-3.043040	86000	-5.555160	91000	-4.778510	96000	-4.528240
81100	-3.027350	86100	-5.608890	91100	-4.771540	96100	-4.491950
81200	-3.019760	86200	-5.662610	91200	-4.763010	96200	-4.456400
81300	-3.021890	86300	-5.709880	91300	-4.753090	96300	-4.421730
81400	-3.034300	86400	-5.749910	91400	-4.741580	96400	-4.387940
81500	-3.057610	86500	-5.780880	91500	-4.728080	96500	-4.354710
81600	-3.089660	86600	-5.801840	91600	-4.712420	96600	-4.321600
81700	-3.132970	86700	-5.811400	91700	-4.694790	96700	-4.287970
81800	-3.183670	86800	-5.811170	91800	-4.676210	96800	-4.253690
81900	-3.239940	86900	-5.801540	91900	-4.656820	96900	-4.218720
82000	-3.300900	87000	-5.782390	92000	-4.637080	97000	-4.183050
82100	-3.366790	87100	-5.754960	92100	-4.617390	97100	-4.146650
82200	-3.432680	87200	-5.721400	92200	-4.598840	97200	-4.109570
82300	-3.498570	87300	-5.682710	92300	-4.582420	97300	-4.071600
82400	-3.566010	87400	-5.639120	92400	-4.570390	97400	-4.033230
82500	-3.633450	87500	-5.592110	92500	-4.558910	97500	-3.994810
82600	-3.700370	87600	-5.542210	92600	-4.549870	97600	-3.956030
82700	-3.765120	87700	-5.489830	92700	-4.547370	97700	-3.916980
82800	-3.827560	87800	-5.436170	92800	-4.546540	97800	-3.876790
82900	-3.887430	87900	-5.383310	92900	-4.548460	97900	-3.835860
83000	-3.944650	88000	-5.333860	93000	-4.555680	98000	-3.792350
83100	-3.999690	88100	-5.289650	93100	-4.566780	98100	-3.748820
83200	-4.052560	88200	-5.249210	93200	-4.583280	98200	-3.701650
83300	-4.103100	88300	-5.214310	93300	-4.604470	98300	-3.654130
83400	-4.152570	88400	-5.183740	93400	-4.629900	98400	-3.603260
83500	-4.200580	88500	-5.156720	93500	-4.658680	98500	-3.550020
83600	-4.248190	88600	-5.132130	93600	-4.689620	98600	-3.494570
83700	-4.295860	88700	-5.109170	93700	-4.720980	98700	-3.436220
83800	-4.343460	88800	-5.087940	93800	-4.751720	98800	-3.377590
83900	-4.390970	88900	-5.068600	93900	-4.779840	98900	-3.317310
84000	-4.438560	89000	-5.051430	94000	-4.806670	99000	-3.256680
84100	-4.486480	89100	-5.036170	94100	-4.833510	99100	-3.196940
84200	-4.535280	89200	-5.022180	94200	-4.856680	99200	-3.137490
84300	-4.585130	89300	-5.008750	94300	-4.874950	99300	-3.080920
84400	-4.636450	89400	-4.995880	94400	-4.888050	99400	-3.027070
84500	-4.689350	89500	-4.983450	94500	-4.896010	99500	-2.976640
84600	-4.743170	89600	-4.971270	94600	-4.898730	99600	-2.932360
84700	-4.796990	89700	-4.959060	94700	-4.895520	99700	-2.893050
84800	-4.850810	89800	-4.946070	94800	-4.886120	99800	-2.858970
84900	-4.905300	89900	-4.931340	94900	-4.872720	99900	-2.834610

Temperature

Vostok isotopic temperature record

J. Jouzel, C. Lorius, J.R. Petit, N.I. Barkov, and V.M. Kotlyakov (continued)

VOSTOK ISOTOPE TEMPERATURE RECORD

Vostok Isotope Temperature Record (continued)^a

Years BP	Temperature variation (°C)	Years BP	Temperature variation (°C)	Years BP	Temperature variation (°C)	Years BP	Temperature variation (°C)
100000	-2.819270	105000	-4.176680	110000	-6.566370	115000	-4.877930
100100	-2.808070	105100	-4.186170	110100	-6.552430	115100	-4.806100
100200	-2.811930	105200	-4.209140	110200	-6.538500	115200	-4.733620
100300	-2.820130	105300	-4.236370	110300	-6.524560	115300	-4.659320
100400	-2.838590	105400	-4.280300	110400	-6.510620	115400	-4.582770
100500	-2.866840	105500	-4.327890	110500	-6.496680	115500	-4.504840
100600	-2.899610	105600	-4.392250	110600	-6.482740	115600	-4.423260
100700	-2.946120	105700	-4.459120	110700	-6.468800	115700	-4.341060
100800	-2.995940	105800	-4.540520	110800	-6.454860	115800	-4.256820
100900	-3.054250	105900	-4.623910	110900	-6.446730	115900	-4.171510
101000	-3.118310	106000	-4.721200	111000	-6.442630	116000	-4.085650
101100	-3.186210	106100	-4.819190	111100	-6.439080	116100	-3.999470
101200	-3.261450	106200	-4.927780	111200	-6.436030	116200	-3.913150
101300	-3.338460	106300	-5.037590	111300	-6.431020	116300	-3.826830
101400	-3.419900	106400	-5.157190	111400	-6.425660	116400	-3.740510
101500	-3.502530	106500	-5.276800	111500	-6.420310	116500	-3.654200
101600	-3.586730	106600	-5.396400	111600	-6.414950	116600	-3.567880
101700	-3.670310	106700	-5.516500	111700	-6.409600	116700	-3.485310
101800	-3.753060	106800	-5.641660	111800	-6.404240	116800	-3.404680
101900	-3.831130	106900	-5.761280	111900	-6.398880	116900	-3.325670
102000	-3.906530	107000	-5.880490	112000	-6.393530	117000	-3.246780
102100	-3.973630	107100	-5.999700	112100	-6.381320	117100	-3.168210
102200	-4.040720	107200	-6.118900	112200	-6.368260	117200	-3.089190
102300	-4.098490	107300	-6.238110	112300	-6.352810	117300	-3.009650
102400	-4.148920	107400	-6.339490	112400	-6.325700	117400	-2.929430
102500	-4.194040	107500	-6.436510	112500	-6.298590	117500	-2.848600
102600	-4.230500	107600	-6.512570	112600	-6.271480	117600	-2.766990
102700	-4.264360	107700	-6.588630	112700	-6.244380	117700	-2.685220
102800	-4.289210	107800	-6.664690	112800	-6.217270	117800	-2.603450
102900	-4.311540	107900	-6.719300	112900	-6.188620	117900	-2.521930
103000	-4.327970	108000	-6.765140	113000	-6.147520	118000	-2.440880
103100	-4.340420	108100	-6.810990	113100	-6.102890	118100	-2.361890
103200	-4.349050	108200	-6.840120	113200	-6.055650	118200	-2.282900
103300	-4.353140	108300	-6.863680	113300	-6.002440	118300	-2.208930
103400	-4.354660	108400	-6.871010	113400	-5.947330	118400	-2.135570
103500	-4.350970	108500	-6.867520	113500	-5.888200	118500	-2.067170
103600	-4.345250	108600	-6.864030	113600	-5.825150	118600	-2.001240
103700	-4.339220	108700	-6.860530	113700	-5.760790	118700	-1.940160
103800	-4.327410	108800	-6.857040	113800	-5.696250	118800	-1.881970
103900	-4.315010	108900	-6.853550	113900	-5.629950	118900	-1.826430
104000	-4.299050	109000	-6.839950	114000	-5.563550	119000	-1.775340
104100	-4.282140	109100	-6.817760	114100	-5.497080	119100	-1.726170
104200	-4.263880	109200	-6.794240	114200	-5.430570	119200	-1.679300
104300	-4.245500	109300	-6.765080	114300	-5.363400	119300	-1.634960
104400	-4.227170	109400	-6.735920	114400	-5.296110	119400	-1.591550
104500	-4.210740	109500	-6.706760	114500	-5.227410	119500	-1.549020
104600	-4.195550	109600	-6.677600	114600	-5.158500	119600	-1.507440
104700	-4.187970	109700	-6.648130	114700	-5.088690	119700	-1.468010
104800	-4.180400	109800	-6.618660	114800	-5.018880	119800	-1.428570
104900	-4.172820	109900	-6.592330	114900	-4.948470	119900	-1.389130

Vostok isotopic temperature record

J. Jouzel, C. Lorius, J.R. Petit, N.I. Barkov, and V.M. Kotlyakov (continued)

VOSTOK ISOTOPE TEMPERATURE RECORD

Vostok Isotope Temperature Record (continued)^a

Years BP	Temperature variation (°C)	Years BP	Temperature variation (°C)	Years BP	Temperature variation (°C)	Years BP	Temperature variation (°C)
120000	-1.353480	125000	0.086079	130000	1.096870	135000	1.608940
120100	-1.319700	125100	0.097726	130100	1.187200	135100	1.530780
120200	-1.287160	125200	0.108831	130200	1.283350	135200	1.444910
120300	-1.258140	125300	0.119015	130300	1.383180	135300	1.353850
120400	-1.231460	125400	0.129599	130400	1.484490	135400	1.259330
120500	-1.207770	125500	0.141566	130500	1.585900	135500	1.155420
120600	-1.186350	125600	0.155528	130600	1.685720	135600	1.043220
120700	-1.166120	125700	0.172424	130700	1.783260	135700	0.924646
120800	-1.147060	125800	0.192780	130800	1.873000	135800	0.800264
120900	-1.128560	125900	0.217582	130900	1.962750	135900	0.670533
121000	-1.110610	126000	0.244271	131000	2.052490	136000	0.534639
121100	-1.092690	126100	0.273898	131100	2.136160	136100	0.394313
121200	-1.074800	126200	0.305503	131200	2.214510	136200	0.250709
121300	-1.055620	126300	0.337921	131300	2.286120	136300	0.104672
121400	-1.035220	126400	0.370467	131400	2.351410	136400	-0.044217
121500	-1.013270	126500	0.402818	131500	2.411900	136500	-0.194462
121600	-0.988824	126600	0.434112	131600	2.466560	136600	-0.345572
121700	-0.962183	126700	0.464514	131700	2.513580	136700	-0.497722
121800	-0.933838	126800	0.493022	131800	2.555870	136800	-0.650307
121900	-0.901786	126900	0.519087	131900	2.593150	136900	-0.803149
122000	-0.868174	127000	0.542301	132000	2.622980	137000	-0.956142
122100	-0.831393	127100	0.561644	132100	2.648330	137100	-1.107770
122200	-0.792235	127200	0.575480	132200	2.668480	137200	-1.258320
122300	-0.750544	127300	0.585158	132300	2.682590	137300	-1.405350
122400	-0.706721	127400	0.594836	132400	2.694480	137400	-1.549790
122500	-0.662898	127500	0.599075	132500	2.696330	137500	-1.691430
122600	-0.618926	127600	0.600610	132600	2.698180	137600	-1.827500
122700	-0.574709	127700	0.600605	132700	2.696430	137700	-1.960410
122800	-0.532589	127800	0.598391	132800	2.685270	137800	-2.089460
122900	-0.491725	127900	0.595529	132900	2.669850	137900	-2.210610
123000	-0.453490	128000	0.592090	133000	2.646110	138000	-2.330780
123100	-0.418179	128100	0.588695	133100	2.618870	138100	-2.446540
123200	-0.385004	128200	0.586172	133200	2.585930	138200	-2.558330
123300	-0.352940	128300	0.585092	133300	2.548270	138300	-2.665900
123400	-0.322373	128400	0.585331	133400	2.506470	138400	-2.771180
123500	-0.292135	128500	0.588028	133500	2.462360	138500	-2.875220
123600	-0.262321	128600	0.592326	133600	2.416610	138600	-2.979260
123700	-0.232684	128700	0.598032	133700	2.368130	138700	-3.083080
123800	-0.203327	128800	0.605203	133800	2.316820	138800	-3.186980
123900	-0.173970	128900	0.615104	133900	2.265510	138900	-3.292300
124000	-0.144634	129000	0.627430	134000	2.213170	139000	-3.398600
124100	-0.115299	129100	0.643046	134100	2.159160	139100	-3.506520
124200	-0.086544	129200	0.662947	134200	2.103620	139200	-3.617030
124300	-0.058003	129300	0.688719	134300	2.046450	139300	-3.729070
124400	-0.031981	129400	0.722022	134400	1.988560	139400	-3.846080
124500	-0.006474	129500	0.762863	134500	1.930140	139500	-3.967150
124600	0.016738	129600	0.811345	134600	1.871480	139600	-4.094070
124700	0.037745	129700	0.868460	134700	1.810920	139700	-4.220990
124800	0.055903	129800	0.936139	134800	1.747950	139800	-4.355260
124900	0.072119	129900	1.013040	134900	1.681620	139900	-4.494870

Temperature

Vostok isotopic temperature record

J. Jouzel, C. Lorius, J.R. Petit, N.I. Barkov, and V.M. Kotlyakov (continued)

VOSTOK ISOTOPE TEMPERATURE RECORD

Vostok Isotope Temperature Record (continued)^a

Years BP	Temperature variation (°C)	Years BP	Temperature variation (°C)	Years BP	Temperature variation (°C)	Years BP	Temperature variation (°C)
140000	-4.640790	145000	-8.689950	150000	-8.513590	155000	-8.806560
140100	-4.790970	145100	-8.733430	150100	-8.513460	155100	-8.825380
140200	-4.943460	145200	-8.776920	150200	-8.513800	155200	-8.843620
140300	-5.100180	145300	-8.811680	150300	-8.514830	155300	-8.861850
140400	-5.257370	145400	-8.844900	150400	-8.517780	155400	-8.878970
140500	-5.415470	145500	-8.872360	150500	-8.520730	155500	-8.892130
140600	-5.572300	145600	-8.894700	150600	-8.524790	155600	-8.905290
140700	-5.728840	145700	-8.916930	150700	-8.531560	155700	-8.916440
140800	-5.881710	145800	-8.928930	150800	-8.538320	155800	-8.922660
140900	-6.033430	145900	-8.940930	150900	-8.545080	155900	-8.928880
141000	-6.181110	146000	-8.950160	151000	-8.551850	156000	-8.931480
141100	-6.325980	146100	-8.953480	151100	-8.558610	156100	-8.929470
141200	-6.463660	146200	-8.956810	151200	-8.565410	156200	-8.927470
141300	-6.598360	146300	-8.953290	151300	-8.572310	156300	-8.918600
141400	-6.722020	146400	-8.948370	151400	-8.579210	156400	-8.904970
141500	-6.843480	146500	-8.941650	151500	-8.586120	156500	-8.891330
141600	-6.952400	146600	-8.929790	151600	-8.593020	156600	-8.877700
141700	-7.055800	146700	-8.917940	151700	-8.599920	156700	-8.864060
141800	-7.150560	146800	-8.902280	151800	-8.605650	156800	-8.850420
141900	-7.231340	146900	-8.885500	151900	-8.611190	156900	-8.836790
142000	-7.305840	147000	-8.867220	152000	-8.616730	157000	-8.823150
142100	-7.380340	147100	-8.847730	152100	-8.622120	157100	-8.809100
142200	-7.454840	147200	-8.828240	152200	-8.625910	157200	-8.793480
142300	-7.519160	147300	-8.807760	152300	-8.629690	157300	-8.777850
142400	-7.576390	147400	-8.786990	152400	-8.632690	157400	-8.763340
142500	-7.628700	147500	-8.766830	152500	-8.631240	157500	-8.749820
142600	-7.676270	147600	-8.748790	152600	-8.629780	157600	-8.736290
142700	-7.718230	147700	-8.730760	152700	-8.627660	157700	-8.723020
142800	-7.756290	147800	-8.712720	152800	-8.621030	157800	-8.710950
142900	-7.792830	147900	-8.694680	152900	-8.614410	157900	-8.698870
143000	-7.823630	148000	-8.678750	153000	-8.607650	158000	-8.687010
143100	-7.854430	148100	-8.664270	153100	-8.600350	158100	-8.676320
143200	-7.883720	148200	-8.649800	153200	-8.593050	158200	-8.665640
143300	-7.912570	148300	-8.637730	153300	-8.586260	158300	-8.656370
143400	-7.943060	148400	-8.626370	153400	-8.584750	158400	-8.647650
143500	-7.973980	148500	-8.615010	153500	-8.583240	158500	-8.638960
143600	-8.008860	148600	-8.603720	153600	-8.582270	158600	-8.630500
143700	-8.045700	148700	-8.593860	153700	-8.588450	158700	-8.622030
143800	-8.082540	148800	-8.584000	153800	-8.594630	158800	-8.611760
143900	-8.124190	148900	-8.574400	153900	-8.601300	158900	-8.601160
144000	-8.167810	149000	-8.566510	154000	-8.615610	159000	-8.590570
144100	-8.211430	149100	-8.558610	154100	-8.629930	159100	-8.579980
144200	-8.260330	149200	-8.551170	154200	-8.644440	159200	-8.567000
144300	-8.310480	149300	-8.544740	154300	-8.663760	159300	-8.552740
144400	-8.364380	149400	-8.538310	154400	-8.683070	159400	-8.538430
144500	-8.419480	149500	-8.532570	154500	-8.702580	159500	-8.523830
144600	-8.475550	149600	-8.527330	154600	-8.723640	159600	-8.509340
144700	-8.532150	149700	-8.522090	154700	-8.744700	159700	-8.495650
144800	-8.587120	149800	-8.518800	154800	-8.765530	159800	-8.481970
144900	-8.639320	149900	-8.516190	154900	-8.786040	159900	-8.468560

Vostok isotopic temperature record

J. Jouzel, C. Lorius, J.R. Petit, N.I. Barkov, and V.M. Kotlyakov (continued)

VOSTOK ISOTOPE TEMPERATURE RECORD

Vostok Isotope Temperature Record (continued)^a

Years BP	Temperature variation (°C)	Years BP	Temperature variation (°C)	Years BP	Temperature variation (°C)	Years BP	Temperature variation (°C)
160000	-8.455250	161200	-8.288270	162300	-8.012200	163400	-7.720110
160100	-8.442250	161300	-8.268940	162400	-7.981290	163500	-7.704120
160200	-8.429710	161400	-8.246640	162500	-7.950060	163600	-7.691360
160300	-8.417170	161500	-8.224350	162600	-7.918830	163700	-7.682680
160400	-8.405270	161600	-8.201490	162700	-7.887930	163800	-7.674020
160500	-8.393520	161700	-8.176540	162800	-7.859660	163900	-7.667370
160600	-8.381570	161800	-8.151590	162900	-7.831380	164000	-7.662760
160700	-8.368310	161900	-8.124700	163000	-7.803110	164100	-7.658150
160800	-8.355050	162000	-8.096580	163100	-7.780070	164200	-7.653650
160900	-8.341790	162100	-8.068450	163200	-7.757020	164300	-7.649390
161000	-8.324140	162200	-8.040330	163300	-7.736090	164400	-7.645130
161100	-8.306210						

^aThese temperature variations are relative to the mean annual surface temperature for Vostok (-55.5°C). The Vostok temperature record is reconstructed from the continuous deuterium profile measured along the core and refers to the atmospheric temperature change just above the inversion layer. Paleotemperature reconstruction is based on the present correlations between the ratios $^2\text{H}(\text{D}):^1\text{H}$ and $^{18}\text{O}:^{16}\text{O}$ in the snow and the temperature conditions just above the inversion layer, where the precipitation is formed, and at the surface (Lorius et al. 1990).

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Global and hemispheric temperature anomalies—land
and marine instrumental records

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Period of Record

1854–1993 (relative to a 1950–79 reference period)

Methods

These global and hemispheric temperature anomaly estimates were compiled by Jones et al. (1986a,b,c), Jones (1988a,b), Jones and Wigley (1990), and Jones et al. (1991) and are based on corrected land and marine data. Land data were derived from meteorological data and fixed-position weather ship data that were corrected for nonclimatic errors, such as station shifts and/or instrument changes (Jones et al. 1985, 1986d; Jones and Wigley 1990; Jones and Briffa 1992). The marine data were from the Comprehensive Ocean-Atmosphere Data Set (COADS) compilation (Woodruff et al. 1987) and sea surface temperature (SST) estimates produced by the United Kingdom Meteorological Office (Bottomley et al. 1990). Both SSTs and marine air temperatures were corrected, but only SST data were used in the combined land-marine data set. Two series of global and hemispheric temperature anomaly estimates are provided, one adjusted for the influence of El Niño/Southern Oscillation (ENSO) events and the other uncorrected for ENSO events. The ENSO influence was extracted by using regression techniques (Jones 1988b, Angell 1990).

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Global and hemispheric temperature anomalies—land and marine instrumental records

P.D. Jones, T.M.L. Wigley, and K.R. Briffa (continued)

GLOBAL AND HEMISPHERIC ANOMALIES

Trends

These variations in global and hemispheric annual temperatures compiled by Jones and others at the Climatic Research Unit show little trend during the nineteenth century, marked warming to 1940, relatively steady conditions to the mid-1970s, followed by a rapid warming during the 1980s and early 1990s. The 1980s was a decade of unprecedented warmth, with 1990 the warmest year since comparable records began in the middle of the 19th century. Jones and Briffa (1993) concluded that the surface air temperature of the world has warmed 0.5°C since the middle of the nineteenth century and this same half-degree warming is seen in all seasons in the Southern Hemisphere. According to Jones and Briffa (1992), the warming in the Northern Hemisphere only occurred in winter, spring, and autumn and that summers are now no warmer than in the 1860s and 1870s. Briffa and Jones (1993) also concluded that the warming has varied in extent and magnitude across the face of the earth and a few areas have even cooled since the nineteenth century.

The warmest years in the unadjusted global record presented here have occurred since 1980. The five warmest years of the unadjusted global record, in descending order, are 1990, 1991, 1988, 1983, and 1987. After correction for ENSO events, the 4-year period 1988–91 are the warmest years in the global record. According to Jones (1988), the Southern Oscillation Index (SOI) explains 20–30% of the high-frequency temperature variance.

Global annual temperature anomalies, 1854–1993.

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Global and hemispheric temperature anomalies—land and marine instrumental records

P.D. Jones, T.M.L. Wigley, and K.R. Briffa (continued)

GLOBAL AND HEMISPHERIC ANOMALIES

Northern Hemisphere annual temperature anomalies, 1854–1993.

Southern Hemisphere annual temperature anomalies, 1854–1993.

CITE AS: Jones, P.D., T.M.L. Wigley, and K.R. Briffa. 1994. Global and hemispheric temperature anomalies—land and marine instrumental records. pp. 603–608. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Temperature

Global and hemispheric temperature anomalies—land and marine instrumental records

P.D. Jones, T.M.L. Wigley, and K.R. Briffa (continued)

GLOBAL AND HEMISPHERIC ANOMALIES

Annual Temperature Anomalies^a

Year	North- ern Hem.	South- ern Hem.	Global	ENSO-subtracted ^b			Year	North- ern Hem.	South- ern Hem.	Global	ENSO-subtracted ^b		
				North- ern Hem.	South- ern Hem.	Global					North- ern Hem.	South- ern Hem.	Global
1854	-0.16	-0.07	-0.12				1897	-0.15	-0.05	-0.10	-0.26	-0.16	-0.21
1855	-0.39	-0.46	-0.43				1898	-0.28	-0.34	-0.31	-0.26	-0.31	-0.29
1856	-0.37	-0.19	-0.28				1899	-0.16	-0.20	-0.18	-0.15	-0.19	-0.17
1857	-0.42	-0.53	-0.47				1900	-0.06	-0.05	-0.05	-0.08	-0.07	-0.07
1858	-0.33	-0.43	-0.38				1901	-0.07	-0.21	-0.14	-0.06	-0.20	-0.13
1859	-0.10	-0.26	-0.18				1902	-0.31	-0.19	-0.25	-0.30	-0.17	-0.23
1860	-0.48	-0.29	-0.38				1903	-0.35	-0.42	-0.38	-0.36	-0.42	-0.38
1861	-0.33	-0.57	-0.45				1904	-0.44	-0.50	-0.47	-0.38	-0.43	-0.40
1862	-0.75	-0.41	-0.58				1905	-0.28	-0.34	-0.31	-0.37	-0.43	-0.40
1863	-0.13	-0.33	-0.23				1906	-0.19	-0.26	-0.22	-0.25	-0.32	-0.28
1864	-0.43	-0.49	-0.46				1907	-0.48	-0.35	-0.41	-0.44	-0.31	-0.37
1865	-0.22	-0.24	-0.23				1908	-0.44	-0.44	-0.44	-0.44	-0.44	-0.44
1866	-0.19	-0.20	-0.20				1909	-0.39	-0.33	-0.36	-0.37	-0.31	-0.34
1867	-0.27	-0.19	-0.23	-0.28	-0.20	-0.24	1910	-0.39	-0.32	-0.35	-0.33	-0.26	-0.29
1868	-0.16	-0.37	-0.27	-0.19	-0.39	-0.29	1911	-0.40	-0.40	-0.40	-0.36	-0.35	-0.35
1869	-0.08	-0.34	-0.21	-0.09	-0.35	-0.22	1912	-0.44	-0.18	-0.31	-0.53	-0.27	-0.40
1870	-0.22	-0.39	-0.31	-0.20	-0.37	-0.29	1913	-0.44	-0.22	-0.33	-0.48	-0.26	-0.37
1871	-0.35	-0.38	-0.37	-0.37	-0.40	-0.39	1914	-0.21	-0.12	-0.16	-0.26	-0.17	-0.21
1872	-0.21	-0.36	-0.28	-0.18	-0.32	-0.24	1915	-0.03	-0.07	-0.05	-0.09	-0.13	-0.11
1873	-0.25	-0.35	-0.30	-0.22	-0.32	-0.27	1916	-0.33	-0.25	-0.29	-0.31	-0.22	-0.27
1874	-0.28	-0.50	-0.39	-0.31	-0.53	-0.42	1917	-0.55	-0.38	-0.47	-0.44	-0.27	-0.36
1875	-0.57	-0.32	-0.44	-0.54	-0.29	-0.41	1918	-0.42	-0.29	-0.35	-0.30	-0.16	-0.23
1876	-0.37	-0.42	-0.40	-0.32	-0.37	-0.35	1919	-0.35	-0.14	-0.25	-0.42	-0.21	-0.32
1877	-0.06	-0.17	-0.12	-0.09	-0.20	-0.15	1920	-0.28	-0.17	-0.23	-0.32	-0.21	-0.27
1878	0.17	-0.13	0.02	0.08	-0.22	-0.07	1921	-0.17	-0.24	-0.20	-0.13	-0.20	-0.16
1879	-0.28	-0.42	-0.35	-0.18	-0.32	-0.25	1922	-0.28	-0.29	-0.28	-0.26	-0.27	-0.26
1880	-0.36	-0.28	-0.32	-0.28	-0.19	-0.23	1923	-0.22	-0.27	-0.25	-0.19	-0.24	-0.22
1881	-0.35	-0.23	-0.29	-0.34	-0.22	-0.28	1924	-0.25	-0.33	-0.29	-0.29	-0.37	-0.33
1882	-0.32	-0.27	-0.30	-0.36	-0.31	-0.34	1925	-0.11	-0.24	-0.17	-0.06	-0.19	-0.12
1883	-0.42	-0.29	-0.35	-0.44	-0.31	-0.37	1926	0.05	-0.06	0.00	-0.02	-0.13	-0.07
1884	-0.53	-0.35	-0.44	-0.56	-0.38	-0.47	1927	-0.06	-0.20	-0.13	-0.03	-0.17	-0.10
1885	-0.44	-0.32	-0.38	-0.47	-0.35	-0.41	1928	-0.08	-0.20	-0.14	-0.08	-0.20	-0.14
1886	-0.37	-0.16	-0.27	-0.39	-0.18	-0.29	1929	-0.32	-0.32	-0.32	-0.28	-0.27	-0.27
1887	-0.34	-0.45	-0.40	-0.27	-0.38	-0.33	1930	-0.02	-0.25	-0.14	0.00	-0.22	-0.12
1888	-0.28	-0.35	-0.31	-0.32	-0.39	-0.35	1931	0.04	-0.11	-0.04	0.06	-0.08	-0.01
1889	-0.23	-0.11	-0.17	-0.29	-0.17	-0.23	1932	-0.04	-0.17	-0.11	-0.05	-0.17	-0.11
1890	-0.38	-0.41	-0.40	-0.31	-0.34	-0.33	1933	-0.26	-0.19	-0.22	-0.29	-0.22	-0.25
1891	-0.32	-0.36	-0.34	-0.31	-0.35	-0.33	1934	-0.09	-0.13	-0.11	-0.07	-0.11	-0.09
1892	-0.45	-0.30	-0.38	-0.44	-0.29	-0.37	1935	-0.12	-0.19	-0.16	-0.12	-0.19	-0.16
1893	-0.51	-0.34	-0.43	-0.47	-0.30	-0.39	1936	-0.07	-0.18	-0.13	-0.05	-0.16	-0.11
1894	-0.36	-0.33	-0.35	-0.33	-0.30	-0.32	1937	0.09	-0.08	0.01	0.09	-0.08	0.01
1895	-0.41	-0.21	-0.31	-0.42	-0.22	-0.32	1938	0.17	-0.02	0.08	0.19	0.00	0.10
1896	-0.19	-0.08	-0.14	-0.26	-0.15	-0.21	1939	0.04	-0.10	-0.03	0.10	-0.03	0.04

Global and hemispheric temperature anomalies—land
and marine instrumental records

P.D. Jones, T.M.L. Wigley, and K.R. Briffa (continued)

GLOBAL AND HEMISPHERIC ANOMALIES

Annual Temperature Anomalies (continued)^a

Year	North- ern Hem.	South- ern Hem.	Global	ENSO-subtracted ^b			Year	North- ern Hem.	South- ern Hem.	Global	ENSO-subtracted ^b		
				North- ern Hem.	South- ern Hem.	Global					North- ern Hem.	South- ern Hem.	Global
1940	-0.01	0.06	0.03	-0.07	0.00	-0.03	1967	0.05	-0.07	-0.01	0.06	-0.05	0.01
1941	0.03	0.06	0.04	-0.08	-0.06	-0.08	1968	-0.03	-0.09	-0.06	-0.02	-0.07	-0.04
1942	0.08	0.02	0.05	0.01	-0.05	-0.02	1969	0.00	0.12	0.06	-0.03	0.09	0.03
1943	0.10	-0.10	0.00	0.13	-0.06	0.03	1970	0.00	0.09	0.05	-0.03	0.06	0.02
1944	0.21	0.12	0.16	0.21	0.12	0.16	1971	-0.13	-0.03	-0.08	-0.05	0.05	0.00
1945	0.02	0.07	0.05	0.02	0.07	0.05	1972	-0.19	0.23	0.02	-0.18	0.25	0.04
1946	0.07	-0.18	-0.06	0.06	-0.18	-0.07	1973	0.10	0.19	0.14	0.05	0.14	0.09
1947	0.04	-0.11	-0.04	0.00	-0.15	-0.08	1974	-0.22	0.01	-0.10	-0.12	0.12	0.00
1948	0.05	-0.15	-0.05	0.06	-0.14	-0.04	1975	-0.09	-0.08	-0.09	-0.04	-0.03	-0.04
1949	0.02	-0.17	-0.08	0.00	-0.19	-0.10	1976	-0.29	-0.14	-0.22	-0.20	-0.04	-0.12
1950	-0.11	-0.17	-0.14	-0.06	-0.11	-0.08	1977	0.08	0.14	0.11	0.02	0.08	0.05
1951	0.07	-0.10	-0.02	0.13	-0.03	0.04	1978	0.01	0.08	0.04	-0.06	0.01	-0.03
1952	0.09	0.06	0.08	0.06	0.03	0.05	1979	0.07	0.13	0.10	0.07	0.13	0.10
1953	0.24	0.02	0.13	0.20	-0.02	0.09	1980	0.14	0.24	0.19	0.11	0.21	0.16
1954	-0.03	-0.19	-0.11	-0.05	-0.21	-0.13	1981	0.33	0.20	0.27	0.31	0.19	0.26
1955	-0.03	-0.25	-0.14	0.01	-0.21	-0.10	1982	0.04	0.13	0.09	0.03	0.12	0.08
1956	-0.24	-0.20	-0.22	-0.15	-0.10	-0.13	1983	0.25	0.34	0.30	0.09	0.18	0.14
1957	0.05	0.12	0.09	0.07	0.15	0.11	1984	0.00	0.24	0.12	0.00	0.24	0.12
1958	0.17	0.04	0.11	0.12	-0.01	0.06	1985	-0.03	0.20	0.09	-0.03	0.20	0.09
1959	0.11	0.00	0.05	0.09	-0.02	0.03	1986	0.11	0.23	0.17	0.11	0.23	0.17
1960	0.08	-0.11	-0.02	0.09	-0.10	-0.01	1987	0.23	0.36	0.30	0.14	0.27	0.21
1961	0.12	0.12	0.12	0.13	0.13	0.13	1988	0.34	0.34	0.34	0.31	0.31	0.31
1962	0.19	0.03	0.11	0.22	0.07	0.14	1989	0.25	0.24	0.25	0.35	0.34	0.35
1963	0.21	0.06	0.13	0.23	0.08	0.15	1990	0.47	0.31	0.39	0.46	0.30	0.38
1964	-0.15	-0.20	-0.18	-0.16	-0.21	-0.19	1991	0.35	0.34	0.35	0.31	0.28	0.30
1965	-0.15	-0.08	-0.12	-0.15	-0.07	-0.11	1992	0.13	0.21	0.17			
1966	0.00	-0.07	-0.04	-0.08	-0.15	-0.12	1993	0.18	0.24	0.21			

^aExpressed in degrees Celsius and relative to a 1950–79 reference period.^bData corrected for the influences of El Niño/Southern Oscillation (ENSO).

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Global and hemispheric temperature anomalies—land and marine instrumental records

P.D. Jones, T.M.L. Wigley, and K.R. Briffa (continued)

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Global and hemispheric temperature anomalies from instrumental surface air temperature records

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Period of Record

1880–1993 (relative to a 1951–80 reference period)

Methods

Temperature change over the past century is calculated from surface air temperatures published in the *World Weather Records* and the World Meteorological Organization's *Monthly Climatic Data for the World*, supplemented by monthly mean station records available from NOAA's Climate Analysis Center a few days after the end of each month. At a given gridpoint, data from all nearby stations are combined to form an estimate of the temperature change, essentially as described by Hansen and Lebedeff (1987). The gridded data are combined to ultimately obtain estimates for the temperature change record of regions, latitudinal zones, the hemispheres, and the globe.

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Temperature

Global and hemispheric temperature anomalies from instrumental surface air temperature records

H. Wilson and J. Hansen (continued)

GLOBAL AND HEMISPHERIC ANOMALIES

Trends

The Goddard Institute for Space Studies (GISS) analysis indicates shifts in the linear trend of global surface air temperature over the period of record. Global temperature warmed by about 0.5°C over the decades from 1880 to 1940, cooled by about 0.2°C during the period from 1940 to 1965, and then warmed again by about 0.5°C from 1965 to 1993. The pattern of Northern Hemisphere temperature change is similar to the global change. The Northern Hemisphere warmed by 0.7°C from 1880 to 1940, cooled by 0.2°C over the next 30 years, and then warmed by 0.6°C from about 1970 to 1993. The Southern Hemisphere temperature change shows a more steady increase, with a linear trend of about 0.5°C over the period 1880 to 1993. The largest rate of Southern Hemisphere warming occurred over the years from 1965 to 1993. (Values for 1993 are provisional.)

The GISS researchers estimate that the global average data contain an "urban warming" bias on the order of 0.1°C , with larger biases at specific locations. They also report that the global surface air temperatures in the last decade are the warmest in the history of meteorological records and that the eight warmest years on record are all in the 14-year period 1980–93 (the warmest year was 1990). Cooling since 1990 is consistent with the expected global surface temperature drop following the injection of sunlight-blocking sulfuric acid particles into the stratosphere by the June 1991 eruption of the Philippine volcano Mt. Pinatubo.

Global annual temperature anomalies, 1880–1993.

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Global and hemispheric temperature anomalies from instrumental surface air temperature records

H. Wilson and J. Hansen (continued)

GLOBAL AND HEMISPHERIC ANOMALIES

Northern Hemisphere annual temperature anomalies, 1880–1993.

Southern Hemisphere annual temperature anomalies, 1880–1993.

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Temperature

Global and hemispheric temperature anomalies from instrumental surface air temperature records

H. Wilson and J. Hansen (continued)

GLOBAL AND HEMISPHERIC ANOMALIES

Annual Temperature Anomalies^a

Year	Global	Northern Hemisphere	Southern Hemisphere	Year	Global	Northern Hemisphere	Southern Hemisphere
1880	-0.33	-0.53	-0.12	1925	-0.15	-0.05	-0.24
1881	-0.33	-0.40	-0.25	1926	0.10	0.17	0.02
1882	-0.40	-0.46	-0.34	1927	-0.03	0.01	-0.08
1883	-0.40	-0.54	-0.25	1928	0.03	0.11	-0.06
1884	-0.65	-0.78	-0.53	1929	-0.18	-0.16	-0.20
1885	-0.43	-0.54	-0.32	1930	-0.07	0.08	-0.21
1886	-0.40	-0.48	-0.33	1931	0.04	0.16	-0.09
1887	-0.52	-0.60	-0.45	1932	0.02	0.09	-0.05
1888	-0.30	-0.43	-0.18	1933	-0.14	-0.22	-0.05
1889	-0.12	-0.21	-0.03	1934	0.02	0.05	0.00
1890	-0.40	-0.41	-0.39	1935	-0.07	-0.01	-0.13
1891	-0.42	-0.43	-0.42	1936	0.02	0.05	-0.02
1892	-0.40	-0.48	-0.31	1937	0.12	0.24	0.01
1893	-0.46	-0.53	-0.38	1938	0.13	0.26	-0.01
1894	-0.35	-0.43	-0.27	1939	-0.03	0.14	-0.20
1895	-0.36	-0.46	-0.26	1940	0.14	0.17	0.11
1896	-0.19	-0.35	-0.04	1941	0.12	0.15	0.09
1897	-0.15	-0.21	-0.08	1942	0.09	0.08	0.10
1898	-0.37	-0.40	-0.34	1943	0.03	0.06	0.01
1899	-0.22	-0.23	-0.22	1944	0.11	0.13	0.08
1900	-0.01	-0.07	0.06	1945	-0.04	-0.05	-0.04
1901	-0.08	-0.10	-0.07	1946	0.01	0.09	-0.06
1902	-0.25	-0.36	-0.13	1947	0.12	0.16	0.09
1903	-0.36	-0.40	-0.32	1948	-0.01	0.08	-0.10
1904	-0.49	-0.50	-0.48	1949	-0.07	0.02	-0.16
1905	-0.27	-0.30	-0.24	1950	-0.15	-0.14	-0.15
1906	-0.19	-0.18	-0.20	1951	-0.02	0.06	-0.10
1907	-0.43	-0.49	-0.37	1952	0.04	0.09	-0.01
1908	-0.30	-0.38	-0.22	1953	0.13	0.31	-0.04
1909	-0.30	-0.38	-0.23	1954	-0.07	0.02	-0.15
1910	-0.29	-0.41	-0.17	1955	-0.06	-0.10	-0.03
1911	-0.29	-0.31	-0.27	1956	-0.17	-0.30	-0.03
1912	-0.28	-0.43	-0.13	1957	0.10	0.02	0.18
1913	-0.23	-0.36	-0.10	1958	0.10	0.18	0.02
1914	-0.04	-0.15	0.07	1959	0.05	0.12	-0.02
1915	-0.02	-0.07	0.03	1960	-0.01	0.11	-0.12
1916	-0.24	-0.37	-0.12	1961	0.08	0.07	0.10
1917	-0.42	-0.61	-0.22	1962	0.02	0.10	-0.05
1918	-0.35	-0.45	-0.25	1963	0.02	0.10	-0.06
1919	-0.17	-0.30	-0.03	1964	-0.26	-0.23	-0.29
1920	-0.17	-0.21	-0.13	1965	-0.16	-0.18	-0.13
1921	-0.10	-0.10	-0.10	1966	-0.09	-0.06	-0.12
1922	-0.13	-0.19	-0.08	1967	-0.02	-0.01	-0.03
1923	-0.16	-0.11	-0.21	1968	-0.12	-0.13	-0.11
1924	-0.15	-0.12	-0.17	1969	0.03	-0.02	0.08

Global and hemispheric temperature anomalies from instrumental
surface air temperature records

H. Wilson and J. Hansen (continued)

GLOBAL AND HEMISPHERIC ANOMALIES

Annual Temperature Anomalies (continued)^a

Year	Global	Northern Hemisphere	Southern Hemisphere	Year	Global	Northern Hemisphere	Southern Hemisphere
1970	0.04	-0.02	0.10	1982	0.06	0.06	0.07
1971	-0.11	-0.18	-0.05	1983	0.29	0.36	0.22
1972	-0.07	-0.24	0.10	1984	0.11	0.09	0.12
1973	0.20	0.17	0.22	1985	0.10	0.00	0.20
1974	-0.07	-0.17	0.02	1986	0.15	0.15	0.16
1975	-0.05	-0.05	-0.04	1987	0.32	0.31	0.33
1976	-0.22	-0.26	-0.18	1988	0.35	0.42	0.29
1977	0.16	0.16	0.17	1989	0.25	0.30	0.20
1978	0.09	0.08	0.11	1990	0.47	0.62	0.31
1979	0.14	0.15	0.13	1991	0.41	0.48	0.34
1980	0.28	0.22	0.34	1992	0.13	0.14	0.12
1981	0.39	0.50	0.28	1993 ^b	0.20	0.25	0.15

^aAnomalies expressed in degrees Celsius.

^b1993 data are preliminary and subject to change.

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Global and hemispheric temperature anomalies from instrumental surface air temperature records

H. Wilson and J. Hansen (continued)

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Global and hemispheric temperature anomalies from instrumental surface air temperature records

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Period of Record

1881–1993 (relative to a 1951–75 reference period)

Methods

The mean monthly and annual values of surface air temperature compiled by Vinnikov et al. have been taken mainly from the *World Weather Records*, *Monthly Climatic Data for the World*, and *Meteorological Data for Individual Years over the Northern Hemisphere Excluding the USSR*. These published records were supplemented with information from different national publications. After removal of station records believed to be inhomogeneous or biased, 301 and 265 stations were used to determine the mean temperatures for the Northern and Southern hemispheres, respectively. The departures of the individual station mean monthly temperatures from an average for the period from 1951 to 1975 were spatially averaged. Details on the spatial averaging method may be found in Kagan (1979), Vinnikov and Lugina (1982), Groisman and Lugina (1985), and Vinnikov et al. (1987, 1990).

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Temperature

Global and hemispheric temperature anomalies from instrumental surface air temperature records

K.Ya. Vinnikov, P.Ya. Groisman, and K.M. Lugina (continued)

GLOBAL AND HEMISPHERIC ANOMALIES

Trends

Based on these mean monthly and annual surface air temperature anomaly data, Vinnikov et al. (1990) reported that both hemispheres were warming at a rate of $0.5^{\circ}\text{C}/100$ year. These anomaly estimates agree well with those from Hansen and Lebedeff (1987, 1988) and Jones et al. (1986a,b). Like other records, these anomalies show that the 1980s and early 1990s were a period of unprecedented warmth. In the global record, the nine warmest years have occurred since 1980. In descending order they are 1990, 1991, 1988, 1987, 1981, 1983, 1993, 1989, and 1980.

Global annual temperature anomalies, 1881–1993.

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Global and hemispheric temperature anomalies from instrumental surface air temperature records

K.Ya. Vinnikov, P.Ya. Groisman, and K.M. Lugina (continued)

GLOBAL AND HEMISPHERIC ANOMALIES

Northern Hemisphere annual temperature anomalies, 1881–1993.

Southern Hemisphere annual temperature anomalies, 1881–1993.

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Temperature

Global and hemispheric temperature anomalies from instrumental surface air temperature records

K.Ya. Vinnikov, P.Ya. Groisman, and K.M. Lugina (continued)

GLOBAL (60° S–90° N)

Monthly and Annual Temperature Anomalies^a

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1881	-0.57	-0.25	-0.33	-0.38	-0.16	-0.73	-0.67	-0.08	-0.02	0.04	-0.45	-0.16	-0.31
1882	-0.03	-0.09	0.05	-0.40	-0.25	-0.82	-0.46	0.11	-0.10	-0.31	-0.41	-0.56	-0.27
1883	-0.44	-0.38	-0.03	-0.42	-0.50	0.23	-0.12	-0.19	-0.55	-0.34	-0.58	-0.37	-0.30
1884	-0.52	-0.41	-0.51	-0.78	-1.19	-0.83	-0.79	0.45	-0.50	-0.71	-0.95	-0.33	-0.59
1885	-0.62	-0.55	-0.93	-0.80	-0.52	-0.42	-0.32	-0.17	-0.21	-0.26	0.01	0.04	-0.39
1886	-0.18	-0.54	-0.60	-0.33	-0.54	-0.69	-0.25	-0.26	-0.04	-0.51	-0.44	-0.35	-0.39
1887	-0.55	-0.68	-0.56	-0.73	-0.77	-0.45	-0.37	-0.14	-0.37	-0.56	-0.62	-0.48	-0.52
1888	-0.27	-0.51	-0.64	-0.19	-0.64	-0.28	0.03	0.16	-0.09	-0.01	0.03	-0.02	-0.20
1889	-0.15	0.33	0.04	0.18	0.22	-0.09	-0.11	-0.39	-0.25	-0.13	-0.41	-0.19	-0.08
1890	-0.69	-0.54	-0.53	-0.47	-0.64	-0.26	-0.38	-0.46	-0.09	0.00	-0.29	-0.05	-0.37
1891	-0.58	-0.80	-0.31	-0.56	-0.37	-0.38	-0.43	-0.30	-0.31	-0.36	-0.45	-0.19	-0.42
1892	-0.37	-0.23	-0.40	-0.57	-0.65	-0.33	-0.32	-0.31	-0.38	-0.27	-0.36	-0.48	-0.39
1893	-1.10	-0.92	-0.45	-0.34	-0.60	-0.50	-0.05	-0.23	-0.29	-0.23	-0.15	-0.33	-0.43
1894	-0.55	-0.42	-0.36	-0.57	-0.55	-0.59	-0.31	-0.26	-0.40	-0.11	-0.14	-0.20	-0.37
1895	-0.42	-0.58	-0.51	-0.26	-0.34	-0.17	-0.32	-0.09	-0.08	-0.18	-0.29	0.07	-0.26
1896	-0.34	-0.12	-0.49	-0.36	-0.28	-0.27	0.12	-0.07	-0.06	0.16	-0.19	0.10	-0.15
1897	-0.08	-0.10	0.06	0.15	-0.02	-0.12	-0.09	-0.13	-0.17	-0.12	-0.11	-0.07	-0.07
1898	-0.18	-0.40	-0.80	-0.44	-0.62	-0.16	-0.36	-0.22	-0.19	-0.43	-0.28	-0.21	-0.36
1899	-0.39	-0.46	-0.29	-0.23	-0.27	-0.53	-0.11	-0.10	-0.05	-0.30	0.07	0.02	-0.22
1900	-0.33	0.13	0.13	0.09	0.09	0.12	0.07	-0.03	0.10	0.24	0.11	0.01	0.06
1901	-0.16	-0.07	-0.06	0.01	-0.15	0.01	-0.13	-0.07	0.03	-0.11	-0.27	-0.03	-0.08
1902	-0.29	0.17	-0.12	-0.06	-0.01	0.04	-0.12	-0.31	-0.20	-0.30	-0.31	-0.42	-0.16
1903	-0.31	-0.07	-0.06	-0.37	-0.40	-0.45	-0.23	-0.34	-0.21	-0.50	-0.39	-0.41	-0.31
1904	-0.83	-0.63	-0.39	-0.40	-0.54	-0.36	-0.30	-0.30	-0.38	-0.42	-0.24	-0.36	-0.43
1905	-0.54	-0.73	-0.16	-0.13	-0.20	-0.18	-0.22	-0.25	-0.16	-0.19	0.02	-0.03	-0.23
1906	-0.26	-0.31	-0.23	0.05	-0.04	-0.16	-0.14	-0.09	-0.18	0.00	-0.26	-0.10	-0.14
1907	-0.36	-0.43	-0.27	-0.37	-0.57	-0.49	-0.36	-0.42	-0.31	-0.24	-0.46	-0.35	-0.38
1908	-0.47	-0.30	-0.40	-0.41	-0.21	-0.26	-0.19	-0.34	-0.18	-0.35	-0.56	-0.32	-0.33
1909	-0.62	-0.29	-0.30	-0.32	-0.39	-0.22	-0.14	-0.01	-0.10	-0.07	0.02	-0.32	-0.23
1910	-0.33	-0.19	-0.43	-0.30	-0.18	-0.24	-0.28	-0.01	-0.09	-0.23	-0.24	-0.34	-0.24
1911	-0.49	-0.50	-0.42	-0.33	-0.30	-0.33	-0.25	-0.28	-0.31	-0.14	0.11	-0.15	-0.28
1912	-0.01	0.04	-0.29	-0.02	-0.06	0.14	-0.40	-0.36	-0.38	-0.38	-0.18	-0.14	-0.17
1913	-0.25	-0.33	-0.29	-0.17	-0.43	-0.27	-0.16	-0.17	-0.20	-0.18	-0.03	0.14	-0.19
1914	0.06	-0.05	0.04	-0.11	-0.02	0.06	-0.09	-0.11	-0.05	0.08	-0.07	0.06	-0.02
1915	-0.13	0.03	-0.06	0.07	0.02	-0.08	0.02	0.07	0.25	0.09	0.13	-0.04	0.03
1916	-0.01	0.02	-0.20	-0.12	-0.14	-0.32	-0.23	-0.16	-0.02	-0.07	-0.22	-0.57	-0.17
1917	-0.42	-0.52	-0.59	-0.52	-0.71	-0.37	-0.01	-0.32	-0.25	-0.38	-0.33	-0.71	-0.43
1918	-0.61	-0.42	-0.46	-0.43	-0.56	-0.40	-0.41	-0.25	-0.13	0.10	-0.22	-0.31	-0.34
1919	-0.37	-0.16	0.01	-0.02	-0.13	-0.24	-0.13	-0.08	-0.27	-0.08	-0.38	-0.17	-0.17
1920	0.04	-0.21	0.02	0.05	-0.23	-0.15	0.06	-0.09	-0.07	-0.17	-0.07	-0.35	-0.10
1921	-0.13	-0.11	-0.11	-0.11	-0.07	-0.01	-0.03	-0.22	-0.09	-0.10	-0.11	-0.08	-0.09
1922	-0.25	-0.38	-0.11	0.09	-0.29	-0.23	-0.04	-0.12	-0.12	-0.19	-0.09	-0.02	-0.14
1923	-0.28	-0.26	-0.20	-0.28	-0.22	-0.25	-0.44	-0.30	-0.12	-0.07	0.09	0.12	-0.18
1924	-0.16	-0.34	-0.07	-0.25	-0.20	-0.14	0.01	-0.12	-0.08	-0.15	0.03	-0.22	-0.14
1925	-0.43	-0.27	-0.14	-0.08	-0.12	-0.19	-0.20	0.10	-0.07	-0.08	0.11	0.32	-0.09
1926	0.34	0.30	0.34	0.15	-0.11	0.14	0.03	0.17	0.12	0.13	0.13	-0.05	0.14
1927	-0.03	0.05	-0.16	-0.01	0.06	-0.10	0.13	0.00	0.00	0.20	0.17	-0.08	0.02
1928	0.21	0.17	-0.05	0.15	-0.09	-0.27	0.08	0.02	0.05	0.01	0.20	0.08	0.04
1929	-0.14	-0.23	-0.21	-0.18	-0.29	-0.23	-0.18	-0.20	-0.15	0.17	0.07	-0.40	-0.16
1930	-0.03	-0.15	0.07	0.05	0.11	0.03	0.12	-0.02	-0.08	-0.08	0.25	0.12	0.03
1931	0.12	-0.13	0.11	-0.03	0.03	0.17	0.21	0.22	0.01	0.19	0.09	0.27	0.10

Global and hemispheric temperature anomalies from instrumental
surface air temperature records

K.Ya. Vinnikov, P.Ya. Groisman, and K.M. Lugina (continued)

GLOBAL (60° S–90° N)

Monthly and Annual Temperature Anomalies (continued)^a

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1932	0.30	0.01	-0.02	0.30	-0.02	-0.13	0.03	-0.12	0.07	0.24	0.10	-0.05	0.06
1933	-0.20	-0.01	-0.10	-0.07	-0.02	-0.14	-0.16	-0.13	-0.12	-0.03	-0.32	-0.34	-0.14
1934	-0.12	-0.08	-0.26	-0.13	0.18	0.07	0.09	0.11	0.09	0.11	0.30	0.27	0.05
1935	-0.07	0.31	0.17	-0.10	-0.20	-0.02	-0.02	-0.02	-0.23	0.10	-0.23	-0.01	-0.03
1936	-0.17	-0.24	-0.13	0.15	-0.07	0.07	0.25	0.08	0.02	0.10	0.19	0.17	0.04
1937	-0.03	0.23	-0.03	0.05	0.11	0.15	0.12	0.19	0.21	0.26	0.36	0.12	0.14
1938	0.01	0.19	0.19	0.16	0.12	0.03	0.09	0.03	0.14	0.36	0.19	-0.07	0.12
1939	-0.01	-0.13	-0.26	-0.01	0.07	0.16	0.01	-0.08	-0.07	0.01	-0.01	0.33	0.00
1940	-0.08	0.05	0.03	0.07	0.17	0.22	0.29	0.18	0.20	0.17	0.10	0.38	0.15
1941	0.16	0.37	0.08	0.16	0.19	0.20	0.22	0.20	-0.12	0.12	0.04	0.19	0.15
1942	0.35	0.12	0.10	0.18	0.17	0.14	0.06	0.07	0.13	0.13	0.23	0.19	0.15
1943	-0.08	0.06	-0.07	0.01	0.03	-0.13	0.03	-0.21	-0.01	0.28	0.06	0.21	0.02
1944	0.32	0.23	0.16	0.07	-0.01	0.04	0.06	0.13	0.24	0.38	0.23	0.04	0.16
1945	0.13	0.06	0.05	0.28	-0.13	-0.07	-0.06	0.29	0.11	0.17	0.13	-0.15	0.07
1946	0.03	0.07	0.08	0.08	0.09	-0.03	0.04	0.01	0.08	0.01	0.11	-0.04	0.04
1947	0.05	0.11	0.22	0.27	0.15	0.18	0.12	0.11	0.12	0.30	0.25	-0.02	0.15
1948	0.22	0.02	-0.03	0.01	0.21	0.16	0.03	0.01	0.11	0.10	0.01	-0.12	0.06
1949	0.04	-0.14	0.10	-0.04	0.00	0.04	0.07	0.02	0.04	0.11	-0.01	0.03	0.02
1950	-0.16	-0.07	0.07	-0.05	-0.05	-0.02	-0.05	-0.11	-0.07	-0.10	-0.17	-0.08	-0.07
1951	-0.28	-0.33	0.03	0.08	0.15	0.04	0.12	0.18	0.23	0.19	0.09	0.26	0.06
1952	0.20	0.24	-0.05	0.06	0.15	0.01	0.08	0.12	0.16	0.10	-0.10	0.09	0.09
1953	0.18	0.15	0.10	0.32	0.19	0.22	0.12	0.12	0.18	0.15	0.17	0.22	0.17
1954	-0.15	-0.07	-0.08	0.01	-0.08	-0.05	-0.16	-0.03	0.02	0.07	0.24	0.02	-0.02
1955	0.24	0.04	-0.29	-0.11	-0.12	-0.14	-0.19	-0.04	-0.09	-0.04	-0.21	-0.23	-0.10
1956	-0.13	-0.23	-0.21	-0.19	-0.27	-0.13	-0.18	-0.25	-0.23	-0.16	-0.14	-0.16	-0.19
1957	-0.10	0.03	-0.07	0.01	0.10	0.16	0.06	0.15	0.11	0.06	0.14	0.26	0.07
1958	0.42	0.27	0.27	0.13	0.17	0.10	0.12	0.08	0.08	0.18	0.11	0.12	0.17
1959	0.24	0.10	0.28	0.14	-0.01	0.16	0.13	0.08	0.14	-0.02	0.08	0.10	0.12
1960	0.17	0.29	-0.20	-0.13	-0.07	0.13	0.01	0.11	0.15	0.08	0.06	0.24	0.07
1961	0.20	0.23	0.15	0.11	0.09	0.11	0.04	0.03	0.03	0.09	0.10	0.02	0.10
1962	0.16	0.14	0.22	0.13	0.00	-0.03	-0.01	0.01	0.03	0.02	0.13	0.10	0.07
1963	-0.02	0.36	-0.11	-0.03	-0.04	-0.05	0.07	-0.01	0.02	0.21	0.11	0.00	0.04
1964	-0.14	-0.18	-0.21	-0.24	-0.23	-0.30	-0.23	-0.28	-0.24	-0.34	-0.32	-0.35	-0.25
1965	-0.12	-0.28	-0.20	-0.33	-0.19	-0.10	-0.15	-0.12	-0.11	-0.07	-0.03	-0.15	-0.15
1966	-0.13	-0.05	-0.05	-0.12	-0.05	0.05	0.06	0.04	-0.05	-0.24	-0.12	-0.08	-0.06
1967	-0.24	-0.27	-0.03	0.07	0.18	-0.11	-0.06	-0.05	-0.05	0.24	-0.01	-0.03	-0.03
1968	-0.18	-0.19	0.11	-0.20	-0.19	-0.19	-0.07	-0.02	-0.11	-0.08	-0.20	-0.12	-0.12
1969	-0.20	-0.20	0.01	0.07	0.17	-0.02	0.15	0.06	-0.02	-0.01	0.20	0.28	0.04
1970	0.09	0.27	0.06	0.09	-0.01	0.20	0.04	-0.03	-0.06	-0.09	0.03	-0.19	0.03
1971	-0.18	-0.21	-0.19	-0.20	-0.19	-0.24	-0.12	-0.09	-0.02	-0.07	-0.08	-0.21	-0.15
1972	-0.41	-0.36	-0.11	-0.05	-0.04	0.01	0.08	-0.05	0.02	0.02	0.03	0.20	-0.06
1973	0.30	0.38	0.39	0.29	0.30	0.21	0.12	0.13	0.04	0.07	0.07	0.09	0.20
1974	-0.04	-0.17	0.05	-0.05	-0.08	-0.11	0.02	-0.03	-0.16	-0.18	-0.16	-0.17	-0.09
1975	-0.01	0.13	0.15	0.11	0.07	0.02	0.01	-0.09	-0.02	-0.20	-0.19	-0.20	-0.02
1976	-0.01	-0.18	-0.34	-0.15	-0.14	-0.17	-0.07	-0.13	-0.12	-0.30	-0.16	-0.09	-0.15
1977	0.01	0.12	0.22	0.24	0.21	0.28	0.16	0.13	0.15	0.12	0.36	0.19	0.18
1978	0.17	0.17	0.27	0.12	0.09	-0.01	0.19	-0.03	0.03	-0.02	0.14	0.09	0.10
1979	0.26	0.05	0.21	0.05	0.10	0.29	0.28	0.17	0.22	0.18	0.30	0.49	0.22
1980	0.31	0.41	0.34	0.36	0.48	0.32	0.22	0.15	0.16	0.21	0.09	0.23	0.27
1981	0.50	0.48	0.48	0.52	0.32	0.25	0.22	0.30	0.33	0.23	0.25	0.52	0.36
1982	0.15	0.27	0.12	0.18	0.16	0.08	0.13	0.18	0.14	0.03	0.07	0.19	0.14

Temperature

Global and hemispheric temperature anomalies from instrumental surface air temperature records

K.Ya. Vinnikov, P.Ya. Groisman, and K.M. Lugina (continued)

GLOBAL (60° S–90° N)

Monthly and Annual Temperature Anomalies (continued)^a

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1983	0.39	0.40	0.36	0.28	0.34	0.32	0.37	0.40	0.26	0.25	0.47	0.31	0.34
1984	0.13	0.05	0.18	0.07	0.24	0.13	0.06	0.02	0.04	0.17	0.07	−0.20	0.08
1985	0.11	−0.03	0.13	0.06	0.13	0.13	0.07	0.09	0.03	−0.03	0.09	0.12	0.07
1986	0.41	0.25	0.17	0.36	0.25	0.23	0.06	0.17	0.08	0.07	0.15	0.27	0.20
1987	0.31	0.46	0.25	0.33	0.31	0.38	0.57	0.36	0.45	0.22	0.40	0.57	0.38
1988	0.59	0.48	0.53	0.43	0.52	0.40	0.37	0.36	0.34	0.33	0.13	0.34	0.40
1989	0.13	0.50	0.33	0.34	0.27	0.24	0.32	0.33	0.28	0.22	0.25	0.34	0.29
1990	0.39	0.44	0.91	0.63	0.57	0.54	0.39	0.42	0.33	0.58	0.55	0.44	0.51
1991	0.49	0.44	0.45	0.60	0.57	0.45	0.47	0.37	0.42	0.31	0.26	0.18	0.42
1992	0.35	0.27	0.37	0.19	0.20	0.23	−0.01	−0.01	−0.02	0.00	0.01	0.14	0.14
1993 ^b	0.30	0.36	0.32	0.40	0.36	0.33	0.34	0.31	0.14	0.29	0.12	0.15	0.29

^aExpressed in degrees Celsius and relative to a 1951–75 reference period mean.

^b1993 values are preliminary.

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Global and hemispheric temperature anomalies from instrumental
surface air temperature records

K.Ya. Vinnikov, P.Ya. Groisman, and K.M. Lugina (continued)

NORTHERN HEMISPHERE (0°–90° N)

Monthly and Annual Temperature Anomalies^a

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1881	-0.22	-0.15	-0.28	-0.27	-0.15	-0.43	-0.12	-0.04	-0.32	-0.08	-0.40	-0.56	-0.25
1882	-0.03	0.03	0.06	-0.53	-0.05	-0.26	-0.11	0.08	-0.18	-0.68	-0.71	-0.71	-0.26
1883	-0.86	-0.49	-0.22	-0.50	-0.39	-0.15	-0.05	0.15	-0.18	-0.21	-0.82	-0.39	-0.34
1884	-0.58	-0.55	-0.97	-0.99	-0.97	-0.70	-0.38	-0.37	-0.72	-0.76	-1.11	-0.59	-0.72
1885	-0.97	-0.68	-0.48	-0.70	-0.60	-0.04	0.03	-0.05	-0.45	-0.69	-0.45	-0.38	-0.46
1886	-0.93	-1.01	-1.10	-0.67	-0.41	-0.36	0.27	0.08	-0.06	-0.41	-0.69	-0.53	-0.49
1887	-1.21	-0.96	-0.77	-0.68	-0.47	-0.39	-0.17	-0.46	-0.20	-0.62	-0.52	-0.59	-0.59
1888	-0.53	-0.95	-0.65	-0.15	-0.49	-0.02	0.08	0.13	-0.22	-0.08	0.08	-0.32	-0.26
1889	-0.60	0.36	-0.07	0.44	0.36	0.22	0.27	0.01	-0.21	-0.41	-0.90	-0.73	-0.11
1890	-0.89	-0.65	-0.55	-0.29	-0.30	-0.26	-0.12	-0.13	0.00	0.03	-0.45	-0.27	-0.32
1891	-0.42	-0.91	-0.11	-0.39	-0.28	0.00	-0.06	0.18	0.03	-0.41	-0.69	-0.17	-0.27
1892	-0.49	-0.21	-0.66	-0.56	-0.42	-0.02	-0.18	-0.30	-0.09	-0.24	-0.60	-0.67	-0.37
1893	-1.42	-1.00	-0.29	-0.20	-0.54	-0.13	0.11	0.05	0.13	-0.06	-0.01	-0.55	-0.33
1894	-0.88	-0.45	-0.22	-0.41	-0.26	-0.29	0.06	-0.11	-0.18	-0.15	-0.41	-0.25	-0.30
1895	-0.44	-0.80	-0.64	-0.11	-0.13	-0.14	-0.01	-0.07	0.15	-0.19	-0.19	-0.27	-0.24
1896	-0.42	-0.24	-0.75	-0.57	-0.20	0.11	0.17	-0.11	-0.13	0.20	0.00	-0.06	-0.17
1897	-0.08	-0.06	0.06	0.11	0.24	-0.07	0.26	0.21	0.13	-0.12	-0.10	-0.04	0.05
1898	-0.17	-0.53	-0.96	-0.32	-0.35	-0.28	-0.19	-0.04	-0.08	-0.15	-0.22	-0.28	-0.30
1899	-0.15	-0.49	-0.35	-0.17	-0.12	-0.22	0.12	0.14	0.11	-0.13	0.35	-0.08	-0.08
1900	-0.35	0.18	0.27	-0.14	-0.07	0.11	0.05	0.27	0.21	0.29	0.17	0.03	0.09
1901	-0.38	0.01	0.30	0.28	-0.11	-0.05	0.06	0.02	-0.01	-0.17	-0.39	-0.20	-0.05
1902	-0.23	0.13	-0.32	-0.30	-0.34	-0.20	-0.16	-0.01	-0.16	-0.42	-0.48	-0.81	-0.28
1903	-0.35	-0.01	0.00	-0.33	-0.46	-0.58	-0.26	-0.30	-0.14	-0.44	-0.37	-0.49	-0.31
1904	-1.01	-0.55	-0.22	-0.54	-0.49	-0.34	-0.24	-0.06	-0.42	-0.31	-0.21	-0.21	-0.38
1905	-0.59	-0.92	0.02	-0.15	-0.18	-0.17	-0.09	-0.03	0.02	-0.15	0.17	0.00	-0.17
1906	-0.68	-0.57	-0.17	0.07	0.00	-0.09	-0.11	0.06	0.07	0.15	-0.15	0.19	-0.10
1907	-0.31	-0.78	-0.41	-0.49	-0.66	-0.50	-0.33	-0.31	-0.13	-0.07	-0.48	-0.32	-0.40
1908	-0.54	-0.28	-0.51	-0.35	-0.22	-0.08	-0.13	-0.26	-0.15	-0.25	-0.71	-0.47	-0.33
1909	-0.85	-0.19	-0.36	-0.47	-0.40	-0.36	-0.16	-0.01	-0.01	-0.04	0.30	-0.33	-0.24
1910	-0.42	-0.13	-0.43	-0.36	-0.21	-0.37	-0.30	-0.07	-0.17	-0.25	-0.26	-0.50	-0.29
1911	-0.60	-0.60	-0.44	-0.32	-0.25	-0.02	-0.01	0.00	-0.09	-0.11	0.07	-0.29	-0.22
1912	-0.20	0.01	-0.49	-0.05	0.06	0.16	-0.46	-0.51	-0.59	-0.84	-0.26	-0.28	-0.29
1913	-0.28	-0.51	-0.31	-0.24	-0.54	-0.21	-0.37	-0.26	-0.33	-0.33	-0.14	0.28	-0.27
1914	0.11	-0.10	-0.06	-0.39	-0.07	-0.04	-0.20	-0.11	-0.10	0.12	-0.05	0.05	-0.07
1915	-0.27	-0.28	-0.15	0.00	0.09	0.21	0.02	0.10	0.17	-0.04	0.16	-0.06	-0.00
1916	0.15	0.05	-0.18	-0.26	-0.16	-0.26	-0.14	-0.20	-0.23	-0.14	-0.27	-0.95	-0.22
1917	-0.51	-0.55	-0.61	-0.66	-0.69	-0.33	-0.11	-0.14	-0.27	-0.52	-0.40	-1.05	-0.49
1918	-0.78	-0.37	-0.34	-0.74	-0.57	-0.46	-0.24	-0.23	0.00	0.06	-0.38	-0.61	-0.39
1919	-0.45	-0.29	-0.09	-0.16	-0.21	-0.40	-0.27	0.06	-0.14	-0.01	-0.37	-0.23	-0.21
1920	0.07	-0.21	0.18	-0.15	-0.28	-0.02	0.18	0.03	-0.05	-0.17	-0.30	-0.73	-0.12
1921	0.12	-0.24	-0.13	-0.05	-0.14	0.09	0.10	-0.13	-0.12	-0.07	-0.01	-0.07	-0.05
1922	-0.20	-0.55	0.02	0.01	-0.17	0.04	-0.04	-0.10	-0.20	-0.18	-0.13	0.05	-0.12
1923	-0.19	-0.43	-0.27	-0.39	-0.23	-0.20	-0.22	-0.09	0.00	0.22	0.29	0.19	-0.11
1924	-0.13	-0.36	0.06	-0.32	-0.10	-0.15	0.11	0.04	-0.03	-0.11	0.35	-0.21	-0.07
1925	-0.32	-0.28	-0.01	-0.11	0.00	0.01	0.00	0.19	0.19	0.22	0.33	0.40	0.05
1926	0.63	0.42	0.50	0.12	0.01	0.24	0.21	0.23	0.22	0.32	0.35	0.02	0.27
1927	0.15	0.16	-0.20	-0.20	0.24	0.07	0.33	0.17	0.21	0.45	0.34	-0.06	0.14
1928	0.58	0.36	-0.08	-0.07	-0.01	-0.10	0.10	-0.01	0.07	0.05	0.36	0.26	0.13
1929	-0.12	-0.46	0.01	-0.14	-0.11	-0.18	-0.03	-0.04	-0.01	0.28	0.10	-0.46	-0.10
1930	0.17	-0.07	0.25	0.03	-0.05	0.03	0.28	0.34	0.18	0.11	0.58	0.20	0.17
1931	0.22	-0.19	0.23	0.11	0.15	0.46	0.44	0.46	0.34	0.50	0.39	0.27	0.28

Temperature

Global and hemispheric temperature anomalies from instrumental surface air temperature records

K.Ya. Vinnikov, P.Ya. Groisman, and K.M. Lugina (continued)

NORTHERN HEMISPHERE (0°–90° N)

Monthly and Annual Temperature Anomalies (continued)^a

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1932	0.59	0.06	0.11	0.41	0.06	0.01	0.17	0.09	0.22	0.39	0.00	-0.02	0.17
1933	-0.24	-0.04	-0.18	-0.24	-0.21	-0.18	0.03	-0.06	-0.25	-0.13	-0.31	-0.41	-0.19
1934	-0.08	0.25	-0.24	-0.25	0.21	0.08	0.18	0.08	0.09	0.37	0.59	0.53	0.15
1935	-0.08	0.61	0.36	-0.01	-0.14	0.10	0.13	0.09	0.06	0.30	-0.21	0.02	0.10
1936	-0.05	-0.17	-0.11	0.14	0.09	0.25	0.31	0.16	0.11	0.13	0.26	0.28	0.12
1937	0.27	0.55	0.07	0.18	0.28	0.42	0.33	0.32	0.45	0.50	0.52	0.27	0.35
1938	0.36	0.50	0.37	0.30	0.07	0.08	0.17	0.31	0.30	0.55	0.46	-0.03	0.29
1939	0.21	0.00	-0.17	0.12	-0.01	0.07	0.19	0.12	0.10	0.08	0.19	0.76	0.14
1940	-0.09	0.14	0.04	0.31	0.22	0.17	0.27	0.09	0.32	0.28	0.32	0.48	0.21
1941	0.29	0.62	0.14	0.15	0.25	0.24	0.21	0.21	0.04	0.31	0.08	0.17	0.23
1942	0.52	-0.03	0.04	0.13	0.25	0.18	0.08	-0.03	0.18	0.33	0.29	0.35	0.19
1943	-0.11	0.25	-0.05	0.05	0.21	-0.13	0.06	-0.05	0.01	0.37	0.16	0.35	0.09
1944	0.63	0.40	0.19	0.11	0.08	0.11	0.00	0.09	0.24	0.40	0.25	-0.12	0.20
1945	0.04	-0.16	-0.03	0.24	-0.11	0.09	-0.07	0.19	0.15	0.12	0.10	-0.19	0.03
1946	0.24	0.25	0.29	0.18	0.00	0.10	0.00	-0.07	0.09	0.00	0.23	-0.07	0.10
1947	0.13	0.01	0.35	0.37	0.07	0.06	0.17	0.11	0.20	0.62	0.43	0.04	0.21
1948	0.45	0.13	0.08	0.07	0.22	0.15	0.02	0.12	0.13	0.19	0.24	-0.18	0.14
1949	0.18	-0.02	0.24	0.00	0.01	-0.03	-0.10	0.06	0.01	0.15	0.15	0.00	0.05
1950	-0.12	-0.08	0.22	-0.09	-0.01	-0.01	-0.15	-0.15	-0.03	0.00	-0.16	-0.03	-0.05
1951	-0.32	-0.43	-0.02	0.21	0.20	0.02	0.15	0.34	0.37	0.39	0.19	0.52	0.14
1952	0.30	0.30	-0.17	0.16	0.22	0.13	0.13	0.09	0.15	0.08	-0.14	0.10	0.11
1953	0.33	0.34	0.20	0.52	0.24	0.29	0.27	0.24	0.23	0.24	0.18	0.22	0.28
1954	-0.32	-0.12	-0.18	0.04	-0.09	0.05	-0.10	-0.02	0.16	0.15	0.41	0.04	0.00
1955	0.39	0.04	-0.42	-0.12	-0.13	-0.06	-0.12	0.01	-0.09	0.04	-0.28	-0.31	-0.09
1956	-0.02	-0.27	-0.25	-0.24	-0.31	-0.18	-0.30	-0.36	-0.30	-0.25	-0.24	-0.14	-0.24
1957	-0.18	0.06	-0.22	-0.10	-0.09	0.13	0.13	0.14	0.14	0.03	0.04	0.31	0.03
1958	0.62	0.37	0.29	0.08	0.17	0.04	-0.02	0.11	0.15	0.22	-0.02	0.22	0.19
1959	0.37	0.14	0.37	0.23	0.05	0.20	0.07	0.05	0.18	-0.03	0.03	0.05	0.14
1960	0.24	0.45	-0.35	-0.20	0.04	0.23	0.09	0.15	0.19	-0.06	0.04	0.35	0.10
1961	0.29	0.39	0.23	0.14	0.11	0.21	0.02	0.04	-0.02	-0.05	0.07	-0.13	0.11
1962	0.22	0.25	0.38	0.28	-0.01	-0.19	0.07	-0.01	-0.04	0.01	0.18	0.11	0.10
1963	0.08	0.42	-0.17	-0.04	0.01	-0.04	0.11	0.10	0.07	0.40	0.42	0.02	0.12
1964	-0.25	-0.19	-0.29	-0.38	-0.19	-0.16	-0.16	-0.32	-0.32	-0.37	-0.31	-0.33	-0.27
1965	-0.09	-0.46	-0.20	-0.40	-0.22	-0.26	-0.17	-0.22	-0.28	-0.12	-0.02	-0.15	-0.22
1966	-0.19	0.08	-0.03	-0.23	-0.06	0.03	0.13	0.18	0.05	-0.23	-0.07	-0.02	-0.03
1967	-0.27	-0.39	0.11	0.08	0.23	-0.06	0.10	0.00	-0.01	0.32	0.06	0.07	0.02
1968	-0.25	-0.27	0.36	-0.16	-0.05	-0.21	-0.15	-0.05	-0.07	-0.09	-0.36	-0.25	-0.13
1969	-0.43	-0.42	-0.10	0.04	0.13	-0.03	0.10	0.01	0.01	0.05	0.23	0.41	0.00
1970	0.02	0.36	0.07	0.06	0.04	0.12	-0.01	-0.06	-0.04	-0.15	0.12	-0.24	0.02
1971	-0.20	-0.27	-0.31	-0.27	-0.21	-0.24	-0.21	-0.24	-0.05	-0.08	0.05	-0.15	-0.18
1972	-0.69	-0.62	-0.10	-0.13	-0.28	-0.11	-0.02	-0.05	-0.21	-0.07	-0.19	-0.07	-0.21
1973	0.19	0.47	0.38	0.34	0.26	0.18	0.10	0.08	-0.01	-0.03	0.08	0.08	0.18
1974	-0.02	-0.25	0.15	-0.05	-0.13	-0.18	-0.09	-0.05	-0.20	-0.25	-0.27	-0.30	-0.14
1975	0.03	0.18	0.31	0.10	0.04	-0.02	0.01	-0.09	-0.10	-0.18	-0.23	-0.27	-0.02
1976	0.17	-0.19	-0.46	-0.19	-0.23	-0.22	-0.10	-0.21	-0.07	-0.53	-0.35	-0.28	-0.22
1977	-0.12	0.00	0.27	0.25	0.28	0.35	0.14	0.09	0.23	0.02	0.46	0.23	0.18
1978	0.10	0.16	0.40	0.14	0.04	-0.05	0.04	-0.11	-0.03	-0.06	0.19	0.12	0.08
1979	0.22	-0.15	0.20	-0.08	0.07	0.22	0.21	0.09	0.28	0.23	0.38	0.68	0.20
1980	0.20	0.45	0.23	0.27	0.31	0.41	0.27	0.01	0.08	0.21	0.19	0.19	0.24
1981	0.75	0.71	0.80	0.61	0.28	0.39	0.22	0.39	0.33	0.33	0.39	0.70	0.49
1982	0.02	0.28	0.06	0.24	0.06	0.09	0.24	0.07	0.22	0.02	-0.18	0.19	0.11

Global and hemispheric temperature anomalies from instrumental
surface air temperature records

K.Ya. Vinnikov, P.Ya. Groisman, and K.M. Lugina (continued)

NORTHERN HEMISPHERE (0°–90° N)

Monthly and Annual Temperature Anomalies (continued)^a

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1983	0.51	0.43	0.45	0.25	0.27	0.32	0.31	0.44	0.40	0.30	0.61	0.35	0.39
1984	0.20	-0.09	0.29	0.04	0.42	0.25	0.15	0.12	0.00	0.05	-0.09	-0.43	0.08
1985	-0.02	-0.28	0.11	-0.02	0.20	0.13	-0.03	0.03	0.10	0.02	0.00	0.13	0.03
1986	0.56	0.42	0.27	0.37	0.24	0.29	0.09	0.24	0.10	0.06	0.08	0.09	0.23
1987	0.29	0.61	0.11	0.05	0.22	0.38	0.54	0.37	0.56	0.31	0.19	0.62	0.35
1988	0.68	0.56	0.57	0.51	0.56	0.48	0.49	0.43	0.33	0.24	0.03	0.52	0.45
1989	0.01	0.68	0.45	0.39	0.35	0.31	0.43	0.33	0.32	0.29	0.19	0.42	0.35
1990	0.55	0.57	1.32	0.88	0.67	0.72	0.46	0.52	0.45	0.64	0.64	0.46	0.66
1991	0.60	0.58	0.54	0.66	0.51	0.48	0.61	0.42	0.53	0.42	0.38	0.28	0.50
1992	0.51	0.39	0.51	0.07	0.19	0.19	-0.10	0.02	-0.05	-0.08	-0.02	0.32	0.16
1993 ^b	0.37	0.57	0.41	0.36	0.34	0.35	0.27	0.29	0.15	0.36	-0.05	0.02	0.29

^aExpressed in degrees Celsius and relative to a 1951–75 reference period mean.

^b1993 values are preliminary.

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Temperature

Global and hemispheric temperature anomalies from instrumental surface air temperature records

K.Ya. Vinnikov, P.Ya. Groisman, and K.M. Lugina (continued)

SOUTHERN HEMISPHERE (0°–60° S)

Monthly and Annual Temperature Anomalies^a

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1881	-0.92	-0.35	-0.37	-0.48	-0.16	-1.03	-1.22	-0.11	0.28	0.15	-0.49	0.25	-0.37
1882	-0.03	-0.20	0.04	-0.26	-0.45	-1.38	-0.80	0.13	-0.01	0.06	-0.11	-0.41	-0.29
1883	-0.01	-0.26	0.17	-0.33	-0.61	0.61	-0.19	-0.52	-0.91	-0.46	-0.34	-0.35	-0.27
1884	-0.45	-0.26	-0.04	-0.56	-1.40	-0.95	-1.20	1.26	-0.28	-0.66	-0.79	-0.06	-0.45
1885	-0.26	-0.42	-1.37	-0.89	-0.44	-0.79	-0.66	-0.28	0.04	0.18	0.46	0.47	-0.33
1886	0.58	-0.06	-0.09	0.02	-0.66	-1.02	-0.77	-0.59	-0.01	-0.61	-0.18	-0.17	-0.30
1887	0.11	-0.39	-0.34	-0.77	-1.06	-0.50	-0.56	0.19	-0.54	-0.50	-0.72	-0.36	-0.45
1888	0.00	-0.06	-0.62	-0.22	-0.78	-0.54	-0.03	0.19	0.05	0.06	-0.03	0.28	-0.14
1889	0.30	0.29	0.15	-0.08	0.07	-0.39	-0.49	-0.79	-0.29	0.15	0.09	0.35	-0.05
1890	-0.49	-0.43	-0.51	-0.64	-0.97	-0.26	-0.64	-0.78	-0.18	-0.03	-0.12	0.17	-0.41
1891	-0.73	-0.69	-0.51	-0.73	-0.46	-0.75	-0.79	-0.77	-0.64	-0.30	-0.21	-0.21	-0.57
1892	-0.25	-0.25	-0.13	-0.57	-0.87	-0.63	-0.45	-0.31	-0.67	-0.30	-0.11	-0.29	-0.40
1893	-0.77	-0.84	-0.60	-0.47	-0.65	-0.86	-0.20	-0.51	-0.70	-0.40	-0.28	-0.10	-0.53
1894	-0.22	-0.38	-0.49	-0.72	-0.84	-0.88	-0.67	-0.41	-0.61	-0.07	0.13	-0.14	-0.44
1895	-0.40	-0.36	-0.38	-0.41	-0.55	-0.19	-0.63	-0.10	-0.30	-0.16	-0.39	0.41	-0.29
1896	-0.26	0.00	-0.23	-0.15	-0.36	-0.65	0.06	-0.03	0.02	0.12	-0.38	0.25	-0.13
1897	-0.08	-0.13	0.05	0.18	-0.27	-0.16	-0.44	-0.47	-0.47	-0.12	-0.11	-0.09	-0.18
1898	-0.19	-0.26	-0.63	-0.55	-0.89	-0.04	-0.53	-0.40	-0.29	-0.70	-0.33	-0.14	-0.41
1899	-0.62	-0.43	-0.22	-0.29	-0.42	-0.84	-0.34	-0.34	-0.20	-0.47	-0.22	0.12	-0.36
1900	-0.30	0.07	-0.02	0.32	0.24	0.12	0.08	-0.32	-0.01	0.18	0.05	-0.02	0.03
1901	0.07	-0.14	-0.42	-0.27	-0.19	0.06	-0.31	-0.15	0.07	-0.04	-0.15	0.14	-0.11
1902	-0.35	0.21	0.09	0.18	0.32	0.28	-0.08	-0.61	-0.23	-0.18	-0.14	-0.02	-0.04
1903	-0.27	-0.12	-0.12	-0.40	-0.33	-0.32	-0.20	-0.37	-0.27	-0.55	-0.40	-0.32	-0.31
1904	-0.64	-0.70	-0.55	-0.25	-0.58	-0.37	-0.36	-0.54	-0.33	-0.52	-0.27	-0.50	-0.47
1905	-0.48	-0.53	-0.33	-0.10	-0.21	-0.18	-0.34	-0.47	-0.33	-0.22	-0.14	-0.05	-0.28
1906	0.16	-0.04	-0.28	0.03	-0.07	-0.23	-0.17	-0.23	-0.42	-0.15	-0.36	-0.39	-0.18
1907	-0.40	-0.07	-0.12	-0.25	-0.47	-0.47	-0.38	-0.53	-0.48	-0.40	-0.43	-0.38	-0.37
1908	-0.40	-0.32	-0.29	-0.46	-0.19	-0.43	-0.25	-0.42	-0.20	-0.44	-0.41	-0.17	-0.33
1909	-0.38	-0.39	-0.24	-0.17	-0.38	-0.08	-0.11	0.00	-0.19	-0.09	-0.26	-0.31	-0.22
1910	-0.23	-0.25	-0.43	-0.23	-0.15	-0.11	-0.26	0.06	-0.01	-0.21	-0.22	-0.18	-0.19
1911	-0.37	-0.39	-0.39	-0.33	-0.35	-0.64	-0.48	-0.56	-0.52	-0.17	0.15	-0.01	-0.34
1912	0.19	0.07	-0.09	0.01	-0.17	0.11	-0.33	-0.20	-0.16	0.09	-0.09	0.00	-0.05
1913	-0.22	-0.14	-0.27	-0.10	-0.32	-0.32	0.06	-0.08	-0.07	-0.02	0.09	-0.01	-0.12
1914	0.00	0.01	0.13	0.17	0.04	0.16	0.03	-0.11	0.01	0.03	-0.08	0.06	0.04
1915	0.01	0.33	0.04	0.13	-0.06	-0.37	0.01	0.03	0.32	0.21	0.09	-0.01	0.06
1916	-0.17	-0.02	-0.22	0.02	-0.11	-0.37	-0.32	-0.11	0.20	0.00	-0.17	-0.19	-0.12
1917	-0.32	-0.48	-0.57	-0.38	-0.73	-0.41	0.10	-0.50	-0.23	-0.24	-0.25	-0.37	-0.37
1918	-0.43	-0.46	-0.58	-0.12	-0.54	-0.34	-0.57	-0.26	-0.25	0.14	-0.05	-0.01	-0.29
1919	-0.28	-0.03	0.10	0.13	-0.05	-0.07	0.02	-0.21	-0.39	-0.15	-0.38	-0.10	-0.12
1920	0.00	-0.21	-0.15	0.24	-0.18	-0.27	-0.07	-0.20	-0.09	-0.17	0.17	0.03	-0.08
1921	-0.37	0.03	-0.08	-0.17	0.01	-0.11	-0.16	-0.31	-0.05	-0.12	-0.20	-0.09	-0.14
1922	-0.29	-0.21	-0.23	0.16	-0.40	-0.49	-0.03	-0.14	-0.04	-0.19	-0.05	-0.08	-0.17
1923	-0.36	-0.09	-0.12	-0.16	-0.20	-0.30	-0.65	-0.51	-0.24	-0.36	-0.11	0.05	-0.25
1924	-0.19	-0.32	-0.19	-0.17	-0.30	-0.12	-0.09	-0.27	-0.12	-0.19	-0.29	-0.23	-0.21
1925	-0.54	-0.26	-0.27	-0.05	-0.24	-0.39	-0.40	0.01	-0.32	-0.37	-0.12	0.23	-0.23
1926	0.05	0.17	0.17	0.17	-0.23	0.04	-0.16	0.10	0.01	-0.06	-0.10	-0.12	0.00
1927	-0.20	-0.07	-0.11	0.18	-0.13	-0.27	-0.08	-0.17	-0.21	-0.06	0.00	-0.10	-0.10
1928	-0.16	-0.03	-0.02	0.37	-0.17	-0.44	0.06	0.04	0.02	-0.04	0.03	-0.10	-0.04
1929	-0.15	0.00	-0.43	-0.22	-0.46	-0.27	-0.32	-0.35	-0.28	0.06	0.03	-0.34	-0.23
1930	-0.24	-0.23	-0.12	0.07	0.27	0.03	-0.04	-0.38	-0.34	-0.27	-0.08	0.03	-0.11
1931	0.01	-0.07	-0.01	-0.16	-0.09	-0.12	-0.02	-0.02	-0.32	-0.13	-0.21	0.26	-0.07

Global and hemispheric temperature anomalies from instrumental
surface air temperature records

K.Ya. Vinnikov, P.Ya. Groisman, and K.M. Lugina (continued)

SOUTHERN HEMISPHERE (0°–60° S)

Monthly and Annual Temperature Anomalies (continued)^a

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1932	0.01	-0.04	-0.15	0.19	-0.09	-0.26	-0.12	-0.33	-0.09	0.09	0.20	-0.08	-0.06
1933	-0.16	0.02	-0.02	0.10	0.17	-0.10	-0.34	-0.19	0.01	0.08	-0.32	-0.27	-0.09
1934	-0.16	-0.40	-0.28	0.00	0.15	0.06	-0.01	0.14	0.09	-0.16	0.01	0.00	-0.05
1935	-0.06	0.00	-0.03	-0.18	-0.25	-0.14	-0.17	-0.13	-0.51	-0.10	-0.24	-0.03	-0.15
1936	-0.28	-0.30	-0.15	0.15	-0.23	-0.11	0.19	0.00	-0.07	0.07	0.12	0.05	-0.05
1937	-0.32	-0.10	-0.12	-0.08	-0.06	-0.12	-0.10	0.05	-0.04	0.01	0.19	-0.04	-0.06
1938	-0.34	-0.12	0.00	0.02	0.16	-0.02	0.01	-0.26	-0.03	0.17	-0.09	-0.11	-0.05
1939	-0.23	-0.26	-0.35	-0.14	0.15	0.24	-0.17	-0.27	-0.24	-0.07	-0.21	-0.11	-0.14
1940	-0.07	-0.04	0.02	-0.18	0.12	0.27	0.31	0.27	0.08	0.05	-0.12	0.28	0.08
1941	0.02	0.12	0.01	0.17	0.13	0.15	0.23	0.18	-0.27	-0.07	0.00	0.20	0.07
1942	0.18	0.27	0.15	0.23	0.08	0.10	0.04	0.17	0.07	-0.07	0.17	0.02	0.12
1943	-0.04	-0.14	-0.08	-0.04	-0.16	-0.12	0.00	-0.36	-0.03	0.19	-0.04	0.07	-0.06
1944	0.00	0.06	0.13	0.03	-0.09	-0.03	0.11	0.16	0.23	0.35	0.20	0.19	0.11
1945	0.21	0.28	0.13	0.31	-0.14	-0.22	-0.05	0.39	0.06	0.21	0.16	-0.10	0.10
1946	-0.19	-0.12	-0.14	-0.03	0.17	-0.15	0.08	0.09	0.06	0.01	-0.01	0.00	-0.02
1947	-0.04	0.20	0.09	0.16	0.23	0.29	0.06	0.11	0.03	-0.03	0.07	-0.07	0.09
1948	-0.01	-0.09	-0.13	-0.06	0.19	0.17	0.04	-0.10	0.09	0.00	-0.22	-0.06	-0.01
1949	-0.11	-0.25	-0.04	-0.07	-0.01	0.11	0.23	-0.03	0.07	0.06	-0.17	0.05	-0.01
1950	-0.20	-0.06	-0.09	-0.01	-0.09	-0.02	0.05	-0.07	-0.10	-0.20	-0.18	-0.12	-0.09
1951	-0.23	-0.22	0.08	-0.05	0.10	0.05	0.08	0.02	0.09	-0.02	-0.02	0.00	-0.01
1952	0.10	0.17	0.07	-0.04	0.07	-0.11	0.02	0.15	0.17	0.11	-0.05	0.07	0.06
1953	0.02	-0.05	0.00	0.12	0.13	0.14	-0.04	-0.01	0.12	0.05	0.16	0.21	0.07
1954	0.03	-0.02	0.02	-0.03	-0.06	-0.14	-0.21	-0.04	-0.12	-0.02	0.07	0.00	-0.04
1955	0.09	0.04	-0.15	-0.09	-0.11	-0.22	-0.26	-0.09	-0.09	-0.11	-0.14	-0.14	-0.11
1956	-0.24	-0.18	-0.16	-0.13	-0.22	-0.08	-0.05	-0.14	-0.16	-0.06	-0.03	-0.17	-0.14
1957	-0.01	0.00	0.08	0.12	0.29	0.18	-0.02	0.15	0.07	0.09	0.23	0.20	0.12
1958	0.22	0.17	0.24	0.17	0.17	0.15	0.26	0.04	0.00	0.13	0.23	0.01	0.15
1959	0.10	0.06	0.19	0.05	-0.06	0.11	0.19	0.10	0.09	0.00	0.12	0.15	0.09
1960	0.10	0.13	-0.05	-0.05	-0.18	0.02	-0.07	0.06	0.10	0.21	0.08	0.13	0.04
1961	0.11	0.06	0.06	0.08	0.06	0.01	0.05	0.01	0.07	0.23	0.13	0.16	0.09
1962	0.09	0.03	0.05	-0.02	0.01	0.13	-0.08	0.03	0.09	0.03	0.08	0.09	0.04
1963	-0.12	0.30	-0.04	-0.01	-0.08	-0.05	0.03	-0.12	-0.03	0.01	-0.20	-0.02	-0.03
1964	-0.02	-0.17	-0.13	-0.10	-0.26	-0.44	-0.30	-0.24	-0.15	-0.30	-0.32	-0.37	-0.23
1965	-0.14	-0.09	-0.20	-0.25	-0.15	0.07	-0.12	-0.01	0.07	-0.02	-0.04	-0.15	-0.09
1966	-0.07	-0.17	-0.06	-0.01	-0.04	0.07	-0.01	-0.11	-0.14	-0.25	-0.16	-0.14	-0.09
1967	-0.21	-0.14	-0.17	0.05	0.13	-0.16	-0.21	-0.10	-0.09	0.16	-0.08	-0.13	-0.08
1968	-0.10	-0.11	-0.15	-0.23	-0.32	-0.16	0.01	0.01	-0.15	-0.06	-0.03	0.01	-0.11
1969	0.04	0.03	0.12	0.09	0.20	0.00	0.20	0.11	-0.05	-0.07	0.16	0.14	0.08
1970	0.15	0.18	0.05	0.12	-0.06	0.27	0.09	0.00	-0.08	-0.03	-0.06	-0.14	0.04
1971	-0.15	-0.15	-0.06	-0.12	-0.17	-0.24	-0.02	0.06	0.01	-0.06	-0.21	-0.27	-0.12
1972	-0.12	-0.09	-0.11	0.03	0.20	0.12	0.18	-0.05	0.24	0.10	0.25	0.47	0.10
1973	0.40	0.28	0.39	0.24	0.33	0.24	0.14	0.17	0.08	0.16	0.05	0.10	0.22
1974	-0.05	-0.08	-0.06	-0.05	-0.03	-0.04	0.13	-0.01	-0.11	-0.10	-0.05	-0.03	-0.04
1975	-0.05	0.07	-0.01	0.11	0.09	0.06	0.01	-0.08	0.06	-0.21	-0.15	-0.13	-0.02
1976	-0.19	-0.16	-0.21	-0.11	-0.04	-0.12	-0.04	-0.04	-0.17	-0.07	0.04	0.11	-0.08
1977	0.14	0.23	0.16	0.23	0.13	0.21	0.17	0.17	0.07	0.21	0.26	0.14	0.18
1978	0.23	0.18	0.13	0.09	0.13	0.03	0.33	0.06	0.09	0.03	0.09	0.06	0.12
1979	0.29	0.25	0.22	0.17	0.12	0.36	0.34	0.25	0.16	0.13	0.22	0.30	0.23
1980	0.42	0.37	0.45	0.45	0.65	0.22	0.17	0.29	0.24	0.21	-0.01	0.26	0.31
1981	0.25	0.25	0.15	0.42	0.35	0.10	0.21	0.20	0.33	0.12	0.11	0.33	0.24
1982	0.27	0.26	0.18	0.11	0.26	0.07	0.02	0.29	0.05	0.03	0.31	0.18	0.17

Temperature

Global and hemispheric temperature anomalies from instrumental surface air temperature records

K.Ya. Vinnikov, P.Ya. Groisman, and K.M. Lugina (continued)

SOUTHERN HEMISPHERE (0°–60° S)

Monthly and Annual Temperature Anomalies (continued)^a

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1983	0.27	0.36	0.27	0.31	0.40	0.32	0.43	0.35	0.12	0.19	0.32	0.26	0.30
1984	0.06	0.19	0.07	0.10	0.06	0.01	−0.04	−0.08	0.07	0.28	0.22	0.04	0.08
1985	0.24	0.23	0.15	0.14	0.06	0.12	0.16	0.15	−0.04	−0.07	0.17	0.10	0.12
1986	0.26	0.08	0.06	0.34	0.26	0.17	0.03	0.10	0.05	0.08	0.22	0.44	0.17
1987	0.33	0.30	0.38	0.60	0.40	0.38	0.60	0.35	0.34	0.13	0.60	0.52	0.41
1988	0.49	0.39	0.49	0.35	0.47	0.31	0.24	0.28	0.35	0.42	0.22	0.15	0.35
1989	0.25	0.31	0.20	0.29	0.19	0.16	0.21	0.33	0.23	0.15	0.30	0.26	0.24
1990	0.23	0.30	0.44	0.37	0.47	0.35	0.31	0.31	0.21	0.51	0.45	0.41	0.36
1991	0.37	0.29	0.35	0.53	0.63	0.42	0.33	0.32	0.31	0.19	0.14	0.08	0.33
1992	0.19	0.14	0.23	0.31	0.21	0.27	0.09	−0.04	0.01	0.08	0.03	−0.05	0.12
1993 ^b	0.22	0.11	0.22	0.44	0.39	0.30	0.43	0.34	0.13	0.21	0.31	0.29	0.28

^aExpressed in degrees Celsius and relative to a 1951–75 reference period mean.

^b1993 values are preliminary.

CITE AS: Vinnikov, K.Ya., P.Ya. Groisman, and K.M. Lugina. 1994. Global and hemispheric temperature anomalies from instrumental surface air temperature records. pp. 615–627. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Global and hemispheric temperature anomalies from instrumental
surface air temperature records

K.Ya. Vinnikov, P.Ya. Groisman, and K.M. Lugina (continued)

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Global and hemispheric tropospheric and stratospheric temperature anomalies from satellite records

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Period of Record

1979–94

Methods

Microwave radiometers designed to measure deep-layer average temperatures have routinely been in polar orbit since late 1978 on NOAA's Topographical Infrared Operations Satellite (TIROS)-N series. These radiometers, or Microwave Sounding Units (MSUs), are Dicke-type radiometers designed to measure the thermal emission of radiation by atmospheric O₂ at four frequencies near 60 GHz. Lower tropospheric (surface to 5.6-mile) and lower stratospheric (10.5- to 13-mile) temperatures are derived from MSU channels 2R and 4 data, respectively. These MSU channels monitor the microwave radiation thermally emitted by molecular oxygen at frequencies of 53.74 and 57.95 GHz. The satellites provide quasi-global coverage each day. Spencer and Christy (1990, 1992a) suggested that passive microwave radiometry from satellites provides more precise atmospheric temperature information than that obtained from the relatively sparse distribution of thermometers over the earth's surface.

The temperature data presented here are extracted from a larger data set that is internally consistent, taken from multiple copies of a single satellite instrument, and all intercalibrated to a common level. Corrections have been applied for the orbital drift of NOAA-11, which had contributed a spurious warming in the MSU 2R data and a cooling in the MSU 4 data. Corrections have also been applied for the reduced (only 98% of normal) dynamic range of the NOAA-12.

Spencer and Christy (1993) reported that intersatellite comparisons of temperature anomalies reveal excellent noise and signal-to-noise statistics on various space and time scale combinations and that the calibration stability of each satellite's measurements, evaluated during satellite overlap periods, revealed no measurable instrumental drift at the level of 0.01°C per year. Spencer and Christy (1993) analyzed the first 13 years of deep-layer averaged temperatures derived from satellite data and reported a global monthly precision of 0.01°C to 0.02°C. Details on the retrieval, precision, and validation of these satellite measurements are presented in Spencer and Christy (1990, 1992a, 1992b, 1993) and in Christy and Spencer (1993). An evaluation of the MSU monthly mean brightness temperature anomalies from the lower troposphere were examined and compared with monthly means from the European Centre for Medium-Range Weather Forecasts by Hurrell and Trenberth (1992).

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Temperature

Global and hemispheric tropospheric and stratospheric temperature anomalies from satellite records

R.W. Spencer and J.R. Christy (continued)

GLOBAL AND HEMISPHERIC ANOMALIES

Trends

Spencer and Christy (1993) reported that, for the stratosphere, the largest globally averaged variations during the 1979–91 period occurred after the El Chichón (1982) and Pinatubo (1991) volcanic eruptions and that these warm events are superimposed upon a net downward trend in temperatures over the same period. Recent North Polar readings are the coolest since 1990 and cooling trends are still apparent in both polar regions (Christy, personal communication).

Spencer and Christy (1992b), after combining channel 2 data from different view angles (to remove influence from the lower stratosphere and much of the upper troposphere on the measured brightness temperature), reported a warming trend for the lower troposphere of 0.039°C ($\pm 0.03^{\circ}\text{C}$) for the 12-year time series 1979–90. The trend for 1979–92 is $0.00^{\circ}\text{C}/\text{decade}$ ($\pm 0.03^{\circ}\text{C}$) and the decadal global trend since 1979 is -0.067°C (Christy, personal communication).

According to Christy and Spencer (1993), the summer of 1992 was the coolest summer in the satellite record for the Northern Hemisphere, and the following austral summer was the coolest in the Southern Hemisphere in the past 15 years. The maximum cooling of the Northern Hemisphere from Mt. Pinatubo's eruption was during May through September 1992. Earlier warming episodes, such as the warming in 1983, 1987, and 1990–91, were due to El Niño-Southern Oscillation (ENSO) warm events (Christy and Spencer 1993).

Annual temperature anomalies for the lower troposphere, 1979–1993.

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Global and hemispheric tropospheric and stratospheric temperature anomalies from satellite records

R.W. Spencer and J.R. Christy (continued)

GLOBAL AND HEMISPHERIC ANOMALIES

Annual temperature anomalies for the lower stratosphere, 1979–1993.

Seasonal temperature anomalies for the lower troposphere, 1979–spring 1994.

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Temperature

Global and hemispheric tropospheric and stratospheric temperature anomalies from satellite records

R.W. Spencer and J.R. Christy (continued)

GLOBAL AND HEMISPHERIC ANOMALIES

Seasonal temperature anomalies for the lower stratosphere, 1979–spring 1994.

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Global and hemispheric tropospheric and stratospheric temperature anomalies from satellite records

R.W. Spencer and J.R. Christy (continued)

GLOBAL AND HEMISPHERIC ANOMALIES

Seasonal and Annual Temperature Anomalies^a

Year	Global					Northern Hemisphere					Southern Hemisphere				
	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann
Lower troposphere (MSU channel 2R) seasonal and annual temperature anomalies^a															
1979		-0.057	-0.010	0.132	0.032		-0.041	0.118	0.181	0.070		-0.073	-0.138	0.083	-0.006
1980	0.165	0.174	0.210	0.191	0.170	0.115	0.025	0.202	0.210	0.117	0.216	0.321	0.216	0.173	0.223
1981	0.157	0.086	0.082	0.029	0.100	0.114	0.152	0.153	0.075	0.138	0.200	0.021	0.010	-0.018	0.063
1982	0.009	-0.171	-0.145	-0.152	-0.128	-0.075	-0.191	-0.153	-0.270	-0.184	0.092	-0.151	-0.137	-0.035	-0.072
1983	0.059	0.229	0.090	0.050	0.090	0.006	0.123	0.115	0.058	0.064	0.112	0.334	0.066	0.041	0.115
1984	-0.202	-0.087	-0.156	-0.224	-0.175	-0.247	-0.203	-0.118	-0.225	-0.222	-0.156	0.029	-0.194	-0.222	-0.127
1985	-0.244	-0.323	-0.323	-0.241	-0.270	-0.286	-0.333	-0.452	-0.291	-0.307	-0.203	-0.314	-0.194	-0.192	-0.233
1986	-0.112	-0.094	-0.185	-0.182	-0.129	-0.105	-0.083	-0.183	-0.229	-0.149	-0.118	-0.104	-0.186	-0.135	-0.108
1987	0.170	0.066	0.176	0.225	0.199	0.240	0.024	0.119	0.277	0.221	0.100	0.108	0.233	0.173	0.177
1988	0.294	0.196	0.229	0.218	0.195	0.396	0.164	0.296	0.252	0.225	0.192	0.227	0.162	0.184	0.166
1989	-0.127	-0.116	-0.052	0.108	-0.033	-0.110	-0.017	-0.014	0.110	-0.002	-0.143	-0.214	-0.089	0.106	-0.063
1990	0.037	0.108	0.102	0.204	0.121	0.041	0.203	0.141	0.253	0.176	0.033	0.014	0.062	0.155	0.066
1991	0.193	0.192	0.264	-0.005	0.130	0.222	0.312	0.250	0.067	0.179	0.164	0.072	0.278	-0.077	0.081
1992	-0.098	-0.182	-0.356	-0.195	-0.216	-0.084	-0.296	-0.553	-0.203	-0.280	-0.113	-0.067	-0.159	-0.187	-0.152
1993	-0.225	-0.306	-0.155	-0.107	-0.169	-0.162	-0.303	-0.245	-0.199	-0.204	-0.289	-0.309	-0.065	-0.014	-0.134
1994	0.014	-0.141						0.049	-0.017				-0.022	-0.265	
Lower stratosphere (MSU channel 4) seasonal and annual temperature anomalies^a															
1979		0.592	0.191	0.079	0.311		0.479	0.227	-0.223	0.192		0.705	0.154	0.380	0.431
1980	0.326	0.148	0.253	0.250	0.248	-0.131	0.193	0.604	0.406	0.288	0.784	0.102	-0.099	0.094	0.208
1981	0.333	0.288	0.105	0.156	0.211	0.250	0.145	0.215	0.046	0.173	0.416	0.430	-0.006	0.266	0.250
1982	0.302	0.588	0.788	0.978	0.736	0.466	0.733	1.089	0.890	0.861	0.137	0.442	0.488	1.065	0.610
1983	1.105	0.838	0.459	0.493	0.669	0.901	0.821	0.484	0.451	0.645	1.310	0.856	0.434	0.535	0.692
1984	0.306	-0.007	-0.100	-0.112	-0.013	0.349	0.160	-0.349	-0.152	-0.038	0.263	-0.174	0.149	-0.071	0.011
1985	-0.245	-0.305	-0.126	-0.345	-0.284	-0.200	-0.377	-0.161	-0.072	-0.222	-0.291	-0.233	-0.090	-0.617	-0.346
1986	-0.275	-0.140	-0.219	-0.454	-0.261	-0.054	-0.120	-0.726	-0.571	-0.373	-0.497	-0.159	0.289	-0.336	-0.149
1987	-0.299	-0.273	-0.297	-0.468	-0.366	-0.184	-0.306	0.021	0.048	-0.113	-0.414	-0.238	-0.615	-0.985	-0.619
1988	-0.425	-0.332	-0.290	-0.308	-0.305	-0.727	-0.236	-0.460	-0.804	-0.565	-0.122	-0.429	-0.120	0.189	-0.044
1989	-0.065	-0.110	-0.247	-0.355	-0.202	-0.224	-0.086	-0.049	-0.226	-0.155	0.094	-0.134	-0.446	-0.484	-0.249
1990	-0.236	-0.067	-0.232	-0.393	-0.229	-0.451	-0.399	-0.056	-0.239	-0.257	-0.022	0.265	-0.409	-0.547	-0.201
1991	-0.347	-0.193	0.264	0.963	0.255	-0.075	-0.190	0.208	0.676	0.216	-0.618	-0.196	0.320	1.251	0.295
1992	0.734	0.764	0.579	0.502	0.617	0.765	0.658	0.218	0.279	0.445	0.704	0.871	0.938	0.726	0.788
1993	0.390	-0.042	-0.409	-0.610	-0.259	-0.023	-0.203	-0.604	-0.617	-0.419	0.802	0.119	-0.215	-0.604	-0.100
1994	-0.573	-0.303				-0.403	-0.369				-0.743	-0.238			

^aAnomalies expressed in degrees Celsius for Win (DJF), Spr (MAM), Sum (JJA), and Fall (SON). Seasonal anomalies were calculated by taking the arithmetic mean of the monthly anomalies. Annual anomalies are the 12-month running mean for December of each year. Monthly anomalies are computed as the difference between the temperature for that month and the average for all values for that particular month for the 1982–91 period. Corrections have been applied for the orbital drift of NOAA-11 which had contributed a spurious warming in the MSU 2R data and a cooling in the MSU 4 data. Corrections have also been applied for the reduced (only 98% of normal) dynamic range of the NOAA-12.

CITE AS: Spencer, R.W., and J.R. Christy. 1994. Global and hemispheric tropospheric and stratospheric temperature anomalies from satellite records. pp. 629–634. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Global and hemispheric tropospheric and stratospheric temperature anomalies from satellite records

R.W. Spencer and J.R. Christy (continued)

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Temperature

Global, hemispheric, and zonal temperature anomalies derived from radiosonde records

J.K. Angell

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Period of Record

1958–92 (relative to a 1958–77 average)

Methods

Surface temperatures and thickness-derived temperatures from a 63-station, globally distributed radiosonde network have been used to estimate global, hemispheric, and zonal annual and seasonal temperature anomalies. Most of the temperature values used were column-mean temperatures, obtained from the differences in height (thickness) between constant-pressure surfaces at individual radiosonde stations. The pressure-height data before 1980 were obtained from published values in *Monthly Climatic Data for the World*. Since 1980, Angell has used data from both the *Climatic Data for the World* and the Global Telecommunication System Network received at the National Meteorological Center. The data are evaluated as deviations from the mean based on the interval 1958–77. The station deviations have been averaged (with equal weighting) to obtain seasonal temperature deviations for the seven climatic zones. For greater details, see Angell and Korshover (1983) and Angell (1988, 1991).

Physical structure of the atmosphere.

CITE AS: Angell, J.K. 1994. Global, hemispheric, and zonal temperature anomalies derived from radiosonde records. pp. 636–672. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change* ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

GLOBAL, HEMISPHERIC, AND ZONAL ANOMALIES

Trends

Based on this network, Angell (1986) reported that, during the last quarter century, the surface and troposphere have warmed, the tropopause layer and the low stratosphere have cooled, and low-level warming and higher-level cooling have been more pronounced in the Southern Hemisphere than the Northern Hemisphere. For the earth's surface and the troposphere (850–300 mb), Angell (1988) reported a global temperature increase of $0.08^{\circ}\text{C}/10$ year and $0.09^{\circ}\text{C}/10$ year, respectively, over the 30-year interval 1958–87. After adjusting for the influence of El Niño, Angell (1990) found the year-to-year variability in global tropospheric temperature was halved and the temperature was higher in 1989 than in 1988. The year 1990 was the warmest on record both before and after adjustment for the El Niño influence.

Despite the sparsity of the 63-station radiosonde network, the global tropospheric temperatures derived from this network closely correlate with estimates of surface temperature; for example, the correlation with the surface temperatures of Hansen and Lebedeff (1987) is 0.94 between 1958 and 1987 (Angell 1991). Oort and Liu (1993) compared their time series of global and hemispheric mean temperature anomalies for the troposphere and lower stratosphere, derived using 700–800 stations from the same radiosonde network, and found excellent agreement with those presented here.

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Temperature

Global, hemispheric, and zonal temperature anomalies
derived from radiosonde records

J.K. Angell (continued)

GLOBAL, HEMISPHERIC, AND ZONAL ANOMALIES

Global annual temperature anomalies, 1958-92.

CITE AS: Angell, J.K. 1994. Global, hemispheric, and zonal temperature anomalies derived from radiosonde records. pp. 636-672. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

GLOBAL, HEMISPHERIC, AND ZONAL ANOMALIES

Northern Hemisphere annual temperature anomalies, 1958-92.

CITE AS: Angell, J.K. 1994. Global, hemispheric, and zonal temperature anomalies derived from radiosonde records. pp. 636-672. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Temperature

Global, hemispheric, and zonal temperature anomalies
derived from radiosonde records

J.K. Angell (continued)

GLOBAL, HEMISPHERIC, AND ZONAL ANOMALIES

Southern Hemisphere annual temperature anomalies, 1958-92.

CITE AS: Angell, J.K. 1994. Global, hemispheric, and zonal temperature anomalies derived from radiosonde records. pp. 636-672. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

J.K. Angell (continued)

GLOBAL, HEMISPHERIC, AND ZONAL ANOMALIES

North Polar annual temperature anomalies, 1958-92.

CITE AS: Angell, J.K. 1994. Global, hemispheric, and zonal temperature anomalies derived from radiosonde records. pp. 636-672. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Temperature

Global, hemispheric, and zonal temperature anomalies
derived from radiosonde records

J.K. Angell (continued)

GLOBAL, HEMISPHERIC, AND ZONAL ANOMALIES

North Temperate annual temperature anomalies, 1958-92.

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GLOBAL, HEMISPHERIC, AND ZONAL ANOMALIES

North Subtropics annual temperature anomalies, 1958-92.

CITE AS: Angell, J.K. 1994. Global, hemispheric, and zonal temperature anomalies derived from radiosonde records. pp. 636-672. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Temperature

Global, hemispheric, and zonal temperature anomalies
derived from radiosonde records

J.K. Angell (continued)

GLOBAL, HEMISPHERIC, AND ZONAL ANOMALIES

Equatorial annual temperature anomalies, 1958-92.

CITE AS: Angell, J.K. 1994. Global, hemispheric, and zonal temperature anomalies derived from radiosonde records. pp. 636-672. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

GLOBAL, HEMISPHERIC, AND ZONAL ANOMALIES

South Subtropics annual temperature anomalies, 1958-92.

CITE AS: Angell, J.K. 1994. Global, hemispheric, and zonal temperature anomalies derived from radiosonde records. pp. 636-672. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Temperature

Global, hemispheric, and zonal temperature anomalies
derived from radiosonde records

J.K. Angell (continued)

GLOBAL, HEMISPHERIC, AND ZONAL ANOMALIES

South Temperate annual temperature anomalies, 1958-92.

CITE AS: Angell, J.K. 1994. Global, hemispheric, and zonal temperature anomalies derived from radiosonde records. pp. 636-672. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change* ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

J.K. Angell (continued)

GLOBAL, HEMISPHERIC, AND ZONAL ANOMALIES

South Polar annual temperature anomalies, 1958-92.

CITE AS: Angell, J.K. 1994. Global, hemispheric, and zonal temperature anomalies derived from radiosonde records. pp. 636-672. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Temperature

Global, hemispheric, and zonal temperature anomalies
derived from radiosonde records

J.K. Angell (continued)

GLOBAL, HEMISPHERIC, AND ZONAL ANOMALIES

Tropical annual temperature anomalies, 1958-92.

CITE AS: Angell, J.K. 1994. Global, hemispheric, and zonal temperature anomalies derived from radiosonde records. pp. 636-672. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Temperature

Global, hemispheric, and zonal temperature anomalies
derived from radiosonde records

J.K. Angell (continued)

GLOBAL (90° N–90° S)

Annual and Seasonal Temperature Anomalies^a

Year	Surface					850–300 mb					300–100 mb				
	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann
1958	0.70	0.26	-0.04	0.33	0.31	0.39	0.21	0.27	0.32	0.30	0.11	-0.26	0.11	0.03	0.00
1959	0.40	0.28	0.26	0.05	0.25	0.25	0.43	0.36	0.29	0.33	-0.05	0.47	0.19	-0.22	0.10
1960	0.10	-0.05	0.03	-0.07	0.00	0.28	-0.04	0.27	0.13	0.16	0.46	0.15	0.35	0.15	0.28
1961	0.37	0.15	0.10	0.33	0.26	0.29	0.17	0.01	0.27	0.19	0.16	0.59	0.19	-0.32	0.16
1962	0.33	0.11	-0.02	0.07	0.12	0.14	-0.01	-0.01	0.07	0.05	-0.43	-0.43	-0.11	0.40	-0.14
1963	0.11	-0.10	0.02	0.32	0.09	0.07	-0.14	-0.11	-0.03	-0.05	-0.21	0.21	0.38	0.39	0.19
1964	-0.21	-0.47	-0.06	-0.23	-0.24	-0.07	-0.10	-0.25	-0.45	-0.22	0.09	0.31	0.03	0.19	0.16
1965	-0.21	-0.21	-0.17	-0.09	-0.17	-0.58	-0.47	-0.40	-0.04	-0.37	-0.35	-0.46	-0.35	-0.15	-0.33
1966	-0.17	0.07	-0.04	-0.07	-0.05	-0.03	0.07	0.05	0.00	0.02	0.42	0.20	0.39	0.04	0.26
1967	-0.08	0.08	0.05	0.10	0.04	-0.13	-0.03	0.06	0.12	0.01	-0.13	-0.33	-0.14	-0.14	-0.19
1968	-0.10	0.16	-0.22	-0.23	-0.10	-0.02	-0.07	-0.33	-0.31	-0.18	0.00	-1.07	-0.36	0.16	-0.31
1969	-0.45	-0.12	-0.11	0.11	-0.14	-0.16	0.14	0.32	0.18	0.12	0.42	0.58	0.01	-0.32	0.17
1970	0.20	-0.09	-0.15	-0.15	-0.05	0.11	0.13	0.18	0.13	0.14	0.05	0.28	0.35	0.20	0.22
1971	-0.28	-0.20	-0.18	-0.21	-0.22	-0.17	-0.44	-0.39	-0.44	-0.36	-0.02	-0.15	-0.35	-0.53	-0.26
1972	-0.38	-0.30	0.14	-0.23	-0.19	-0.49	-0.13	0.18	0.16	-0.07	-0.48	-0.54	-0.23	0.10	-0.29
1973	0.21	0.28	0.17	0.08	0.19	0.56	0.41	0.25	0.04	0.32	0.45	0.40	0.12	-0.01	0.24
1974	-0.14	0.04	-0.02	0.02	-0.03	0.01	-0.12	-0.11	-0.23	-0.11	-0.44	-0.26	-0.30	-0.08	-0.27
1975	0.08	0.31	0.06	-0.17	0.07	-0.03	0.00	-0.16	-0.10	-0.07	-0.12	0.10	-0.20	-0.17	-0.10
1976	-0.22	-0.42	-0.12	-0.21	-0.24	-0.15	-0.36	-0.27	-0.38	-0.29	-0.54	-0.66	-0.53	-0.25	-0.50
1977	-0.11	0.33	0.31	0.09	0.16	0.13	0.42	0.28	0.18	0.25	0.22	0.12	-0.03	-0.11	0.05
1978	0.10	0.06	0.11	0.15	0.10	-0.03	0.30	0.21	0.03	0.13	0.16	-0.03	-0.27	-0.24	-0.10
1979	-0.02	0.30	0.12	0.28	0.18	0.05	0.53	0.30	0.28	0.29	0.01	0.04	-0.33	-0.06	-0.09
1980	0.53	0.56	0.29	0.15	0.38	0.37	0.39	0.52	0.21	0.37	-0.41	0.28	0.22	-0.13	-0.01
1981	0.44	0.57	0.39	0.28	0.42	0.44	0.40	0.30	0.26	0.35	-0.61	-0.68	-0.37	-0.30	-0.49
1982	0.33	0.10	0.22	0.16	0.20	0.33	-0.05	0.29	0.05	0.16	-0.17	-0.35	-0.08	-0.37	-0.24
1983	0.57	0.51	0.32	0.32	0.43	0.41	0.87	0.52	0.22	0.51	-0.39	0.18	-0.05	-0.33	-0.15
1984	0.35	0.49	0.05	0.27	0.29	0.14	0.26	0.01	0.02	0.11	-1.07	-0.60	-0.36	-0.61	-0.66
1985	-0.11	0.09	0.29	-0.19	0.02	0.15	0.09	0.02	-0.08	0.05	-0.37	-0.20	-0.68	-0.93	-0.55
1986	-0.02	0.36	0.14	0.09	0.14	0.33	0.14	0.12	0.12	0.18	-0.97	-0.53	-0.39	-0.44	-0.58
1987	0.30	0.58	0.69	0.26	0.46	0.46	0.44	0.61	0.35	0.47	-0.10	-0.36	0.10	0.11	-0.06
1988	0.37	0.51	0.27	0.33	0.37	0.51	0.52	0.73	0.36	0.53	-0.31	-0.14	0.19	0.13	-0.03
1989	0.37	0.27	0.20	0.11	0.24	0.15	0.18	0.29	0.31	0.23	-0.78	-0.49	-0.54	-0.66	-0.62
1990	0.48	0.93	0.38	0.45	0.56	0.31	0.59	0.71	0.57	0.55	-0.37	-0.40	-0.08	-0.54	-0.35
1991	0.50	0.50	0.64	0.29	0.48	0.49	0.44	0.69	0.33	0.49	-0.59	-0.50	0.00	-0.41	-0.38
1992	0.38	0.30	-0.22	0.09	0.14	0.10	0.04	-0.08	-0.25	-0.05	-0.50	-0.43	-0.24	-0.69	-0.46

Global, hemispheric, and zonal temperature anomalies
derived from radiosonde records

J.K. Angell (continued)

GLOBAL (90° N–90° S)

Annual and Seasonal Temperature Anomalies^a

Year	Surface–100 mb					100–50 mb					100–30 mb				
	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann
1958	0.39	–0.02	0.17	0.22	0.19	1.01	0.53	0.58	1.22	0.84	0.68	0.34	0.71	1.50	0.81
1959	0.22	0.43	0.30	0.16	0.28	–0.30	0.81	–0.33	–0.62	–0.11	0.02	1.42	0.39	–0.55	0.32
1960	0.28	0.01	0.24	0.10	0.16	1.04	0.51	–0.05	0.36	0.47	1.23	–0.01	–0.78	–0.32	0.03
1961	0.27	0.30	0.04	0.15	0.19	–1.38	–0.38	0.93	0.26	–0.14	–1.25	–1.07	0.59	–0.35	–0.52
1962	0.05	–0.08	–0.03	0.13	0.02	0.07	–0.83	–0.69	–0.30	–0.44	–0.22	–1.23	–1.10	–0.59	–0.79
1963	–0.05	–0.10	0.02	0.12	0.00	–0.43	–0.52	0.54	0.70	0.07	–0.63	–1.40	0.76	1.40	0.03
1964	0.00	–0.07	–0.16	–0.26	–0.12	0.49	1.10	0.61	0.71	0.73	0.25	1.14	0.80	0.47	0.67
1965	–0.47	–0.44	–0.34	–0.09	–0.34	0.36	0.28	0.30	0.79	0.43	–0.01	0.37	0.19	0.66	0.30
1966	0.03	0.10	0.11	–0.01	0.06	–0.13	–0.66	–0.24	0.28	–0.19	–0.64	–0.41	0.06	0.82	–0.04
1967	–0.13	–0.08	0.02	0.05	–0.04	0.28	0.08	–0.02	–0.21	0.03	0.18	0.48	–0.04	–0.17	0.11
1968	0.02	–0.26	–0.31	–0.19	–0.19	–0.48	–0.12	–0.11	–0.12	–0.21	–0.81	0.04	0.00	–0.19	–0.24
1969	–0.03	0.12	0.18	0.06	0.08	–0.12	–0.20	–0.36	0.19	–0.12	–0.72	–0.22	0.08	0.18	–0.17
1970	0.08	0.13	0.18	0.11	0.13	0.06	–0.05	0.50	–0.10	0.10	–0.08	0.09	0.56	0.47	0.26
1971	–0.16	–0.35	–0.34	–0.42	–0.32	0.43	–0.24	–0.22	–0.01	–0.01	0.36	–0.32	–0.31	–0.50	–0.19
1972	–0.50	–0.30	0.08	0.04	–0.17	0.04	–0.02	–0.22	–0.43	–0.16	0.42	0.28	–0.53	–0.31	–0.04
1973	0.49	0.39	0.24	0.05	0.29	–0.14	–0.30	–0.36	–0.28	–0.27	–0.12	–0.73	–0.57	–0.43	–0.46
1974	–0.14	–0.12	–0.14	–0.15	–0.14	–0.16	0.06	–0.37	–0.39	–0.22	0.09	–0.04	–0.43	–0.75	–0.28
1975	–0.08	0.09	–0.12	–0.12	–0.06	–0.15	0.05	0.15	–0.53	–0.12	–0.29	–0.22	–0.20	–0.38	–0.27
1976	–0.25	–0.44	–0.39	–0.32	–0.35	0.18	0.37	–0.05	0.37	0.22	0.26	0.20	0.20	–0.17	0.12
1977	0.11	0.33	0.22	0.10	0.19	–0.76	–0.01	–0.03	0.26	–0.14	–1.43	–0.33	–0.55	0.28	–0.51
1978	0.02	0.21	0.08	–0.01	0.08	–0.30	0.06	0.02	–0.76	–0.25	–0.79	–0.46	–0.26	–0.61	–0.53
1979	0.03	0.37	0.19	0.23	0.21	0.22	0.24	–0.24	–0.53	–0.08	–0.13	0.19	–0.29	–0.81	–0.26
1980	0.27	0.46	0.41	0.16	0.33	–0.09	–0.29	–0.25	–0.01	–0.16	–0.13	–0.83	–0.36	0.05	–0.32
1981	0.20	0.17	0.19	0.14	0.18	0.15	–0.15	–0.61	0.06	–0.14	0.29	–0.35	–0.48	–0.11	–0.16
1982	0.19	–0.07	0.21	–0.02	0.08	0.10	0.17	0.09	0.50	0.22	–0.33	–0.06	–0.03	0.35	–0.02
1983	0.29	0.68	0.36	0.15	0.37	0.62	0.12	–0.29	0.17	0.16	0.19	–0.13	–0.41	0.01	–0.09
1984	–0.10	0.11	–0.06	–0.07	–0.03	0.10	–0.46	–0.59	–0.70	–0.41	–0.30	–0.43	–0.49	–0.67	–0.47
1985	0.02	0.03	–0.10	–0.28	–0.08	–0.98	–1.04	–1.35	–0.96	–1.08	–0.78	–0.81	–1.11	–0.95	–0.91
1986	–0.02	0.03	0.03	0.01	0.01	–1.03	–0.74	–1.02	–1.50	–1.07	–0.80	–0.62	–0.78	–1.08	–0.82
1987	0.33	0.28	0.47	0.29	0.34	–0.90	–1.29	–1.17	–1.53	–1.22	–0.73	–0.92	–1.26	–1.53	–1.11
1988	0.31	0.38	0.52	0.30	0.38	–1.45	–1.41	–1.17	–1.32	–1.34	–1.15	–0.99	–0.96	–0.86	–0.99
1989	–0.01	0.04	0.10	0.08	0.05	–0.87	–1.08	–1.08	–1.44	–1.12	–0.64	–0.82	–0.91	–1.29	–0.92
1990	0.18	0.42	0.47	0.29	0.34	–1.46	–1.14	–1.36	–1.68	–1.41	–1.02	–0.94	–1.12	–1.41	–1.12
1991	0.25	0.24	0.52	0.13	0.29	–1.32	–1.16	–0.82	–0.03	–0.83	–1.05	–0.86	–0.67	–0.15	–0.68
1992	0.01	–0.05	–0.16	–0.23	–0.11	0.18	–0.51	–0.32	–1.03	–0.42	–0.11	–0.41	–0.36	–0.91	–0.45

^aTemperature anomalies (in relation to a 1958–77 average) expressed in degrees Celsius for Win (December–February), Spr (March–May), Sum (June–August), and Fall (September–November).

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Temperature

Global, hemispheric, and zonal temperature anomalies
derived from radiosonde records

J.K. Angell (continued)

NORTH POLAR (60° N–90° N)

Annual and Seasonal Temperature Anomalies^a

Year	Surface					850–300 mb					300–100 mb				
	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann
1958	-0.45	-0.95	0.18	0.16	-0.27	-0.88	-0.14	0.18	0.21	-0.16	0.60	1.12	-0.21	0.56	0.52
1959	0.93	0.41	0.18	0.85	0.59	1.02	0.95	0.42	1.47	0.97	-0.39	1.47	0.04	-0.28	0.21
1960	-0.78	0.00	0.54	-0.51	-0.19	-0.07	0.88	0.84	0.00	0.41	3.47	-0.70	-0.32	0.77	0.81
1961	1.85	-0.56	0.11	1.28	0.67	1.89	-0.42	-0.63	0.49	0.33	0.60	3.05	1.47	0.46	1.40
1962	1.06	0.69	0.21	0.44	0.60	-0.14	0.22	-0.07	-0.32	-0.08	-2.63	-1.68	-0.81	-0.18	-1.33
1963	-0.08	-0.09	-0.39	0.19	-0.09	-0.04	0.25	-0.25	-0.21	-0.06	-0.11	0.28	0.53	-0.53	0.04
1964	0.15	-0.55	-0.18	-0.60	-0.30	0.07	-0.56	-0.70	-0.70	-0.47	-2.91	1.61	0.04	0.74	-0.13
1965	-0.55	0.18	-0.10	0.54	0.02	-0.21	-0.39	-0.88	0.84	-0.16	-1.09	-1.61	0.04	-0.38	-0.76
1966	-3.41	-1.44	0.00	-0.96	-1.45	-1.47	-0.42	0.11	0.21	-0.39	2.49	0.42	0.81	0.49	1.05
1967	-0.28	1.35	-0.66	0.78	0.30	-0.46	0.07	-0.39	0.42	-0.09	-1.40	-3.89	-0.21	-1.47	-1.74
1968	0.00	0.58	-0.25	-0.91	-0.15	-0.18	-0.32	0.00	-0.42	-0.23	1.36	-4.34	-0.49	-0.42	-0.97
1969	-0.70	-0.48	0.01	0.58	-0.15	0.07	0.11	0.49	0.32	0.25	2.98	0.18	0.28	-0.14	0.83
1970	1.31	0.44	-0.36	-0.71	0.17	1.02	-0.21	0.14	-0.18	0.19	2.87	0.28	-0.11	0.18	0.81
1971	-0.82	0.05	0.64	-0.06	-0.05	-0.53	-0.21	-0.11	-1.30	-0.54	0.32	0.53	-0.18	-0.73	-0.02
1972	-0.11	-0.29	-0.20	-0.75	-0.34	-0.25	0.07	0.21	-0.35	-0.08	-3.15	-0.46	-0.49	0.32	-0.95
1973	1.57	-0.25	0.83	-0.14	0.50	0.63	-0.35	0.77	0.11	0.29	0.49	1.26	-0.21	0.32	0.47
1974	0.53	0.14	-0.21	0.14	0.15	0.18	0.74	0.00	-0.28	0.16	-2.63	0.98	-0.28	0.88	-0.26
1975	-0.13	0.91	-0.33	-0.41	0.01	-0.67	0.25	-0.14	-0.21	-0.19	-0.77	1.40	0.04	-0.49	0.05
1976	0.30	0.28	-0.45	-0.93	-0.20	-0.56	-0.21	-0.28	0.48	-0.14	-4.03	-2.24	-1.02	-1.13	-2.11
1977	0.18	-0.79	0.19	-0.55	-0.24	0.78	0.06	0.83	-0.15	0.38	3.27	1.42	-0.88	-0.77	0.76
1978	0.60	0.55	-0.36	-0.18	0.15	0.03	0.54	0.36	-0.38	0.14	-0.65	0.49	-0.14	-1.17	-0.37
1979	-0.46	-0.23	-0.91	-0.18	-0.45	-0.39	0.16	0.25	0.00	0.01	-0.36	0.54	-0.10	0.09	0.04
1980	1.12	0.30	0.00	-0.84	0.15	0.38	0.35	0.17	-0.40	0.13	-2.36	1.15	0.09	-0.23	-0.34
1981	1.85	0.48	-0.45	1.10	0.75	-0.27	0.76	-0.22	0.56	0.21	-1.72	-0.90	-0.02	-0.63	-0.82
1982	0.80	-0.06	-0.19	-1.71	-0.29	0.25	-0.38	0.18	-0.71	-0.17	-0.45	-0.33	-0.12	-1.09	-0.50
1983	0.38	0.52	-0.08	-0.34	0.12	-0.46	0.48	0.56	-0.01	0.14	-4.43	0.23	-0.65	-1.28	-1.53
1984	1.18	0.49	-0.10	0.17	0.44	0.10	0.40	0.07	0.58	0.29	-3.25	1.61	-0.18	-0.93	-0.69
1985	0.13	-0.33	-0.54	-0.51	-0.31	0.43	-0.78	-0.86	-0.04	-0.31	3.75	1.71	-0.02	0.04	1.37
1986	-0.10	-0.19	-0.02	0.81	0.13	0.38	-0.59	-0.01	-0.34	-0.14	-1.43	0.20	-0.89	-1.02	-0.79
1987	-1.21	-0.73	0.00	-0.58	-0.63	-0.47	0.32	-0.02	-0.40	-0.14	1.73	0.26	-0.24	0.61	0.59
1988	0.54	1.06	0.44	-0.45	0.40	0.10	-0.09	0.95	-0.11	0.21	-0.22	-1.35	-0.37	-1.09	-0.76
1989	1.99	1.42	0.62	0.05	1.02	-0.49	0.58	0.29	-0.29	0.02	-3.62	1.09	-0.55	-0.63	-0.93
1990	0.84	3.94	0.46	-1.09	1.04	-0.02	0.22	0.70	-0.82	0.02	-3.88	-5.98	-0.69	-1.22	-2.94
1991	0.25	0.94	0.41	0.96	0.64	0.16	0.45	1.23	0.26	0.53	0.00	0.25	-0.14	-1.13	-0.26
1992	0.92	0.49	-1.37	-0.97	-0.23	-0.06	-0.93	-0.81	-1.17	-0.74	-1.31	-1.01	-1.39	-1.00	-1.18

Global, hemispheric, and zonal temperature anomalies
derived from radiosonde records

J.K. Angell (continued)

NORTH POLAR (60° N–90° N)

Annual and Seasonal Temperature Anomalies^a

Year	Surface–100 mb					100–50 mb					100–30 mb				
	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann
1958	-0.48	0.02	0.09	0.28	-0.02	2.60	-1.60	0.23	2.77	1.00	2.35	-2.47	0.31	3.92	1.03
1959	0.69	0.98	0.30	0.98	0.74	-3.03	6.25	1.08	-1.30	0.75	-2.18	5.95	1.30	-1.27	0.95
1960	0.60	0.38	0.53	0.09	0.40	6.05	4.16	0.28	2.12	3.15	9.25	-0.41	0.09	2.95	2.97
1961	1.60	0.33	-0.04	0.62	0.63	1.32	2.12	-0.21	1.14	1.09	1.17	2.87	0.16	1.18	1.35
1962	-0.49	-0.30	-0.19	-0.16	-0.29	-5.08	-4.23	-1.30	-0.09	-2.68	-6.31	-4.86	-1.67	-0.20	-3.26
1963	-0.06	0.20	-0.10	-0.21	-0.04	-0.19	-3.14	0.97	-1.02	-0.85	1.34	-4.03	0.93	-0.69	-0.61
1964	-0.58	-0.08	-0.45	-0.36	-0.37	-4.29	2.28	0.13	0.35	-0.38	-4.55	3.35	-0.07	0.06	-0.30
1965	-0.46	-0.57	-0.55	0.52	-0.27	-2.68	-2.73	-0.37	-1.02	-1.70	-4.63	-1.78	-0.47	-1.56	-2.11
1966	-0.91	-0.40	0.25	0.08	-0.25	3.18	-0.71	0.33	0.09	0.72	1.49	-0.55	0.06	0.17	0.29
1967	-0.55	-0.60	-0.40	0.06	-0.37	-3.30	-5.61	0.30	-0.99	-2.40	-4.17	-1.94	0.07	-2.15	-2.05
1968	0.19	-1.06	-0.15	-0.50	-0.38	0.25	-4.63	0.10	0.08	-1.05	-3.96	-2.19	0.29	0.41	-1.36
1969	0.59	0.03	0.36	0.26	0.31	1.28	-0.81	-1.76	-0.35	-0.41	-0.59	-0.43	0.02	-0.57	-0.39
1970	1.48	0.01	0.00	-0.19	0.33	2.76	-0.24	0.69	1.62	1.21	3.03	-0.39	0.75	0.02	0.85
1971	-0.39	0.00	0.00	-0.97	-0.34	2.35	-0.84	0.06	-0.33	0.31	0.85	-1.17	-0.12	-0.41	-0.21
1972	-0.87	-0.11	-0.01	-0.27	-0.32	-2.06	0.76	0.06	-0.46	-0.43	-1.91	1.88	-0.11	-0.02	-0.04
1973	0.76	0.02	0.56	0.12	0.37	1.90	-0.65	-0.67	-0.58	0.00	4.09	-1.48	-0.73	-0.35	0.38
1974	-0.39	0.69	-0.10	0.05	0.06	-2.47	2.85	0.02	1.42	0.46	-0.97	3.05	0.01	0.63	0.68
1975	-0.60	0.62	-0.13	-0.31	-0.11	0.57	1.59	-0.11	-0.94	0.28	1.45	0.18	0.26	0.27	0.54
1976	-1.19	-0.58	-0.47	-0.10	-0.59	-4.38	1.40	-0.15	-0.66	-0.95	-1.62	1.26	0.03	-0.49	-0.21
1977	1.23	0.22	0.34	-0.36	0.36	2.94	0.95	1.30	0.95	1.54	0.07	0.74	0.62	0.28	0.43
1978	-0.08	0.52	0.13	-0.52	0.01	-1.10	0.30	-1.09	-2.42	-1.08	-0.91	0.15	-0.91	-0.88	-0.64
1979	-0.39	0.05	-0.03	-0.01	-0.10	2.10	0.49	-0.33	0.23	0.62	0.26	0.48	-0.29	-0.89	-0.11
1980	-0.09	0.52	0.20	-0.24	0.10	-0.12	0.87	0.10	0.41	0.32	1.05	0.83	0.06	0.05	0.50
1981	-0.34	0.28	-0.22	0.34	0.02	-0.13	-1.52	-0.43	-0.18	-0.57	0.47	-2.35	-0.18	-0.21	-0.57
1982	0.17	-0.20	0.03	-0.91	-0.23	1.11	0.42	0.52	-1.08	0.24	0.92	0.96	0.54	-1.90	0.13
1983	-0.98	0.48	0.21	-0.29	-0.15	-4.36	-0.01	-0.81	-0.98	-1.54	-4.00	0.15	-0.90	-1.33	-1.52
1984	-0.47	0.68	-0.01	0.19	0.10	-1.73	1.01	-0.45	-0.76	-0.48	-1.37	0.72	-0.22	-0.42	-0.32
1985	1.12	-0.15	-0.62	-0.10	0.06	3.34	0.22	-0.69	-0.50	0.59	2.13	0.10	-0.43	-0.55	0.31
1986	-0.12	-0.32	-0.24	-0.30	-0.25	-1.54	1.10	-0.62	-1.67	-0.68	-0.79	0.86	-0.41	-1.11	-0.36
1987	-0.11	0.13	-0.06	-0.21	-0.06	3.20	-2.23	-0.34	0.38	0.25	2.27	-1.53	-0.36	0.57	0.24
1988	0.07	-0.18	0.57	-0.39	0.02	-1.48	0.03	-0.81	-1.35	-0.90	-0.72	0.36	-0.58	-0.98	-0.48
1989	-0.77	0.83	0.17	-0.30	-0.02	-0.38	1.11	-0.93	-0.67	-0.22	0.30	0.61	-0.59	-0.39	-0.02
1990	-0.72	-0.54	0.35	-0.96	-0.47	-3.26	-6.17	-0.83	-1.79	-3.01	-1.54	-3.48	-0.52	-1.15	-1.67
1991	0.13	0.48	0.79	0.07	0.37	1.16	-1.02	-0.39	-1.01	-0.32	1.31	-0.56	-0.31	-0.56	-0.03
1992	-0.17	-0.71	-1.04	-1.10	-0.76	0.22	-1.20	-0.95	-1.57	-0.88	0.25	-0.45	-0.47	-0.93	-0.40

^aTemperature anomalies (in relation to a 1958–77 average) expressed in degrees Celsius for Win (December–February), Spr (March–May), Sum (June–August), and Fall (September–November).

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Temperature

Global, hemispheric, and zonal temperature anomalies
derived from radiosonde records

J.K. Angell (continued)

NORTH TEMPERATE (30° N–60° N)

Annual and Seasonal Temperature Anomalies^a

Year	Surface					850–300 mb					300–100 mb				
	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann
1958	1.67	0.03	0.12	0.33	0.54	1.61	0.70	-0.07	0.14	0.60	-0.46	-0.35	0.39	0.98	0.14
1959	0.48	0.31	0.55	-0.49	0.21	0.25	0.95	0.42	0.14	0.44	0.35	0.88	0.63	0.28	0.54
1960	0.52	-0.88	0.10	-0.34	-0.15	-0.04	-0.70	0.14	-0.07	-0.17	0.84	0.60	0.25	0.53	0.56
1961	0.92	0.82	0.25	0.21	0.55	0.42	0.56	0.21	0.67	0.47	0.53	0.42	0.53	-0.28	0.30
1962	0.94	0.39	-0.09	-0.31	0.23	0.46	0.56	0.18	0.04	0.31	-0.70	-0.21	-0.28	0.28	-0.23
1963	0.26	-0.11	0.03	0.97	0.29	0.53	-0.18	0.21	0.81	0.34	-0.53	-0.14	0.56	0.67	0.14
1964	0.12	-0.83	-0.19	-0.17	-0.27	-0.04	0.32	0.21	-0.07	0.11	0.14	0.07	-0.07	0.18	0.08
1965	-0.47	-0.32	-0.20	-0.60	-0.40	0.18	-0.35	-0.39	-0.49	-0.26	0.56	0.14	-0.39	0.25	0.14
1966	0.39	0.37	-0.36	-0.05	0.09	0.00	0.04	0.18	0.56	0.20	-0.25	-0.46	0.77	0.00	0.02
1967	-0.47	0.48	0.64	0.85	0.38	-0.35	0.46	0.46	0.60	0.29	-0.07	0.42	-0.88	-0.67	-0.30
1968	-0.42	1.07	-0.31	-0.16	0.05	0.74	0.42	-0.67	-0.28	0.05	0.00	-0.84	-0.32	-0.04	-0.30
1969	-2.27	-0.93	-0.10	-0.03	-0.83	-0.98	-0.49	0.07	0.14	-0.32	-0.46	0.25	0.21	-0.32	-0.08
1970	0.00	-0.29	-0.23	0.21	-0.08	-0.42	-0.35	0.07	0.18	-0.13	-0.39	-0.42	0.32	-0.21	-0.18
1971	-0.67	-0.35	-0.25	0.65	-0.16	-0.53	-0.60	-0.21	0.14	-0.30	-0.04	0.04	0.07	-0.11	-0.01
1972	-0.90	-0.25	-0.06	-0.60	-0.45	-0.95	-0.35	-0.28	-0.49	-0.52	0.42	-0.46	-0.53	-0.35	-0.23
1973	-0.19	-0.02	0.12	-0.43	-0.13	0.00	-0.21	-0.21	-0.67	-0.27	0.14	0.35	0.00	-0.49	0.00
1974	-0.02	-0.32	-0.47	-0.24	-0.26	-0.39	-0.81	-0.63	-1.12	-0.74	-0.25	-0.11	-0.53	-0.25	-0.29
1975	0.52	0.58	0.51	0.00	0.40	-0.42	0.04	0.32	-0.21	-0.07	0.07	-0.21	-0.77	-0.21	-0.28
1976	0.02	-0.80	-0.05	-0.82	-0.41	-0.25	-1.09	-0.46	-1.03	-0.71	-0.14	-0.46	-1.09	-0.52	-0.55
1977	-0.96	0.53	-0.08	0.17	-0.09	-0.96	0.44	-0.11	0.14	-0.12	-0.12	0.51	0.05	0.14	0.15
1978	-0.20	-0.53	0.07	0.10	-0.14	-0.66	-0.22	-0.05	-0.13	-0.27	0.42	-0.30	0.16	-0.21	0.02
1979	-0.54	0.33	0.16	0.01	-0.01	-0.43	0.73	0.22	0.44	0.24	-0.28	-0.25	-0.31	0.10	-0.19
1980	0.65	-0.14	-0.47	0.03	0.02	0.21	-0.31	0.29	-0.24	-0.01	-0.51	0.92	0.84	0.46	0.43
1981	1.06	1.06	0.31	0.40	0.71	0.73	0.71	0.37	-0.03	0.45	-0.76	-0.79	0.01	0.23	-0.33
1982	0.21	-0.22	-0.05	0.28	0.06	-0.32	-0.28	-0.01	0.20	-0.10	0.69	0.50	0.09	-0.33	0.24
1983	2.92	0.60	0.34	0.57	1.11	0.93	0.98	0.45	0.39	0.69	-0.23	-0.95	-0.11	0.04	-0.31
1984	1.02	0.03	0.26	-0.19	0.28	0.05	-0.25	0.27	-0.61	-0.14	-0.40	-0.32	0.00	0.43	-0.07
1985	-1.29	-0.27	-0.20	-0.99	-0.69	-0.51	-0.26	-0.25	-0.46	-0.37	0.22	0.80	0.01	0.32	0.34
1986	0.14	0.51	-0.40	-0.45	-0.05	-0.07	0.52	-0.06	0.17	0.14	0.31	-0.31	-0.20	-0.12	-0.08
1987	0.78	-0.13	0.10	-0.79	-0.01	0.23	0.22	0.38	-0.41	0.11	-0.05	-0.82	0.29	0.90	0.08
1988	0.55	0.60	0.39	0.26	0.45	-0.05	0.23	0.97	0.37	0.38	-0.70	0.20	-0.06	-0.05	-0.15
1989	1.49	0.79	0.46	0.17	0.73	0.36	0.50	0.54	0.33	0.43	0.49	0.02	-0.85	-0.24	-0.15
1990	1.33	1.77	0.58	0.47	1.04	0.53	1.03	0.66	0.09	0.58	0.33	0.24	-0.14	-0.17	0.07
1991	0.44	0.36	0.26	0.24	0.33	0.27	0.49	0.61	1.02	0.60	-0.62	-0.69	0.08	0.13	-0.28
1992	1.27	-0.17	-0.56	-0.33	0.05	0.76	0.22	-0.26	-0.42	0.08	0.43	-1.40	-1.11	0.31	-0.44

Global, hemispheric, and zonal temperature anomalies
derived from radiosonde records

J.K. Angell (continued)

NORTH TEMPERATE (30° N–60° N)

Annual and Seasonal Temperature Anomalies^a

Year	Surface–100 mb					100–50 mb					100–30 mb				
	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann
1958	1.16	0.36	0.06	0.36	0.49	1.40	1.22	0.89	1.93	1.36	0.36	0.83	1.37	1.94	1.13
1959	0.31	0.83	0.49	0.07	0.43	1.48	2.18	1.32	0.64	1.41	0.60	1.48	0.99	1.21	1.07
1960	0.25	-0.44	0.16	0.02	0.00	1.19	1.33	1.00	0.37	0.97	0.69	1.02	0.77	0.34	0.71
1961	0.53	0.57	0.29	0.38	0.44	-1.30	0.23	0.78	-1.11	-0.35	-0.15	-0.04	0.74	-0.33	0.06
1962	0.28	0.36	0.03	0.06	0.18	0.53	-0.23	-0.80	0.23	-0.07	1.27	-0.53	-1.02	0.11	-0.04
1963	0.25	-0.16	0.26	0.81	0.29	-1.11	0.01	0.70	1.01	0.15	0.56	-1.25	0.41	0.68	0.10
1964	0.03	0.07	0.08	-0.03	0.04	-0.09	0.56	-0.16	-0.91	-0.15	0.70	1.40	-0.22	-0.70	0.30
1965	0.16	-0.24	-0.36	-0.34	-0.20	-0.46	0.07	-0.02	0.19	-0.06	-0.68	1.40	0.14	0.02	0.22
1966	0.01	-0.02	0.22	0.33	0.14	0.59	-0.85	0.24	0.80	0.20	-0.16	-0.50	0.27	0.90	0.13
1967	-0.31	0.45	0.19	0.36	0.17	0.85	0.23	-1.21	-0.28	-0.10	0.09	0.42	-0.44	-0.41	-0.09
1968	0.38	0.25	-0.53	-0.21	-0.03	-0.99	-0.74	0.18	-0.10	-0.41	-1.58	-0.91	0.12	-0.35	-0.68
1969	-1.08	-0.40	0.07	0.01	-0.35	-1.37	0.03	-0.04	1.15	-0.06	-2.03	-0.43	-0.07	-0.63	-0.79
1970	-0.34	-0.36	0.08	0.10	-0.13	0.05	0.37	0.33	-0.27	0.12	-0.28	0.46	0.31	-0.08	0.10
1971	-0.44	-0.42	-0.15	0.17	-0.21	0.03	-0.78	0.00	-0.11	-0.22	-0.75	-0.96	0.02	-0.50	-0.55
1972	-0.64	-0.36	-0.30	-0.48	-0.45	-0.33	0.12	0.30	0.19	0.07	1.26	0.27	-0.45	0.13	0.30
1973	0.00	-0.05	-0.11	-0.59	-0.19	0.56	-0.94	-0.60	-0.38	-0.34	0.49	-1.58	-0.58	-0.89	-0.64
1974	-0.30	-0.57	-0.56	-0.78	-0.55	-0.09	0.46	-0.07	-0.38	-0.02	0.66	0.54	-0.14	0.11	0.29
1975	-0.15	0.07	0.11	-0.29	-0.07	-0.16	-0.09	-0.29	-0.82	-0.34	-0.66	-0.62	-0.12	-0.09	-0.37
1976	-0.18	-0.90	-0.53	-0.88	-0.62	0.04	0.38	-0.58	0.27	0.03	0.72	0.43	-0.35	0.29	0.27
1977	-0.77	0.47	-0.04	0.14	-0.05	-0.17	-0.08	0.42	0.17	0.09	-0.25	-0.30	0.12	-0.13	-0.14
1978	-0.34	-0.09	0.02	-0.10	-0.13	0.24	-1.35	-0.78	-0.29	-0.55	-0.58	-1.29	-0.56	-0.09	-0.63
1979	-0.36	0.45	0.09	0.31	0.12	0.18	0.60	-0.16	0.27	0.22	0.47	0.06	0.00	-0.02	0.13
1980	0.14	0.04	0.27	-0.07	0.10	-0.21	1.02	0.03	1.08	0.48	-0.93	0.41	0.39	0.79	0.17
1981	0.49	0.42	0.28	0.10	0.32	0.52	0.04	-0.09	0.53	0.25	0.45	0.36	0.11	0.83	0.44
1982	-0.02	-0.09	0.03	0.09	0.00	0.93	0.64	0.91	0.24	0.68	1.78	0.68	0.77	0.36	0.90
1983	1.02	0.50	0.28	0.33	0.53	0.28	0.18	-0.39	-0.02	0.01	0.51	0.23	-0.57	0.31	0.12
1984	0.11	-0.22	0.21	-0.34	-0.06	0.00	0.59	-0.79	0.40	0.05	0.23	0.34	-0.49	0.26	0.09
1985	-0.48	-0.03	-0.18	-0.37	-0.27	-0.44	-1.09	-0.65	-0.01	-0.55	-0.26	-0.82	-0.46	-0.04	-0.40
1986	0.05	0.34	-0.15	0.00	0.06	1.07	-0.26	-0.39	0.26	0.17	0.80	-0.09	-0.28	0.19	0.16
1987	0.26	-0.07	0.32	-0.18	0.08	-0.01	-0.68	0.27	0.77	0.09	0.03	-0.40	-0.24	0.63	0.01
1988	-0.09	0.29	0.64	0.26	0.28	-1.36	0.68	-0.23	-0.10	-0.25	-0.68	0.47	-0.23	-0.10	-0.14
1989	0.58	0.44	0.22	0.18	0.36	0.33	-0.87	-0.83	-0.42	-0.45	0.46	-0.54	-0.72	-0.25	-0.26
1990	0.62	0.98	0.47	0.10	0.54	-0.86	-0.42	-0.55	-0.38	-0.55	-0.55	-0.40	-0.35	-0.21	-0.38
1991	0.11	0.21	0.43	0.69	0.36	0.00	-0.43	-0.07	0.11	-0.10	0.24	-0.27	-0.15	0.15	-0.01
1992	0.78	-0.21	-0.50	-0.24	-0.04	0.18	-1.05	-0.48	-0.62	-0.49	0.07	-0.65	-0.44	-0.40	-0.36

^aTemperature anomalies (in relation to a 1958–77 average) expressed in degrees Celsius for Win (December–February), Spr (March–May), Sum (June–August), and Fall (September–November).

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Temperature

Global, hemispheric, and zonal temperature anomalies
derived from radiosonde records

J.K. Angell (continued)

NORTH SUBTROPICS (10° N–30° N)

Annual and Seasonal Temperature Anomalies^a

Year	Surface					850–300 mb					300–100 mb				
	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann
1958	0.22	0.40	0.12	0.30	0.26	0.28	0.77	0.81	0.88	0.69	0.31	0.18	0.56	0.77	0.46
1959	0.05	0.08	-0.02	-0.07	0.01	0.53	0.63	0.42	0.39	0.49	0.67	0.32	0.35	0.70	0.51
1960	0.05	0.00	0.05	-0.47	-0.09	0.49	0.44	0.49	0.18	0.40	0.53	0.11	0.39	-0.21	0.21
1961	-0.07	-0.24	-0.17	-0.38	-0.22	0.18	0.11	0.00	0.04	0.08	0.11	0.28	0.56	0.25	0.30
1962	-0.21	-0.12	-0.12	0.02	-0.11	0.28	-0.14	-0.11	0.18	0.05	0.60	0.35	0.25	0.25	0.36
1963	0.42	0.17	0.10	0.34	0.26	-0.07	-0.25	-0.21	-0.21	-0.19	-0.11	0.18	0.11	0.46	0.16
1964	-0.67	-0.39	-0.14	-0.39	-0.40	0.07	0.07	-0.07	-0.46	-0.10	0.63	0.53	0.14	-0.35	0.24
1965	-0.15	-0.38	-0.18	-0.08	-0.20	-0.91	-0.53	-0.60	-0.25	-0.57	-0.67	-0.49	-0.28	0.07	-0.34
1966	-0.35	0.09	0.06	0.08	-0.03	0.14	0.32	0.25	0.14	0.21	1.02	0.56	0.67	0.24	0.62
1967	-0.31	-0.17	-0.07	-0.47	-0.26	0.25	-0.35	0.14	-0.11	-0.02	0.00	0.11	0.21	0.14	0.12
1968	-0.29	-0.37	0.02	0.01	-0.16	-0.46	-0.60	-0.39	-0.32	-0.44	-0.49	-0.95	-1.02	-0.91	-0.84
1969	0.39	0.42	0.44	0.24	0.37	-0.14	0.11	0.28	0.04	0.07	-0.56	0.39	-0.46	-0.42	-0.26
1970	0.55	0.19	0.28	0.00	0.26	0.11	0.18	0.25	0.07	0.15	-0.21	0.35	0.39	0.28	0.20
1971	-0.11	0.06	-0.27	-0.27	-0.15	-0.25	-0.70	-0.67	-0.60	-0.56	-0.42	-0.74	-1.05	-0.95	-0.79
1972	-0.19	-0.32	0.27	0.30	0.02	-0.67	-0.35	-0.04	-0.11	-0.29	-0.98	-0.77	0.00	0.21	-0.39
1973	0.47	0.62	0.28	0.35	0.43	0.53	0.39	0.07	0.11	0.28	1.05	0.60	0.18	-0.14	0.42
1974	0.12	0.20	-0.32	0.02	0.01	-0.18	-0.21	-0.28	-0.11	-0.20	-0.53	-0.63	-0.53	-0.21	-0.48
1975	0.17	0.12	-0.08	0.09	0.08	-0.25	0.04	-0.32	0.00	-0.13	-0.60	-0.14	-0.11	0.11	-0.19
1976	0.08	-0.23	0.08	0.48	0.10	-0.49	-0.49	-0.49	-0.34	-0.45	-0.35	-0.35	-0.39	-0.40	-0.37
1977	0.09	0.45	0.40	0.71	0.41	0.31	-0.13	-0.20	0.19	0.04	-0.05	-0.15	-0.17	-0.69	-0.27
1978	0.44	-0.14	0.43	0.63	0.34	-0.01	0.08	-0.02	-0.16	-0.03	0.00	-0.64	-0.70	-0.76	-0.53
1979	0.19	0.38	0.16	0.44	0.29	-0.51	-0.02	-0.03	0.08	-0.12	-0.58	0.05	-0.76	-0.88	-0.54
1980	0.71	0.96	0.45	0.56	0.67	0.06	0.14	0.36	0.21	0.19	-0.34	0.12	0.00	-0.24	-0.12
1981	0.54	0.71	0.68	0.33	0.57	0.05	-0.11	0.06	0.18	0.05	-0.56	-0.79	-0.63	-0.74	-0.68
1982	0.57	0.05	0.40	0.45	0.37	-0.17	-0.27	0.10	-0.34	-0.17	-0.53	-0.82	-0.22	-0.67	-0.56
1983	-0.37	-0.13	0.59	0.64	0.18	-0.25	0.12	0.10	0.04	0.00	0.35	0.20	0.21	-0.56	0.05
1984	-0.19	0.48	0.11	0.36	0.19	0.05	0.07	-0.35	-0.19	-0.11	-1.02	-0.87	-0.71	-1.23	-0.96
1985	-0.17	0.02	0.22	0.34	0.10	-0.05	-0.19	-0.28	-0.51	-0.26	-0.74	-0.53	-0.97	-1.03	-0.82
1986	0.07	0.21	0.28	0.27	0.21	0.25	0.07	0.11	0.10	0.13	-0.77	-1.02	-0.60	-0.47	-0.72
1987	0.46	0.42	0.76	1.07	0.68	0.23	-0.15	0.48	0.69	0.31	0.35	-0.35	-0.16	0.22	0.02
1988	0.37	0.47	0.18	0.02	0.26	0.59	0.52	0.81	0.52	0.61	-0.38	-0.21	-0.04	-0.26	-0.22
1989	0.14	0.14	0.30	-0.29	0.07	0.07	0.06	0.21	0.43	0.19	-0.42	-0.92	-0.43	-0.54	-0.58
1990	0.30	0.08	0.35	0.58	0.33	-0.09	0.72	0.78	0.90	0.58	0.76	0.32	0.54	0.17	0.45
1991	0.76	0.47	0.29	0.22	0.44	0.27	0.12	0.30	-0.19	0.13	-0.45	-0.54	0.01	-0.38	-0.34
1992	0.13	0.22	0.16	0.36	0.22	-0.34	-0.02	0.15	-0.14	-0.09	-0.30	-0.33	-0.53	-0.18	-0.34

Global, hemispheric, and zonal temperature anomalies
derived from radiosonde records

J.K. Angell (continued)

NORTH SUBTROPICS (10° N–30° N)

Annual and Seasonal Temperature Anomalies^a

Year	Surface–100 mb					100–50 mb					100–30 mb				
	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann
1958	0.28	0.58	0.64	0.76	0.57	0.60	0.60	-0.47	0.13	0.22	0.71	1.50	-0.19	0.33	0.59
1959	0.48	0.47	0.33	0.41	0.42	0.01	-0.22	0.14	-0.39	-0.12	0.12	-0.73	-0.11	0.33	-0.10
1960	0.43	0.07	0.39	-0.02	0.22	-0.41	-0.48	0.14	0.71	-0.01	-0.48	-0.21	0.11	0.64	0.02
1961	0.12	0.17	0.10	0.02	0.10	-0.38	-0.64	1.38	1.99	0.59	-1.01	-1.17	1.54	1.37	0.18
1962	0.27	-0.03	-0.03	0.17	0.10	0.63	0.08	-0.49	-0.15	0.02	0.83	0.39	-0.39	0.16	0.25
1963	0.00	-0.08	-0.09	0.03	-0.04	0.05	0.81	1.99	0.86	0.93	-0.33	0.84	1.81	1.12	0.86
1964	0.07	0.10	-0.04	-0.42	-0.07	1.19	0.77	1.47	0.18	0.90	1.28	0.72	1.35	0.74	1.02
1965	-0.73	-0.50	-0.46	-0.15	-0.46	1.15	0.55	1.06	1.39	1.04	1.39	1.34	0.79	1.24	1.19
1966	0.25	0.34	0.31	0.15	0.26	-0.09	-0.08	-0.27	-0.08	-0.13	-0.71	-0.53	-0.34	0.46	-0.28
1967	0.10	-0.22	0.12	-0.11	-0.03	0.09	0.57	-0.49	-1.42	-0.31	0.45	0.73	-0.37	-0.67	0.04
1968	-0.44	-0.64	-0.46	-0.40	-0.49	-0.34	1.16	0.00	-0.11	0.18	-0.03	1.04	-0.02	-0.53	0.12
1969	-0.08	-0.22	0.14	-0.03	-0.05	-0.18	0.11	-0.10	0.67	0.13	-1.16	-0.78	-0.84	0.22	-0.64
1970	0.11	0.22	0.29	0.11	0.18	-0.83	-0.57	-0.06	0.03	-0.36	-0.94	-0.20	0.40	0.42	-0.08
1971	-0.26	-0.58	-0.69	-0.62	-0.54	-0.13	-0.05	-0.17	0.01	-0.09	-0.46	-0.32	0.05	-0.32	-0.26
1972	-0.66	-0.44	0.02	0.03	-0.26	0.56	-0.55	-1.62	-0.48	-0.52	0.20	-0.41	-1.61	-1.10	-0.73
1973	0.64	0.48	0.13	0.09	0.34	-0.48	-0.54	-0.18	-0.15	-0.34	-1.72	-1.26	-0.36	-0.55	-0.97
1974	-0.21	-0.24	-0.34	-0.11	-0.23	0.18	-0.77	-0.58	-0.55	-0.43	0.83	-0.69	-0.48	-1.16	-0.38
1975	-0.26	0.01	-0.23	0.04	-0.11	-0.20	0.39	-0.22	-0.09	-0.03	-0.47	0.02	-0.03	-0.35	-0.21
1976	-0.36	-0.42	-0.37	-0.22	-0.34	1.15	0.49	0.77	-0.13	0.57	1.29	0.05	0.16	-0.39	0.28
1977	0.20	-0.04	-0.11	0.09	0.04	-1.57	1.00	0.30	0.06	-0.05	-1.89	0.53	-1.16	-1.23	-0.94
1978	0.00	-0.12	-0.08	-0.16	-0.09	-0.89	-0.66	-0.76	-0.77	-0.77	-2.17	-1.87	-1.13	-1.33	-1.63
1979	-0.41	0.07	0.22	0.02	-0.03	-0.10	0.13	-0.21	-0.24	-0.11	0.06	0.11	-0.31	-0.86	-0.25
1980	0.07	0.26	0.22	0.19	0.19	0.28	-0.52	-0.27	-0.20	-0.18	-0.14	-1.44	0.07	-0.24	-0.44
1981	-0.01	-0.12	0.12	0.06	0.01	-0.22	-0.78	-0.75	-0.31	-0.52	0.04	-1.00	-0.88	-0.59	-0.61
1982	-0.22	-0.33	0.07	-0.29	-0.19	0.04	0.28	0.71	0.90	0.48	-0.67	0.43	0.89	1.14	0.45
1983	-0.14	0.07	0.18	0.09	0.05	1.14	-0.14	-0.37	0.61	0.31	0.22	-1.13	-0.69	0.56	-0.26
1984	-0.22	-0.07	-0.31	-0.22	-0.21	0.29	-0.99	-0.93	-0.26	-0.47	0.35	-0.75	-0.74	-0.32	-0.37
1985	-0.20	-0.21	-0.32	-0.48	-0.30	-1.07	-0.81	-0.39	0.23	-0.51	-0.92	-0.91	-0.50	-0.13	-0.62
1986	-0.01	-0.18	0.02	0.10	-0.02	-1.26	-0.54	-1.65	-1.33	-1.20	-0.89	-0.80	-1.26	-0.96	-0.98
1987	0.33	-0.11	0.40	0.59	0.30	-1.50	-0.47	-0.55	-0.65	-0.79	-0.99	-0.55	-0.74	-0.76	-0.76
1988	0.34	0.42	0.48	0.25	0.37	-1.66	-1.50	-1.21	-1.81	-1.55	-1.23	-1.09	-0.98	-1.21	-1.13
1989	0.05	-0.19	0.09	0.20	0.04	-0.69	-0.70	-0.50	-0.40	-0.57	-0.39	-0.68	-0.42	-0.41	-0.48
1990	0.15	0.55	0.60	0.68	0.50	0.02	0.89	-0.92	-1.02	-0.26	-0.33	-0.32	-0.84	-0.78	-0.57
1991	0.19	0.03	0.28	-0.21	0.07	-1.82	-1.50	-0.24	1.29	-0.57	-1.31	-1.24	-0.42	0.76	-0.55
1992	-0.26	-0.05	-0.03	-0.06	-0.10	0.51	0.70	0.19	0.46	0.46	-0.28	-0.08	-0.45	-0.14	-0.24

^aTemperature anomalies (in relation to a 1958–77 average) expressed in degrees Celsius for Win (December–February), Spr (March–May), Sum (June–August), and Fall (September–November).

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Temperature

Global, hemispheric, and zonal temperature anomalies
derived from radiosonde records

J.K. Angell (continued)

EQUATORIAL (10° S–10° N)

Annual and Seasonal Temperature Anomalies^a

Year	Surface					850–300 mb					300–100 mb				
	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann
1958	0.45	-0.30	-0.90	0.30	-0.11	0.25	-0.30	-0.60	-0.22	-0.22	0.68	-1.65	-0.05	0.37	-0.16
1959	0.15	-0.45	-0.18	0.25	-0.06	-0.04	-0.09	-0.27	-0.27	-0.17	-0.13	-0.19	-0.02	-0.25	-0.15
1960	-0.07	-0.07	0.00	0.23	0.02	-0.03	-0.11	0.15	0.06	0.02	0.11	-0.19	0.38	0.23	0.13
1961	0.12	0.17	0.13	0.02	0.11	-0.11	-0.05	-0.03	-0.35	-0.14	-0.03	-0.12	-0.55	-0.03	-0.18
1962	-0.02	-0.18	-0.12	-0.13	-0.11	-0.14	-0.25	-0.22	0.20	-0.10	0.32	0.21	-0.06	0.29	0.19
1963	-0.22	-0.23	0.07	0.22	-0.04	-0.24	-0.10	0.13	0.19	-0.01	-0.11	0.20	-0.26	-0.07	-0.06
1964	-0.23	-0.09	-0.11	-0.39	-0.21	0.49	0.28	-0.32	-0.47	-0.01	0.21	0.00	-0.34	-0.78	-0.23
1965	-0.64	-0.01	-0.31	0.07	-0.22	-0.76	-0.20	-0.32	0.06	-0.31	-1.08	-0.94	-0.40	0.15	-0.57
1966	-0.10	0.13	0.20	-0.03	0.05	0.30	0.23	0.20	-0.33	0.10	0.35	0.21	0.01	-0.37	0.05
1967	-0.08	-0.09	-0.06	-0.38	-0.15	-0.34	-0.39	-0.10	-0.17	-0.25	-0.20	-0.33	0.21	0.00	-0.08
1968	-0.13	-0.20	0.08	0.09	-0.04	-0.17	-0.35	-0.11	-0.19	-0.21	-0.57	-1.01	0.15	-0.26	-0.42
1969	0.17	0.36	-0.01	0.32	0.21	0.19	0.68	0.25	0.24	0.34	0.30	0.92	-0.13	0.39	0.37
1970	0.38	0.14	-0.11	-0.37	0.01	0.55	0.62	0.38	0.43	0.50	0.41	1.30	0.69	0.57	0.74
1971	-0.14	-0.20	-0.33	-0.47	-0.29	-0.21	-0.55	-0.43	-0.57	-0.44	0.06	-0.82	-0.60	-0.76	-0.53
1972	-0.10	-0.24	0.19	0.24	0.02	-0.55	-0.13	0.45	0.64	0.10	-0.85	-0.46	0.18	0.45	-0.17
1973	0.59	0.37	0.16	0.36	0.37	1.15	0.64	0.39	0.35	0.63	1.13	0.87	0.76	0.37	0.78
1974	0.03	-0.30	0.26	0.12	0.03	-0.37	-0.02	0.08	0.16	-0.04	-0.29	-0.02	0.35	-0.20	-0.04
1975	0.13	0.19	-0.10	-0.27	-0.01	0.18	0.20	-0.02	-0.06	0.08	0.15	0.18	-0.10	0.28	0.13
1976	-0.31	0.08	-0.20	0.07	-0.09	-0.18	-0.34	-0.16	0.37	-0.08	-0.02	-0.42	0.15	0.55	0.07
1977	-0.02	0.43	0.37	0.33	0.28	0.45	0.32	0.44	0.47	0.42	0.36	0.16	0.26	0.33	0.28
1978	0.51	0.26	0.30	0.39	0.37	0.50	0.78	0.11	0.05	0.36	0.10	0.35	-0.29	-0.36	-0.05
1979	0.54	0.60	0.54	0.61	0.57	0.52	0.22	0.50	0.42	0.42	0.36	0.09	-0.01	-0.51	-0.02
1980	0.40	0.49	0.06	0.33	0.32	0.35	0.44	0.57	0.50	0.47	-0.84	-0.60	-0.11	-0.44	-0.50
1981	0.13	0.43	0.15	0.07	0.20	0.31	0.45	0.09	0.37	0.31	-0.89	-0.91	-0.73	-0.54	-0.77
1982	0.26	0.28	0.62	0.33	0.37	0.53	0.24	0.57	0.21	0.39	-0.56	-0.98	-0.40	-0.86	-0.70
1983	0.52	0.58	0.61	0.14	0.46	1.21	1.21	0.77	-0.10	0.77	0.06	0.31	0.21	-0.47	0.03
1984	0.63	-0.01	-0.32	0.13	0.11	-0.04	0.08	-0.04	-0.07	-0.02	-0.86	-0.89	-0.99	-1.20	-0.99
1985	0.56	0.06	0.05	0.28	0.24	0.26	0.08	-0.19	0.11	0.07	-1.04	-1.13	-1.34	-1.25	-1.19
1986	0.35	0.39	0.29	0.22	0.31	0.20	0.02	-0.05	0.37	0.14	-0.90	-0.77	-0.81	-0.64	-0.78
1987	0.81	1.37	1.41	0.87	1.12	0.77	0.80	0.96	0.91	0.86	-0.02	-0.19	0.23	0.30	0.08
1988	1.03	0.74	0.24	0.57	0.65	1.15	0.62	0.77	0.24	0.70	0.22	0.33	0.73	-0.64	0.16
1989	0.23	-0.08	0.16	0.80	0.28	-0.26	-0.30	-0.10	0.27	-0.10	-1.45	-1.18	-0.52	-0.28	-0.86
1990	0.70	1.01	0.70	0.74	0.79	0.48	0.67	0.47	0.50	0.53	-0.39	-0.31	-0.18	-0.83	-0.43
1991	1.07	0.82	0.95	-0.47	0.59	0.48	0.20	0.56	0.13	0.34	-0.51	-0.95	-0.58	-1.25	-0.82
1992	0.48	0.45	-0.29	-0.03	0.15	0.10	-0.23	0.13	-0.41	-0.10	-0.92	-0.01	-0.34	-1.46	-0.68

Global, hemispheric, and zonal temperature anomalies
derived from radiosonde records

J.K. Angell (continued)

EQUATORIAL (10° S–10° N)

Annual and Seasonal Temperature Anomalies^a

Year	Surface–100 mb					100–50 mb					100–30 mb				
	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann
1958	0.37	-1.43	-0.59	-0.21	-0.47										
1959	-0.02	-0.11	-0.20	-0.04	-0.09	-1.87	-2.65	-2.81	1.25	-1.52					
1960	-0.01	-0.10	0.18	0.13	0.05	0.21	-1.07	-2.00	-1.72	-1.15	-0.14	-1.23	-5.18	-4.66	-2.80
1961	-0.06	0.01	-0.28	-0.21	-0.14	-5.23	-2.29	0.83	2.63	-1.02	-4.97	-4.80	-0.56	-1.47	-2.95
1962	-0.01	-0.13	-0.24	0.05	-0.08	0.59	-0.88	-1.21	-2.17	-0.92	-0.37	-2.04	-3.64	-3.12	-2.29
1963	0.20	-0.05	0.02	0.13	-0.03	-1.45	-2.03	-0.47	1.02	-0.73	-3.99	-3.46	0.72	3.89	-0.71
1964	0.37	0.19	-0.28	-0.49	-0.05	1.38	2.27	1.70	1.50	1.71	0.62	1.99	1.49	0.64	1.19
1965	-0.81	-0.41	-0.33	0.08	-0.37	0.99	0.51	-0.55	-0.83	0.03	0.57	-0.09	-1.14	-1.37	-0.51
1966	0.15	0.21	0.12	-0.29	0.05	-1.86	-1.97	-0.48	2.23	-0.52	-2.34	-0.93	1.72	2.30	0.19
1967	-0.31	-0.32	-0.01	-0.15	-0.20	1.49	2.12	0.33	0.23	1.04	2.04	2.03	0.88	0.14	1.27
1968	-0.25	-0.47	-0.01	-0.15	-0.22	-0.30	1.14	-0.91	-1.16	-0.31	-1.06	0.09	-0.95	-0.48	-0.60
1969	0.21	0.63	0.09	0.29	0.31	-1.18	-1.59	0.34	0.57	-0.47	-1.25	-0.38	1.22	1.59	0.30
1970	0.49	0.69	0.37	0.40	0.49	0.28	0.20	0.39	0.69	0.39	-0.70	-0.55	0.10	0.65	-0.13
1971	-0.19	-0.56	-0.45	-0.59	-0.45	0.20	-0.63	1.09	1.25	0.48	1.67	1.66	1.14	-0.42	1.01
1972	-0.54	-0.22	0.36	0.52	0.03	1.84	1.26	-0.82	-2.22	0.02	1.80	0.54	-1.36	-0.72	0.07
1973	0.94	0.65	0.43	0.36	0.60	-1.74	-0.79	0.89	0.71	-0.23	-1.80	-0.22	0.51	0.37	-0.29
1974	-0.29	-0.16	0.17	0.08	-0.05	1.64	0.46	-1.01	-1.59	-0.13	1.27	-0.72	-2.05	-2.32	-0.96
1975	0.17	0.19	-0.05	-0.01	0.08	-0.78	-0.53	0.76	1.24	0.17	-0.54	-0.11	0.26	1.44	0.26
1976	-0.16	-0.29	-0.10	0.36	-0.05	3.31	1.44	0.91	1.22	1.72	2.51	0.50	0.48	-1.53	0.49
1977	0.35	0.30	0.39	0.41	0.36	-1.34	-0.72	-0.65	-1.21	-0.98	-3.83	-1.59	-1.40	1.22	-1.40
1978	0.43	0.58	0.06	0.01	0.27	-0.52	0.52	2.34	1.41	0.94	-0.03	0.80	1.19	0.60	0.64
1979	0.49	0.25	0.40	0.31	0.36	0.60	-0.10	-0.96	-2.24	-0.68	-0.42	-0.63	-0.81	-2.08	-0.99
1980	0.16	0.34	0.34	0.24	0.27	-0.79	-1.93	0.05	1.60	-0.27	-1.14	-2.53	0.69	1.37	-0.40
1981	-0.01	0.14	-0.11	0.08	0.03	1.33	0.55	-0.12	-0.07	0.42	1.44	-0.23	-1.32	-1.11	-0.31
1982	0.23	0.03	0.36	0.00	0.16	-0.98	-0.41	-0.32	1.92	0.05	-2.76	-2.23	0.44	2.42	-0.53
1983	0.89	0.98	0.62	-0.06	0.61	1.55	1.19	0.60	0.76	1.03	0.87	0.55	-0.87	-1.10	-0.14
1984	-0.16	-0.17	-0.32	-0.29	-0.24	0.45	-1.10	-2.11	-2.44	-1.30	-0.94	-1.40	-1.49	-1.68	-1.38
1985	0.02	-0.19	-0.41	-0.16	-0.19	-2.86	-1.42	-0.05	0.38	-0.99	-1.74	-0.76	0.13	-0.27	-0.66
1986	-0.01	-0.10	-0.16	0.12	-0.04	-0.92	-1.16	-1.82	-2.65	-1.64	-1.01	-1.30	-1.62	-2.03	-1.49
1987	0.68	0.72	0.69	0.88	0.74	-2.55	-3.27	-3.70	-1.43	-2.74	-2.25	-2.46	-2.20	-0.89	-1.95
1988	0.96	0.58	0.68	0.10	0.58	-1.38	-2.29	-1.49	-2.04	-1.80	-1.08	-1.83	-1.13	-1.65	-1.42
1989	-0.44	-0.46	-0.17	0.23	-0.21	-0.68	-1.58	-1.89	-2.45	-1.65	-0.83	-1.27	-1.45	-1.77	-1.33
1990	0.29	0.47	0.37	0.19	0.33	-2.80	-2.14	-0.57	-0.30	-1.45	-2.03	-1.33	-0.53	-0.58	-1.12
1991	0.36	0.05	0.38	-0.22	0.14	-1.10	-1.07	-1.43	-0.62	-1.06	-1.14	-1.37	-1.09	-0.53	-1.03
1992	-0.06	-0.12	0.22	-0.58	-0.14	-0.08	-1.37	-1.25	-0.51	-0.80	-0.41	-1.13	-0.66	-0.33	-0.63

^aTemperature anomalies (in relation to a 1958–77 average) expressed in degrees Celsius for Win (December–February), Spr (March–May), Sum (June–August), and Fall (September–November).

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Temperature

Global, hemispheric, and zonal temperature anomalies
derived from radiosonde records

J.K. Angell (continued)

SOUTH SUBTROPICS (10° S–30° S)

Annual and Seasonal Temperature Anomalies^a

Year	Surface					850–300 mb					300–100 mb				
	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann
1958	1.10	1.00	-0.10	0.40	0.60	0.70	0.04	0.56	0.53	0.46	-0.14	0.04	0.00	-1.51	-0.40
1959	0.47	0.50	0.67	0.52	0.54	0.21	0.07	0.32	0.28	0.22	-0.63	-0.21	-0.53	-0.56	-0.48
1960	0.34	0.20	0.01	0.37	0.23	0.46	0.07	0.56	0.32	0.35	0.53	-0.18	0.00	0.18	0.13
1961	0.06	0.15	-0.08	0.26	0.10	-0.04	0.49	0.18	0.11	0.19	-0.18	0.39	-0.11	-0.32	-0.06
1962	0.08	0.04	-0.04	0.26	0.09	0.18	-0.28	-0.04	-0.04	-0.05	-0.07	0.07	0.11	0.28	0.10
1963	-0.13	0.00	-0.16	-0.10	-0.10	-0.18	-0.14	0.07	-0.14	-0.10	-0.56	0.07	0.25	0.07	-0.04
1964	-0.13	-0.01	-0.23	0.05	-0.08	0.00	0.07	-0.42	-0.56	-0.23	0.42	0.04	-0.32	-0.67	-0.13
1965	-0.08	-0.28	-0.09	-0.28	-0.18	-1.16	-0.60	-0.63	-0.28	-0.67	-1.19	-0.60	-0.49	0.04	-0.56
1966	-0.08	-0.25	-0.16	-0.25	-0.19	0.04	-0.18	0.04	-0.18	-0.07	0.25	0.42	0.00	0.11	0.20
1967	0.09	0.09	-0.16	0.10	0.03	-0.28	-0.04	-0.07	-0.18	-0.14	-0.42	-0.42	-0.25	-0.32	-0.35
1968	0.17	-0.72	-0.60	-0.21	-0.34	-0.23	-0.35	-0.14	0.07	-0.16	-0.11	-0.67	0.04	0.14	-0.15
1969	0.12	0.28	0.02	-0.03	0.10	0.28	0.60	0.53	0.32	0.43	0.14	0.98	0.39	0.35	0.47
1970	0.03	-0.14	-0.09	-0.24	-0.11	0.35	0.53	0.49	0.28	0.41	0.49	0.53	0.63	0.77	0.61
1971	-0.16	-0.23	-0.17	-0.25	-0.20	-0.21	-0.63	-0.56	-0.67	-0.52	0.77	-0.42	-0.46	-0.60	-0.18
1972	-0.13	-0.21	0.20	-0.06	-0.05	-0.39	0.00	0.21	0.60	0.11	0.46	-0.46	0.04	0.18	0.06
1973	0.48	0.59	0.51	0.02	0.40	0.95	0.95	0.35	0.28	0.63	0.91	0.35	0.42	0.39	0.52
1974	-0.41	-0.15	0.10	-0.05	-0.13	0.07	0.07	-0.32	-0.14	-0.08	-0.18	-0.25	-0.21	0.04	-0.15
1975	-0.45	0.11	0.15	-0.09	-0.07	-0.25	-0.21	-0.35	-0.25	-0.26	-0.14	0.11	-0.02	-0.11	-0.04
1976	-0.57	-0.32	-0.26	-0.19	-0.34	-0.32	-0.32	-0.46	-0.35	-0.36	-0.70	-0.35	-0.53	0.00	-0.40
1977	0.16	0.36	0.24	0.16	0.23	0.38	0.62	0.80	0.47	0.57	-0.07	0.03	-0.37	0.20	-0.05
1978	-0.09	0.12	-0.02	0.04	0.01	0.33	0.24	0.46	0.26	0.32	0.21	-0.04	0.07	0.13	0.09
1979	-0.24	0.14	0.10	0.03	0.01	0.17	0.51	0.45	0.28	0.35	0.07	0.18	-0.15	-0.03	0.02
1980	0.49	0.97	0.53	0.44	0.61	0.61	0.88	0.75	0.41	0.66	-0.27	-0.09	0.23	0.31	0.05
1981	0.01	0.26	-0.31	0.55	0.13	0.53	0.23	0.28	0.21	0.31	-0.19	-0.22	-0.46	-0.34	-0.30
1982	0.38	0.87	0.51	0.38	0.54	0.62	-0.04	0.33	0.35	0.32	-0.07	-0.01	-0.20	-0.05	-0.08
1983	0.47	0.76	0.58	0.79	0.65	0.78	1.22	0.40	0.03	0.61	0.41	0.59	0.02	-0.10	0.23
1984	0.40	0.71	0.81	0.84	0.69	0.42	0.89	0.26	0.31	0.47	-1.24	-0.88	-0.91	-0.82	-0.96
1985	-0.24	0.29	0.57	0.20	0.21	0.39	0.53	0.12	0.45	0.37	-1.22	-0.79	-0.79	-0.63	-0.86
1986	-0.70	0.49	0.59	0.64	0.26	0.60	0.23	0.04	0.12	0.25	-0.86	-0.10	-0.23	-0.03	-0.31
1987	0.76	1.66	0.70	0.70	0.96	0.79	0.76	0.49	0.64	0.67	-0.13	-0.14	0.83	1.03	0.40
1988	0.39	0.23	0.40	0.73	0.44	0.99	0.99	0.92	0.16	0.77	0.49	0.47	0.66	0.23	0.46
1989	-0.29	0.37	0.22	0.13	0.11	0.05	0.16	0.27	0.10	0.15	-0.58	-0.51	-0.15	0.15	-0.27
1990	-0.03	0.64	0.23	0.69	0.38	0.00	0.48	0.65	0.66	0.45	0.04	0.18	0.51	0.35	0.27
1991	0.24	0.66	0.71	0.87	0.62	0.82	0.75	0.80	0.46	0.71	0.37	0.15	0.34	-0.02	0.21
1992	0.57	1.27	0.64	0.89	0.84	0.29	0.68	0.36	-0.17	0.29	-0.32	0.11	0.04	0.09	-0.02

Global, hemispheric, and zonal temperature anomalies
derived from radiosonde records

J.K. Angell (continued)

SOUTH SUBTROPICS (10° S–30° S)

Annual and Seasonal Temperature Anomalies^a

Year	Surface–100 mb					100–50 mb					100–30 mb				
	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann
1958	0.58	0.44	0.33	–0.48	0.22										
1959	0.07	0.08	0.19	0.13	0.12										
1960	0.46	0.04	0.34	0.30	0.29										
1961	–0.05	0.41	0.07	0.04	0.12										
1962	–0.03	–0.34	–0.01	0.08	–0.08										
1963	–0.26	–0.07	0.14	–0.09	–0.07										
1964	0.07	0.05	–0.37	–0.10	–0.09	1.15	1.97	1.30	0.75	1.29	0.27	1.09	1.78	–0.07	0.77
1965	–0.99	–0.55	–0.51	–0.21	–0.57	1.58	0.33	1.20	1.63	1.19	0.43	–0.26	0.78	2.13	0.77
1966	0.18	–0.06	–0.01	–0.13	–0.01	–0.12	0.05	–0.86	0.22	–0.18	–0.12	–0.16	–0.72	0.33	–0.17
1967	–0.25	–0.10	–0.13	–0.02	–0.13	1.00	0.41	0.94	–0.10	0.56	0.39	0.67	0.14	–0.21	0.25
1968	–0.15	–0.48	0.11	–0.27	–0.20	–0.81	0.49	0.60	0.72	0.25	–0.62	0.75	0.68	0.32	0.28
1969	0.22	0.71	0.41	0.27	0.40	–0.16	–0.04	–1.20	0.19	–0.30	–0.42	–0.81	–1.41	0.65	–0.50
1970	0.45	0.23	0.42	0.36	0.37	–0.52	–0.29	1.48	0.10	0.19	–0.77	0.24	1.51	1.16	0.54
1971	0.02	–0.52	–0.47	–0.58	–0.39	1.17	0.25	–1.16	–0.33	–0.02	1.46	–0.32	–1.12	–0.62	–0.15
1972	–0.27	–0.08	0.25	0.40	0.08	–0.14	–0.56	0.42	–0.35	–0.16	0.05	0.06	–0.74	–1.05	–0.42
1973	–0.86	0.76	0.29	0.26	0.54	–0.77	–0.23	–0.59	–0.66	–0.56	–0.67	–0.67	–0.64	–0.49	–0.62
1974	–0.07	–0.04	–0.23	–0.09	–0.11	0.40	–0.10	0.50	–0.03	0.19	–0.18	–0.07	1.05	–0.44	0.09
1975	–0.26	0.02	–0.20	–0.19	–0.16	–0.38	0.09	–0.35	0.03	–0.15	–0.31	0.35	–1.56	–0.83	–0.59
1976	–0.34	–0.33	–0.44	–0.25	–0.34	0.72	–0.06	–0.18	–0.18	0.08	0.27	–0.34	0.91	–0.30	0.14
1977	0.24	0.43	0.45	0.36	0.37	–2.32	–0.63	–0.18	–0.28	–0.85	–2.91	–0.63	–0.08	–0.88	–1.13
1978	0.23	0.23	0.29	0.19	0.24	–0.33	–0.25	–0.38	–1.25	–0.55	–1.45	–1.13	–0.64	–1.54	–1.19
1979	0.05	0.38	0.26	0.17	0.22	–0.82	0.19	0.05	–0.30	–0.22	–1.80	0.41	0.43	–1.03	–0.50
1980	0.53	0.90	0.64	0.46	0.63	–0.37	–1.76	–1.20	–0.06	–0.85	0.19	–2.28	–1.73	–0.56	–1.10
1981	0.18	0.10	0.05	0.17	0.13	–0.41	–0.82	–0.12	0.46	–0.22	–0.22	–0.45	1.23	0.49	0.26
1982	0.43	0.10	0.24	0.26	0.26	–0.58	0.01	1.16	1.16	0.44	–0.78	0.08	0.69	–0.09	–0.03
1983	0.66	1.01	0.39	0.15	0.55	0.99	–0.99	–0.03	0.87	0.21	0.66	–0.73	0.47	1.56	0.49
1984	0.04	0.49	0.08	0.13	0.19	0.20	–1.30	0.18	–0.19	–0.28	–0.87	–0.95	–0.20	–0.61	–0.66
1985	–0.07	0.17	–0.12	0.17	0.04	–1.36	–1.61	–1.75	–1.15	–1.47	–1.10	–1.44	–1.36	–1.20	–1.28
1986	0.06	0.20	0.07	0.18	0.13	–2.21	–2.53	–2.57	–2.52	–2.46	–1.80	–1.79	–1.64	–1.98	–1.80
1987	0.58	0.71	0.60	0.76	0.66	–1.49	–1.42	–0.38	–0.32	–0.90	–1.34	–1.28	–0.70	–0.80	–1.03
1988	0.78	0.75	0.75	0.27	0.64	–1.12	–3.38	–1.85	–3.52	–2.47	–1.62	–2.23	–1.49	–2.61	–1.99
1989	–0.14	0.05	0.17	0.12	0.05	–1.84	–2.16	–0.62	–0.54	–1.29	–1.59	–1.63	–0.65	–0.98	–1.21
1990	0.00	0.44	0.53	0.60	0.39	–1.90	–1.64	–2.42	–1.56	–1.88	–1.42	–1.45	–2.02	–1.62	–1.63
1991	0.62	0.60	0.68	0.40	0.58	–2.72	–2.84	–2.11	–0.63	–2.08	–2.58	–2.12	–1.10	–0.70	–1.63
1992	0.21	0.53	–0.08	0.40	0.26	–0.07	–1.36	–0.84	–0.50	–0.69	–0.41	–0.64	–0.64	–0.87	–0.64

^aTemperature anomalies (in relation to a 1958–77 average) expressed in degrees Celsius for Win (December–February), Spr (March–May), Sum (June–August), and Fall (September–November).

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Temperature

Global, hemispheric, and zonal temperature anomalies
derived from radiosonde records

J.K. Angell (continued)

SOUTH TEMPERATE (30° S–60° S)

Annual and Seasonal Temperature Anomalies^a

Year	Surface					850–300 mb					300–100 mb				
	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann
1958	0.63	0.70	0.73	0.70	0.69	-0.12	-0.06	0.33	0.89	0.26	-0.34	-0.68	0.08	-0.45	-0.35
1959	1.10	0.63	0.78	0.68	0.80	0.47	0.00	1.11	1.19	0.69	-0.47	0.51	0.53	-0.35	0.06
1960	0.68	0.63	0.67	0.10	0.52	0.90	0.22	0.03	0.42	0.39	-0.71	-0.41	1.68	0.25	0.20
1961	0.60	0.42	0.70	0.54	0.57	0.28	0.06	0.00	0.37	0.18	-0.05	0.56	-0.21	-1.02	-0.18
1962	0.95	0.65	0.55	0.55	0.68	0.62	0.44	0.38	0.18	0.41	-0.54	-1.72	0.06	0.40	-0.45
1963	0.55	0.28	0.13	0.12	0.27	0.47	0.02	-0.58	-0.46	-0.14	-0.40	0.43	1.00	2.20	0.81
1964	-0.45	-0.23	0.03	0.28	-0.09	-1.07	-0.36	-0.95	-0.64	-0.76	0.93	1.12	1.21	0.62	0.97
1965	0.38	-0.17	-0.08	0.66	0.20	-0.86	-0.75	0.30	0.43	-0.22	0.47	0.19	-0.84	-0.45	-0.16
1966	0.65	0.10	-0.15	0.18	0.20	-0.02	-0.17	-0.19	-0.20	-0.15	0.15	0.08	0.18	0.28	0.17
1967	-0.15	-0.22	-0.48	0.40	-0.11	-0.12	0.15	0.01	0.29	0.08	0.48	0.59	-0.16	-0.06	0.21
1968	0.35	0.47	-0.20	-0.18	0.11	0.10	0.29	-0.40	-0.70	-0.18	0.20	-0.38	-0.52	0.75	0.01
1969	-0.93	-0.93	-0.50	-0.36	-0.68	-0.10	-0.09	0.76	0.10	0.17	0.78	0.78	-0.16	-0.69	0.18
1970	-0.28	-0.53	-0.28	-0.80	-0.47	-0.16	-0.39	-0.13	-0.46	-0.29	-0.55	-0.25	-0.33	-0.38	-0.38
1971	-0.55	-0.53	-0.45	-0.65	-0.55	0.43	-0.12	-0.30	-0.36	-0.09	-0.12	0.42	-0.29	-0.62	-0.15
1972	-0.98	-0.47	-0.50	-0.53	-0.62	-0.48	0.03	0.26	0.49	0.08	-0.12	-0.57	-0.39	-0.37	-0.36
1973	-0.63	-0.32	-0.50	-0.47	-0.48	0.57	0.58	0.34	-0.40	0.27	-0.59	-0.12	-0.69	-0.14	-0.39
1974	-0.74	0.20	-0.17	-0.75	-0.37	0.78	0.58	-0.14	-0.19	0.26	-0.37	-1.18	-0.90	-0.74	-0.80
1975	-0.75	-0.50	-0.32	-0.50	-0.52	-0.06	-0.03	-0.32	0.07	-0.09	-0.11	0.06	-0.08	-0.41	-0.14
1976	-0.97	-0.62	-0.08	-0.28	-0.49	0.38	0.35	0.26	-0.90	0.02	0.12	-0.63	-0.51	-0.50	-0.38
1977	-0.55	0.05	-0.13	0.08	-0.14	-0.38	0.87	-0.31	0.00	0.05	-0.26	-0.04	0.63	-0.24	0.02
1978	0.15	0.12	0.00	-0.15	0.03	0.15	0.11	0.77	0.16	0.30	-0.19	-0.32	-0.26	-0.18	-0.24
1979	0.00	0.12	0.48	0.05	0.16	0.49	1.23	1.10	0.36	0.80	0.25	-0.05	0.25	0.45	0.23
1980	0.03	0.23	0.29	-0.07	0.12	0.43	0.74	0.61	0.25	0.51	-0.22	0.33	-0.48	0.03	-0.09
1981	-0.13	0.28	0.31	-0.20	0.07	0.93	0.73	0.71	0.42	0.70	-0.78	-0.82	-0.89	0.00	-0.62
1982	-0.02	0.28	-0.02	0.02	0.07	0.83	0.64	0.77	0.32	0.64	-0.28	-0.06	0.01	0.80	0.12
1983	-0.67	-0.32	-0.42	-0.03	-0.36	-0.29	0.86	0.65	0.83	0.51	-0.11	0.50	0.00	-0.38	0.00
1984	-0.43	0.14	-0.45	-0.11	-0.21	0.23	0.23	0.02	0.25	0.18	-0.71	-0.56	0.80	0.15	-0.08
1985	0.06	0.43	0.58	-0.44	0.16	0.14	0.85	0.81	0.12	0.48	-0.70	-0.39	-0.94	-1.30	-0.83
1986	-0.40	0.32	-0.28	-0.30	-0.17	0.29	0.09	0.43	0.29	0.28	-1.66	-0.70	-0.21	0.01	-0.64
1987	-0.51	0.45	0.56	-0.11	0.10	0.72	0.65	1.08	0.43	0.72	-0.52	-0.08	-0.22	0.41	-0.10
1988	-0.74	-0.48	-0.61	0.00	-0.46	0.11	0.48	-0.10	0.18	0.17	-0.54	-0.32	0.23	0.35	-0.07
1989	-0.11	-0.13	-0.23	-0.07	-0.14	0.49	0.41	0.31	0.53	0.44	-1.20	-0.81	-0.82	-1.01	-0.96
1990	0.06	-0.14	0.07	0.05	0.01	0.61	0.39	0.58	0.62	0.55	-0.64	0.63	-0.31	-0.71	-0.26
1991	-0.26	0.39	0.00	-0.24	-0.03	0.27	0.60	0.18	0.08	0.28	-0.92	-1.09	0.26	0.05	-0.43
1992	-1.33	-0.57	-0.61	-0.26	-0.69	-0.80	-0.47	-0.59	0.19	-0.42	-0.64	-0.05	1.04	-0.99	-0.16

Global, hemispheric, and zonal temperature anomalies
derived from radiosonde records

J.K. Angell (continued)

SOUTH TEMPERATE (30° S–60° S)

Annual and Seasonal Temperature Anomalies^a

Year	Surface–100 mb					100–50 mb					100–30 mb				
	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann
1958	-0.04	-0.03	0.34	0.56	0.21										
1959	0.44	0.23	0.93	0.76	0.59										
1960	0.45	0.15	0.41	0.33	0.34										
1961	0.26	0.23	0.07	-0.01	0.14										
1962	0.42	0.02	0.34	0.30	0.27										
1963	-0.10	-0.17	-0.11	0.23	-0.04										
1964	-0.28	-0.01	-0.31	-0.21	-0.20	1.90	0.55	-0.29	0.22	0.60	1.12	0.46	1.06	0.47	0.78
1965	-0.36	-0.44	0.01	0.17	-0.16	0.89	0.92	1.03	0.86	0.93	1.10	0.59	1.43	1.31	1.11
1966	0.18	-0.07	-0.09	-0.03	0.00	-0.28	0.08	-1.14	-0.88	-0.56	-0.94	1.03	-1.45	0.77	-0.15
1967	-0.04	0.18	-0.11	0.22	0.06	0.10	-0.10	0.97	0.27	0.31	0.28	0.13	-0.05	0.47	0.21
1968	0.16	0.13	-0.37	-0.29	-0.09	-0.63	-0.67	0.21	-0.32	-0.35	0.52	0.33	-0.19	-0.34	0.08
1969	0.17	-0.04	0.35	-0.15	0.08	1.04	0.47	0.71	0.37	0.65	0.61	0.98	1.57	0.63	0.95
1970	-0.44	-0.38	-0.15	-0.50	-0.37	0.02	0.26	0.23	-0.08	0.11	0.27	1.36	0.37	1.24	0.81
1971	0.12	-0.10	-0.33	-0.47	-0.20	0.00	-0.40	-0.40	-0.89	-0.42	-0.20	-1.53	-1.14	-0.94	-0.95
1972	-0.48	-0.74	-0.09	0.13	-0.30	-0.37	-0.64	0.42	0.59	0.00	0.40	0.29	1.22	1.21	0.78
1973	0.11	0.28	0.17	-0.36	0.05	0.92	0.82	-1.39	-0.45	-0.03	1.23	0.04	-1.50	-0.52	-0.19
1974	0.27	0.12	-0.33	-0.39	-0.08	-1.77	-1.57	-0.29	-0.57	-1.05	-1.55	-1.56	-0.33	-1.25	-1.17
1975	-0.18	-0.14	-0.24	-0.12	-0.17	0.18	0.01	1.64	-1.76	0.02	-0.39	-0.71	-0.45	-2.10	-0.91
1976	0.04	-0.03	-0.52	-0.71	-0.31	-1.72	-0.87	-1.13	0.90	-0.71	-2.05	-0.75	-0.38	0.73	-0.61
1977	-0.38	0.53	-0.07	-0.04	0.01	-0.82	-0.18	0.10	0.25	-0.16	-0.47	-0.21	-0.31	0.50	-0.12
1978	0.07	-0.09	0.36	0.04	0.10	0.10	0.30	0.31	-0.50	0.05	-0.29	0.08	0.22	0.49	0.13
1979	0.30	0.76	0.80	0.32	0.55	0.52	0.47	0.38	0.41	0.45	0.35	0.77	0.90	0.13	0.54
1980	0.23	0.56	0.31	0.16	0.32	0.77	-0.11	-0.91	-0.85	-0.28	0.76	-0.28	-1.25	-0.39	-0.29
1981	0.45	0.28	0.26	0.23	0.31	-0.64	0.07	-0.94	0.16	-0.34	-0.48	-0.19	-0.99	0.03	-0.41
1982	0.44	0.42	0.49	0.37	0.43	-0.22	0.53	0.13	1.05	0.37	-0.53	0.36	-0.09	0.39	0.03
1983	-0.31	0.62	0.33	0.42	0.27	1.72	0.23	0.32	0.56	0.71	1.26	0.32	0.62	0.25	0.61
1984	-0.09	0.03	0.12	0.17	0.06	0.42	-0.66	0.14	-0.31	-0.10	-0.01	-0.42	-0.14	-0.47	-0.26
1985	0.06	0.55	0.39	-0.29	0.18	-1.09	-1.05	-1.71	-1.87	-1.43	-0.97	-0.61	-1.06	-0.72	-0.84
1986	-0.26	-0.05	0.17	0.13	0.00	-1.44	-0.99	0.24	-0.93	-0.78	-0.84	-0.65	-0.09	-0.15	-0.43
1987	0.24	0.45	0.71	0.34	0.44	-0.72	-0.72	-0.56	-0.97	-0.74	-0.25	0.01	-1.56	-0.90	-0.68
1988	-0.18	0.14	-0.11	0.19	0.01	-1.98	-1.97	-1.53	-2.21	-1.92	-1.45	-1.42	-1.34	-1.56	-1.44
1989	0.01	0.06	0.00	0.09	0.04	-1.68	-2.01	-0.84	-0.90	-1.36	-1.18	-1.38	-0.63	-0.52	-0.93
1990	0.24	0.36	0.29	0.23	0.28	-1.26	-0.33	-1.76	-2.13	-1.37	-0.69	-0.28	-1.20	-0.90	-0.77
1991	-0.09	0.19	0.17	0.02	0.07	-2.08	-1.48	0.07	1.13	-0.59	-1.40	-0.75	-0.12	0.62	-0.41
1992	-0.88	-0.40	-0.23	-0.11	-0.40	0.35	0.62	0.84	-1.89	-0.02	0.14	0.26	0.16	-0.93	-0.09

^aTemperature anomalies (in relation to a 1958–77 average) expressed in degrees Celsius for Win (December–February), Spr (March–May), Sum (June–August), and Fall (September–November).

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Temperature

Global, hemispheric, and zonal temperature anomalies
derived from radiosonde records

J.K. Angell (continued)

SOUTH POLAR (60° S–90° S)

Annual and Seasonal Temperature Anomalies^a

Year	Surface					850–300 mb					300–100 mb				
	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann
1958	0.68	0.36	-0.58	-0.22	0.06	0.11	0.34	1.01	-0.83	0.16	0.56	0.69	-0.41	-0.55	0.07
1959	-0.60	0.84	-0.66	-2.02	-0.61	-0.86	1.12	-0.16	-1.50	-0.35	0.26	1.56	0.25	-2.04	0.01
1960	-1.02	-0.38	-1.88	-0.12	-0.85	-0.09	-0.45	-0.35	-0.23	-0.28	-0.58	2.61	-0.83	-0.92	0.07
1961	-0.65	0.86	-0.61	1.36	0.24	0.10	0.13	0.06	1.10	0.35	0.50	0.96	0.40	-1.49	0.09
1962	-0.58	-0.91	-0.78	-0.37	-0.66	-0.99	-0.65	-0.40	0.06	-0.50	-1.72	-0.89	-0.62	1.93	-0.33
1963	-0.38	-1.36	0.28	0.53	-0.23	-0.23	-0.55	-0.33	-0.56	-0.42	1.06	0.78	0.68	-1.44	0.27
1964	0.10	-1.94	0.71	-0.93	-0.52	0.21	-1.40	0.83	-0.30	-0.17	-0.63	-1.45	-0.90	3.50	0.13
1965	-0.03	-0.37	-0.22	-1.10	-0.43	0.23	-0.34	-0.59	-0.31	-0.25	0.73	-0.46	0.57	-1.59	-0.19
1966	0.40	1.39	0.32	0.30	0.60	0.16	0.74	-0.48	-0.20	0.06	-0.48	0.33	0.64	-0.57	-0.02
1967	1.15	-0.51	1.51	-0.60	0.39	0.58	-0.12	0.26	0.12	0.21	0.27	-0.86	0.26	1.61	0.32
1968	-0.58	0.80	-0.37	-0.96	-0.28	0.00	0.62	-0.48	-0.42	-0.07	0.60	-0.89	-0.52	2.97	0.54
1969	0.35	0.68	-1.05	0.50	0.12	-0.45	-0.03	-0.38	0.12	-0.19	1.66	0.19	0.11	-2.27	-0.08
1970	-0.28	-0.27	-0.53	1.31	0.06	-0.59	0.63	-0.16	0.77	0.16	-1.77	0.09	0.96	0.12	-0.15
1971	0.66	0.00	0.18	-0.46	0.10	0.03	0.15	-0.19	0.16	0.04	-1.07	0.75	0.68	0.44	0.20
1972	0.10	-0.32	1.73	-0.71	0.20	0.41	-0.01	0.75	0.06	0.30	-0.43	-0.55	-0.88	0.65	-0.30
1973	-0.52	1.12	0.08	1.45	0.53	-0.26	0.55	0.29	1.01	0.40	-0.35	-0.60	0.26	-0.44	-0.28
1974	-0.15	1.10	1.20	1.87	1.01	0.09	-0.58	1.26	0.33	0.28	0.56	0.20	0.35	0.91	0.51
1975	1.85	1.80	0.75	-0.05	1.09	0.89	-0.28	-0.37	-0.12	0.03	0.58	-0.26	-0.28	-0.81	-0.19
1976	0.57	-1.59	0.00	-0.05	-0.27	0.54	-0.38	-0.34	-0.51	-0.17	-0.32	-1.20	-0.65	-0.17	-0.59
1977	1.03	1.13	1.93	-1.30	0.70	1.15	0.70	1.30	-0.24	0.73	-0.34	-1.05	-0.24	0.02	-0.40
1978	-1.00	0.50	0.04	-0.10	-0.14	-0.96	1.06	-0.44	0.34	0.00	1.50	1.07	-1.06	1.08	0.65
1979	0.31	0.73	-0.53	1.20	0.43	0.52	0.81	-1.17	0.20	0.09	0.87	-0.12	-1.85	0.95	-0.04
1980	0.70	1.36	1.75	0.06	0.97	0.79	0.54	0.86	0.67	0.72	1.76	0.84	1.54	-1.58	0.64
1981	0.25	0.82	2.88	-0.10	0.96	0.44	0.03	0.77	0.28	0.38	0.75	-0.18	0.98	-0.24	0.33
1982	0.33	-1.26	-0.06	0.71	-0.07	0.72	-0.79	-0.20	-0.17	-0.11	-0.11	-1.07	0.56	-1.07	-0.42
1983	0.77	2.57	0.54	0.00	0.97	0.60	1.18	0.90	0.21	0.72	-1.19	0.60	-0.62	0.22	-0.25
1984	0.18	2.66	-0.08	0.96	0.93	0.14	0.67	-0.23	0.29	0.22	-1.17	-1.72	-0.47	-1.03	-1.10
1985	0.77	0.30	1.59	-0.54	0.53	0.90	-0.21	0.67	-0.30	0.27	-1.25	-0.06	-0.04	-3.36	-1.18
1986	0.92	0.70	0.68	-0.50	0.45	1.06	0.43	0.52	-0.29	0.43	-2.50	-0.72	0.34	-1.72	-1.15
1987	0.21	0.10	1.19	0.19	0.42	0.52	0.39	0.54	0.05	0.38	-2.12	-1.47	-0.49	-4.97	-2.26
1988	0.75	1.98	1.56	1.20	1.37	0.49	0.60	1.04	1.46	0.90	-1.67	-1.32	-0.43	3.42	0.00
1989	-0.52	-0.40	0.00	-0.22	-0.29	0.84	-0.11	0.78	0.63	0.54	0.54	-0.11	-0.39	-3.39	-0.84
1990	0.16	0.46	0.22	1.44	0.57	0.72	0.25	1.52	2.09	1.15	-0.80	-0.88	-1.11	-2.84	-1.41
1991	1.26	-0.30	2.79	1.25	1.25	1.47	0.53	2.19	0.75	1.24	-2.85	0.00	-0.05	-0.81	-0.93
1992	1.43	0.76	0.08	0.76	0.76	1.20	1.06	0.32	0.09	0.67	-1.21	-0.83	0.26	-2.87	-1.16

Global, hemispheric, and zonal temperature anomalies
derived from radiosonde records

J.K. Angell (continued)

SOUTH POLAR (60° S–90° S)

Annual and Seasonal Temperature Anomalies^a

Year	Surface–100 mb					100–50 mb					100–30 mb				
	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann
1958	0.41	0.42	0.43	-0.67	0.15	-0.52	1.17	2.42	0.42	0.87	-0.41	-0.14	1.56	0.56	0.39
1959	-0.57	1.18	-0.14	-1.71	-0.31	1.38	1.61	-1.02	-6.63	-1.17	0.88	1.04	-0.75	-5.10	-0.98
1960	-0.35	0.26	-0.63	-0.36	-0.27	-0.29	0.39	1.04	2.06	0.80	0.47	1.18	2.29	1.84	1.45
1961	0.06	0.44	0.06	0.78	0.34	1.43	0.28	1.66	-6.10	-0.68	1.07	0.57	1.12	-3.09	-0.08
1962	-1.08	-0.75	-0.39	0.41	-0.45	2.11	-0.33	0.78	1.91	1.12	1.12	-0.62	2.95	1.20	1.16
1963	0.04	-0.39	0.00	-0.57	-0.23	1.79	1.39	-1.13	0.81	0.72	1.14	0.57	-1.31	0.47	0.22
1964	0.06	-1.51	0.43	0.44	-0.15	-0.85	-1.30	-0.90	4.73	0.42	-0.41	-1.04	-1.22	3.37	0.18
1965	0.30	-0.38	-0.27	-0.73	-0.27	-1.34	1.27	-1.42	3.99	0.63	-1.14	0.28	-1.22	2.79	0.18
1966	0.06	0.76	-0.02	-0.20	0.15	-1.19	-1.73	1.80	-1.28	-0.60	-0.59	-2.23	1.69	0.11	-0.26
1967	0.63	-0.35	0.47	0.26	0.25	-0.34	0.14	-1.61	1.03	-0.20	-0.17	-0.23	-0.81	1.50	0.07
1968	0.04	0.32	-0.45	0.26	0.04	0.14	0.38	-1.57	0.39	-0.17	-0.18	0.01	0.46	0.13	0.11
1969	0.15	0.18	-0.38	-0.35	-0.10	1.00	0.39	-2.00	-3.30	-0.98	0.44	0.59	0.04	-2.14	-0.27
1970	-0.80	0.36	0.10	0.74	0.10	-0.08	-0.27	0.53	-3.74	-0.89	0.85	-1.13	0.62	-1.22	-0.22
1971	-0.05	0.22	0.06	0.16	0.10	0.26	1.21	-1.44	0.34	0.09	0.07	0.23	-1.55	0.05	-0.30
1972	0.22	0.28	0.62	0.05	0.29	-0.60	-0.24	-0.04	-0.20	-0.27	-0.52	0.03	-0.35	-0.71	-0.39
1973	0.03	0.45	0.27	0.94	0.42	-0.51	0.47	0.07	-0.94	-0.23	-0.53	0.11	-0.96	-0.70	-0.52
1974	-0.09	0.14	1.02	0.76	0.46	-0.22	0.86	-1.55	0.13	-0.20	0.01	1.52	-1.28	0.55	0.20
1975	1.01	0.15	-0.09	-0.03	0.26	0.28	-0.78	-1.19	-2.63	-1.08	-0.15	-0.68	1.16	-0.96	-0.16
1976	0.40	-0.72	-0.32	-0.35	-0.25	-0.46	0.31	-0.04	0.98	0.20	-0.81	1.41	0.77	0.84	0.55
1977	0.80	0.38	1.06	-0.36	0.47	0.37	0.10	-1.63	4.22	0.77	0.19	-0.25	-1.54	0.65	-0.24
1978	-0.42	0.97	-0.50	0.44	0.12	0.28	3.27	-0.19	-3.94	-0.15	0.32	1.21	-0.13	-2.64	-0.31
1979	0.57	0.59	-1.21	0.54	0.12	-0.21	-0.15	-0.78	-2.35	-0.87	0.26	0.41	-3.61	-1.18	-1.03
1980	1.11	0.78	1.16	0.16	0.80	-0.34	2.29	1.59	-3.69	-0.04	-0.04	1.50	-0.75	-1.41	-0.18
1981	0.51	0.12	1.33	0.10	0.52	0.71	1.67	-2.82	-0.66	-0.28	0.52	1.15	-1.91	-0.45	-0.17
1982	0.38	-0.93	0.08	-0.23	-0.18	1.63	-0.53	-4.65	-3.49	-1.76	1.10	-0.32	-6.27	-2.35	-1.96
1983	0.21	1.34	0.49	0.22	0.57	0.35	0.52	-2.91	-2.53	-1.14	0.23	-0.20	-1.96	-1.71	-0.91
1984	-0.07	0.47	-0.28	0.11	0.06	0.26	0.45	0.45	-2.03	-0.22	0.21				
1985	0.40	-0.09	0.71	-1.02	0.00	-1.50	-0.68	-6.41	-6.16	-3.69					
1986	0.25	0.22	0.72	-0.64	0.14	-1.30	1.02	0.82	-1.95	-0.35					
1987	-0.12	-0.18	0.25	-1.04	-0.27	-1.45	-0.12	-3.87	-13.51	-4.74					
1988	0.01	0.40	0.80	1.85	0.77	-0.95	-0.07	-0.65	4.93	0.82					
1989	0.55	-0.16	0.39	-0.40	0.10	-0.92	0.56	-2.64	-7.17	-2.54					
1990	0.29	0.03	0.72	0.88	0.48	-0.63	-0.25	-3.03	-7.55	-2.87					
1991	0.47	0.27	1.56	0.12	0.61	-1.56	1.77	-1.94	-1.90	-0.91					
1992	0.70	0.59	0.31	-0.47	0.28	0.17	0.03	0.17	-4.66	-1.07					

^aTemperature anomalies (in relation to a 1958–77 average) expressed in degrees Celsius for Win (December–February), Spr (March–May), Sum (June–August), and Fall (September–November).

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Temperature

Global, hemispheric, and zonal temperature anomalies
derived from radiosonde records

J.K. Angell (continued)

TROPICAL (30° S–30° N)

Annual and Seasonal Temperature Anomalies^a

Year	Surface					850–300 mb					300–100 mb				
	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann
1958	0.59	0.37	-0.29	0.33	0.25	0.41	0.17	0.26	0.40	0.31	0.28	-0.48	0.17	-0.12	-0.04
1959	0.22	0.04	0.16	0.23	0.16	0.23	0.20	0.16	0.13	0.18	-0.03	-0.03	-0.07	-0.04	-0.04
1960	0.11	0.04	0.02	0.04	0.05	0.31	0.01	0.40	0.19	0.23	0.39	-0.09	0.26	0.07	0.16
1961	0.04	0.03	-0.04	-0.03	0.00	0.01	0.18	0.05	-0.07	0.04	-0.03	0.18	-0.03	-0.03	0.02
1962	-0.05	-0.09	-0.09	0.05	-0.05	0.11	-0.22	-0.12	0.11	-0.03	0.28	0.21	0.10	0.27	0.22
1963	0.02	-0.02	0.00	0.15	0.04	-0.16	-0.16	0.00	-0.05	-0.09	-0.26	0.15	0.03	0.15	0.02
1964	-0.34	-0.16	-0.16	-0.24	-0.23	0.19	0.14	-0.27	-0.50	-0.11	0.42	0.19	-0.17	-0.60	-0.04
1965	-0.29	-0.22	-0.19	-0.10	-0.20	-0.94	-0.44	-0.52	-0.16	-0.52	-0.98	-0.68	-0.39	0.09	-0.49
1966	-0.18	-0.01	0.03	-0.07	-0.06	0.16	0.12	0.16	-0.12	0.08	0.54	0.40	0.23	-0.01	0.29
1967	-0.10	-0.06	-0.10	-0.25	-0.13	-0.12	-0.26	-0.01	-0.15	-0.14	-0.21	-0.21	0.06	-0.06	-0.11
1968	-0.08	-0.43	-0.17	-0.04	-0.18	-0.29	-0.43	-0.21	-0.15	-0.27	-0.39	-0.88	-0.28	-0.34	-0.47
1969	0.23	0.35	0.15	0.18	0.23	0.11	0.46	0.35	0.20	0.28	-0.04	0.76	-0.07	0.11	0.19
1970	0.32	0.06	0.03	-0.20	0.05	0.34	0.44	0.37	0.26	0.35	0.23	0.73	0.57	0.54	0.52
1971	-0.14	-0.12	-0.26	-0.33	-0.21	-0.22	-0.63	-0.55	-0.61	-0.50	0.14	-0.66	-0.70	-0.77	-0.50
1972	-0.14	-0.26	0.22	0.16	-0.01	-0.54	-0.16	0.21	0.38	-0.03	-0.46	-0.56	0.07	0.28	-0.17
1973	0.51	0.53	0.32	0.24	0.40	0.88	0.66	0.27	0.25	0.52	1.03	0.61	0.45	0.21	0.58
1974	-0.09	-0.08	0.01	0.03	-0.03	-0.16	-0.18	-0.17	-0.03	-0.14	-0.33	-0.30	-0.13	-0.12	-0.22
1975	-0.05	0.14	-0.01	-0.09	0.00	0.06	0.01	-0.23	-0.10	-0.07	-0.20	0.05	-0.08	0.09	-0.04
1976	-0.27	-0.16	-0.13	0.12	-0.11	-0.33	-0.38	-0.37	-0.11	-0.30	-0.36	-0.37	-0.26	0.05	-0.24
1977	0.08	0.41	0.34	0.40	0.31	0.38	0.27	0.35	0.38	0.35	0.08	0.01	-0.09	-0.05	-0.01
1978	0.29	0.08	0.24	0.35	0.24	0.27	0.37	0.18	0.05	0.22	0.10	-0.11	-0.31	-0.33	-0.16
1979	0.16	0.37	0.27	0.36	0.29	0.06	0.24	0.31	0.26	0.22	-0.05	0.11	-0.31	-0.47	-0.18
1980	0.53	0.81	0.35	0.44	0.53	0.34	0.49	0.56	0.37	0.44	-0.48	-0.19	0.04	-0.12	-0.19
1981	0.23	0.47	0.17	0.32	0.30	0.30	0.19	0.14	0.25	0.22	-0.55	-0.64	-0.61	-0.54	-0.59
1982	0.40	0.40	0.51	0.39	0.43	0.33	-0.02	0.33	0.07	0.18	-0.39	-0.60	-0.27	-0.53	-0.45
1983	0.21	0.40	0.59	0.52	0.43	0.58	0.85	0.42	-0.01	0.46	0.27	0.37	0.15	-0.38	0.10
1984	0.28	0.39	0.20	0.44	0.33	0.14	0.35	-0.04	0.02	0.12	-1.04	-0.88	-0.87	-1.08	-0.97
1985	0.05	0.12	0.28	0.27	0.18	0.20	0.14	-0.12	0.02	0.06	-1.00	-0.82	-1.03	-0.97	-0.96
1986	-0.09	0.36	0.39	0.38	0.26	0.35	0.11	0.03	0.20	0.17	-0.84	-0.63	-0.55	-0.38	-0.60
1987	0.68	1.15	0.96	0.88	0.92	0.60	0.47	0.64	0.75	0.62	0.07	-0.23	0.30	0.52	0.17
1988	0.60	0.48	0.27	0.44	0.45	0.91	0.71	0.83	0.31	0.69	0.11	0.20	0.45	-0.22	0.14
1989	0.03	0.14	0.23	0.21	0.15	-0.04	-0.03	0.13	0.27	0.08	-0.82	-0.87	-0.37	-0.22	-0.57
1990	0.32	0.58	0.43	0.67	0.50	0.13	0.62	0.63	0.69	0.52	0.14	0.06	0.29	-0.10	0.10
1991	0.69	0.65	0.65	0.21	0.55	0.52	0.36	0.55	0.13	0.39	-0.20	-0.45	-0.08	-0.55	-0.32
1992	0.39	0.65	0.17	0.41	0.40	0.02	0.14	0.21	-0.24	0.03	-0.51	-0.08	-0.28	-0.52	-0.35

Global, hemispheric, and zonal temperature anomalies
derived from radiosonde records

J.K. Angell (continued)

TROPICAL (30° S–30° N)

Annual and Seasonal Temperature Anomalies^a

Year	Surface–100 mb					100–50 mb					100–30 mb				
	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann
1958	0.41	-0.22	0.13	0.20	0.13	0.60	0.60	-0.47	0.13	0.22	0.71	1.50	-0.19	0.33	0.59
1959	0.18	0.15	0.11	0.17	0.15	-0.93	-1.52	-1.34	0.43	-0.84	0.12	-0.73	-0.11	0.33	-0.10
1960	0.29	0.00	0.30	0.14	0.18	-0.10	-0.78	-0.93	-0.51	-0.58	-0.31	-0.72	-2.54	-2.01	-1.40
1961	0.00	0.20	-0.04	-0.05	0.03	-2.81	-1.47	1.11	2.31	-0.22	-2.99	-2.99	0.49	-0.05	-1.39
1962	0.12	-0.10	-0.09	0.10	0.01	0.61	-0.40	-0.85	-1.16	-0.45	0.23	-0.83	-2.02	-1.48	-1.03
1963	-0.15	-0.07	0.00	0.02	-0.05	-0.70	-0.61	0.76	0.94	0.10	-2.16	-1.31	1.27	2.51	0.08
1964	0.17	0.11	-0.23	-0.46	-0.10	1.24	1.67	1.49	0.81	1.30	0.72	1.27	1.54	0.44	0.99
1965	-0.84	-0.49	-0.43	-0.09	-0.46	1.24	0.46	0.57	0.73	0.75	0.80	0.33	0.14	0.67	0.49
1966	0.16	0.16	0.14	-0.09	0.09	-0.69	-0.67	-0.54	0.79	-0.28	-1.06	-0.54	0.22	1.03	-0.09
1967	-0.15	-0.21	-0.01	-0.14	-0.13	0.86	1.03	0.26	-0.43	0.43	0.96	1.14	0.22	-0.25	0.52
1968	-0.18	-0.53	-0.22	-0.17	-0.28	-0.48	0.93	-0.10	-0.18	0.04	-0.57	0.63	-0.10	-0.23	-0.07
1969	0.12	0.35	0.21	0.18	0.22	-0.51	-0.51	-0.32	0.48	-0.22	-0.94	-0.66	-0.35	0.82	-0.28
1970	0.31	0.44	0.36	0.27	0.35	-0.36	-0.22	0.60	0.27	0.07	-0.80	-0.17	0.67	0.74	0.11
1971	-0.14	-0.55	-0.54	-0.60	-0.46	0.41	-0.14	-0.08	0.31	0.13	0.89	0.34	0.02	-0.45	0.20
1972	-0.52	-0.27	0.18	0.32	-0.07	0.75	0.05	-0.67	-1.02	-0.22	0.68	0.06	-1.24	-0.96	-0.37
1973	0.81	0.63	0.32	0.24	0.50	-1.00	-0.52	0.04	-0.03	-0.38	-1.40	-0.72	-0.16	-0.22	-0.63
1974	-0.19	-0.23	-0.13	-0.04	-0.15	0.74	-0.14	-0.36	-0.72	-0.12	0.64	-0.49	-0.49	-1.31	-0.41
1975	-0.12	0.07	-0.16	-0.05	-0.07	-0.45	-0.02	0.06	0.39	-0.01	-0.44	0.09	-0.44	0.09	-0.18
1976	-0.32	-0.35	-0.30	-0.04	-0.25	1.73	0.62	0.50	0.30	0.79	1.36	0.07	0.52	-0.74	0.30
1977	0.26	0.23	0.24	0.29	0.26	-1.74	-0.12	-0.18	-0.48	-0.63	-2.66	-0.56	-0.88	-0.30	-1.10
1978	0.22	0.23	0.09	0.01	0.14	-0.58	-0.13	0.40	-0.20	-0.13	-1.20	-0.73	-0.19	-0.76	-0.72
1979	0.04	0.23	0.29	0.17	0.18	-0.11	0.07	-0.37	-0.93	-0.34	-0.72	-0.04	-0.23	-1.30	-0.57
1980	0.25	0.50	0.40	0.30	0.36	-0.29	-1.40	-0.47	0.45	-0.43	-0.36	-2.08	-0.32	0.19	-0.64
1981	0.05	0.04	0.02	0.10	0.05	0.23	-0.35	-0.33	0.03	-0.11	0.42	-0.56	-0.32	-0.40	-0.22
1982	0.15	-0.07	0.22	-0.01	0.07	-0.51	-0.04	0.52	1.33	0.33	-1.40	-0.57	0.67	1.16	-0.04
1983	0.47	0.69	0.40	0.06	0.41	1.23	0.02	0.07	0.75	0.52	0.58	-0.44	-0.36	0.34	0.03
1984	-0.11	0.08	-0.18	-0.13	-0.09	0.31	-1.13	-0.95	-0.96	-0.68	-0.49	-1.03	-0.81	-0.87	-0.80
1985	-0.08	-0.08	-0.28	-0.16	-0.15	-1.76	-1.28	-0.73	-0.18	-0.99	-1.25	-1.04	-0.58	-0.53	-0.85
1986	0.01	-0.03	-0.02	0.13	0.02	-1.46	-1.41	-2.01	-2.17	-1.76	-1.23	-1.30	-1.51	-1.66	-1.43
1987	0.53	0.44	0.56	0.74	0.57	-1.85	-1.72	-1.54	-0.80	-1.48	-1.53	-1.43	-1.21	-0.81	-1.25
1988	0.69	0.58	0.64	0.21	0.53	-1.39	-2.39	-1.52	-2.46	-1.94	-1.31	-1.72	-1.20	-1.82	-1.51
1989	-0.13	-0.20	0.03	0.18	-0.03	-1.07	-1.48	-1.00	-1.13	-1.17	-0.94	-1.19	-0.84	-1.05	-1.01
1990	0.15	0.49	0.50	0.49	0.41	-1.56	-0.96	-1.30	-0.98	-1.20	-1.26	-1.03	-1.13	-0.99	-1.10
1991	0.39	0.23	0.45	-0.01	0.27	-1.88	-1.80	-1.26	0.01	-1.23	-1.68	-1.58	-0.87	-0.16	-1.07
1992	-0.04	0.12	0.04	-0.08	0.01	0.12	-0.68	-0.63	-0.18	-0.34	-0.37	-0.62	-0.58	-0.45	-0.50

^aTemperature anomalies (in relation to a 1958–77 average) expressed in degrees Celsius for Win (December–February), Spr (March–May), Sum (June–August), and Fall (September–November).

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Temperature

Global, hemispheric, and zonal temperature anomalies
derived from radiosonde records

J.K. Angell (continued)

NORTHERN HEMISPHERE (0–90° N)

Annual and Seasonal Temperature Anomalies^a

Year	Surface					850–300 mb					300–100 mb				
	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann
1958	0.63	-0.06	-0.04	0.29	0.21	0.53	0.42	0.18	0.34	0.37	0.16	-0.15	0.27	0.74	0.26
1959	0.36	0.12	0.18	0.00	0.16	0.42	0.67	0.31	0.38	0.45	0.25	0.61	0.33	0.24	0.36
1960	0.05	-0.30	0.14	-0.32	-0.11	0.13	-0.08	0.38	0.05	0.12	1.05	0.09	0.22	0.27	0.41
1961	0.61	0.13	0.07	0.16	0.24	0.50	0.15	-0.04	0.26	0.22	0.31	0.72	0.52	0.06	0.40
1962	0.42	0.18	-0.05	-0.04	0.12	0.20	0.09	-0.03	0.05	0.08	-0.42	-0.20	-0.16	0.20	-0.15
1963	0.18	-0.03	-0.01	0.50	0.16	0.11	-0.12	-0.02	0.20	0.04	-0.25	0.09	0.27	0.28	0.09
1964	-0.20	-0.51	-0.16	-0.35	-0.31	0.10	0.08	-0.12	-0.37	-0.08	-0.19	0.47	-0.03	-0.06	0.05
1965	-0.41	-0.21	-0.20	-0.13	-0.24	-0.41	-0.39	-0.53	-0.10	-0.36	-0.40	-0.54	-0.28	0.07	-0.29
1966	-0.57	-0.07	-0.07	-0.16	-0.22	-0.15	0.09	0.20	0.21	0.09	0.73	0.14	0.62	0.10	0.40
1967	-0.32	0.31	0.07	0.19	0.06	-0.17	-0.02	0.12	0.21	0.04	-0.29	-0.53	-0.22	-0.42	-0.37
1968	-0.26	0.30	-0.13	-0.19	-0.07	0.04	-0.17	-0.37	-0.30	-0.20	-0.03	-1.49	-0.50	-0.43	-0.61
1969	-0.71	-0.19	0.11	0.22	-0.14	-0.33	0.01	0.24	0.15	0.02	0.21	0.40	-0.06	-0.21	0.09
1970	0.47	0.06	-0.06	-0.11	0.09	0.16	0.01	0.19	0.13	0.12	0.35	0.24	0.33	0.15	0.27
1971	-0.42	-0.12	-0.12	0.04	-0.16	-0.38	-0.56	-0.38	-0.47	-0.45	-0.09	-0.28	-0.46	-0.60	-0.36
1972	-0.40	-0.28	0.07	-0.19	-0.20	-0.67	-0.24	0.00	-0.15	-0.27	-0.85	-0.56	-0.23	0.08	-0.39
1973	0.45	0.22	0.30	0.01	0.25	0.47	0.11	0.15	-0.11	0.16	0.67	0.67	0.15	-0.10	0.35
1974	0.13	-0.07	-0.26	-0.03	-0.06	-0.22	-0.22	-0.29	-0.43	-0.29	-0.75	-0.09	-0.34	-0.04	-0.31
1975	0.23	0.42	0.07	-0.08	0.16	-0.31	0.10	-0.03	-0.12	-0.09	-0.28	0.15	-0.30	-0.07	-0.13
1976	0.03	-0.28	-0.10	-0.26	-0.15	-0.37	-0.62	-0.39	-0.32	-0.43	-0.84	-0.71	-0.64	-0.40	-0.65
1977	-0.26	0.27	0.20	0.26	0.12	-0.01	0.17	0.11	0.16	0.11	0.55	0.38	-0.14	-0.26	0.13
1978	0.27	-0.09	0.16	0.28	0.16	-0.14	0.17	0.06	-0.15	-0.02	0.05	-0.17	-0.25	-0.58	-0.24
1979	-0.10	0.30	0.05	0.22	0.12	-0.29	0.30	0.19	0.24	0.11	-0.29	0.04	-0.38	-0.33	-0.24
1980	0.71	0.41	0.00	0.11	0.31	0.21	0.08	0.34	0.01	0.16	-0.82	0.44	0.28	-0.04	-0.04
1981	0.86	0.74	0.28	0.44	0.58	0.27	0.40	0.12	0.21	0.25	-0.88	-0.83	-0.33	-0.37	-0.60
1982	0.44	-0.02	0.19	0.01	0.16	-0.03	-0.21	0.16	-0.13	-0.05	-0.12	-0.33	-0.13	-0.66	-0.31
1983	1.00	0.34	0.40	0.37	0.53	0.35	0.65	0.41	0.13	0.39	-0.69	-0.14	-0.04	-0.47	-0.34
1984	0.58	0.25	0.05	0.11	0.25	0.04	0.02	-0.02	-0.18	-0.04	-1.16	-0.28	-0.43	-0.62	-0.62
1985	-0.37	-0.13	-0.08	-0.26	-0.21	-0.07	-0.27	-0.35	-0.31	-0.25	0.28	0.19	-0.55	-0.44	-0.13
1986	0.11	0.27	0.01	0.11	0.13	0.16	0.10	0.01	0.10	0.09	-0.54	-0.54	-0.55	-0.47	-0.53
1987	0.35	0.20	0.52	0.14	0.30	0.20	0.21	0.44	0.18	0.26	0.38	-0.38	0.04	0.53	0.14
1988	0.57	0.66	0.30	0.11	0.41	0.39	0.34	0.88	0.32	0.48	-0.36	-0.17	0.03	-0.39	-0.22
1989	0.91	0.53	0.38	0.10	0.48	0.02	0.23	0.28	0.25	0.20	-0.82	-0.32	-0.61	-0.41	-0.54
1990	0.80	1.44	0.50	0.29	0.76	0.22	0.73	0.68	0.28	0.48	-0.35	-0.86	-0.01	-0.34	-0.39
1991	0.62	0.57	0.41	0.24	0.46	0.29	0.31	0.60	0.34	0.39	-0.44	-0.53	-0.09	-0.48	-0.39
1992	0.70	0.17	-0.41	-0.16	0.08	0.15	-0.13	-0.15	-0.45	-0.14	-0.33	-0.75	-0.84	-0.37	-0.57

Global, hemispheric, and zonal temperature anomalies
derived from radiosonde records

J.K. Angell (continued)

NORTHERN HEMISPHERE (0–90° N)

Annual and Seasonal Temperature Anomalies^a

Year	Surface–100 mb					100–50 mb					100–30 mb				
	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann
1958	0.46	0.08	0.15	0.39	0.27	1.32	0.41	0.21	1.38	0.83	0.90	0.44	0.53	1.69	0.89
1959	0.38	0.58	0.29	0.32	0.39	-0.32	1.25	0.20	0.07	0.30	-0.15	1.49	0.61	0.36	0.58
1960	0.33	-0.08	0.30	0.04	0.15	1.30	0.80	0.09	0.43	0.66	1.59	0.00	-0.57	0.04	0.27
1961	0.47	0.30	0.08	0.20	0.26	-1.22	-0.16	0.82	0.92	0.09	-1.02	-0.73	0.69	0.30	-0.19
1962	0.10	0.04	-0.07	0.06	0.03	-0.36	-0.90	-0.85	-0.35	-0.62	-0.41	-1.20	-1.36	-0.46	-0.86
1963	0.04	-0.06	0.04	0.27	0.07	-0.63	-0.59	0.98	0.62	0.10	-0.37	-1.39	1.02	1.13	0.10
1964	0.00	0.08	-0.11	-0.29	-0.08	-0.12	1.20	0.74	0.06	0.47	0.01	1.60	0.61	0.13	0.59
1965	-0.40	-0.41	-0.42	-0.06	-0.32	-0.05	-0.16	0.19	0.22	0.05	-0.44	0.60	0.04	-0.07	0.03
1966	-0.04	0.08	0.24	0.13	0.10	0.38	-0.76	-0.03	0.63	0.06	-0.43	-0.59	0.27	0.87	0.03
1967	-0.21	-0.38	0.04	0.07	-0.12	0.01	-0.31	-0.46	-0.69	-0.36	-0.18	0.40	-0.11	-0.70	-0.15
1968	-0.03	-0.39	-0.36	-0.31	-0.27	-0.45	-0.44	-0.07	-0.25	-0.30	-1.37	-0.31	-0.08	-0.31	-0.52
1969	-0.25	-0.12	0.17	0.10	-0.03	-0.50	-0.35	-0.28	0.64	-0.12	-1.37	-0.54	-0.10	0.03	-0.50
1970	0.30	0.08	0.22	0.13	0.18	0.24	-0.07	0.27	0.31	0.19	-0.02	-0.07	0.38	0.23	0.13
1971	-0.40	-0.51	-0.43	-0.49	-0.46	0.39	-0.52	0.14	0.12	0.03	0.02	-0.35	0.19	-0.41	-0.14
1972	-0.80	-0.39	-0.04	-0.13	-0.34	0.04	0.19	-0.57	-0.54	-0.22	0.47	0.36	-0.93	-0.45	-0.14
1973	0.60	0.31	0.21	-0.10	0.26	0.05	-0.73	-0.22	-0.15	-0.26	-0.03	-1.23	-0.35	-0.48	-0.52
1974	-0.34	-0.22	-0.25	-0.33	-0.29	-0.10	0.45	-0.38	-0.34	-0.09	0.55	0.34	-0.55	-0.28	0.02
1975	-0.25	0.19	-0.08	-0.16	-0.08	-0.16	0.28	-0.06	-0.25	-0.05	-0.23	-0.19	0.04	0.14	-0.06
1976	-0.49	-0.70	-0.57	-0.32	-0.52	0.22	0.76	0.19	0.14	0.33	0.82	0.45	0.02	-0.37	0.23
1977	0.07	0.23	0.07	0.09	0.12	-0.31	0.35	0.35	0.03	0.11	-1.34	-0.07	-0.48	-0.20	-0.52
1978	-0.05	0.11	0.01	-0.17	-0.03	-0.49	-0.53	-0.31	-0.52	-0.46	-1.05	-0.90	-0.52	-0.52	-0.75
1979	-0.24	0.22	0.17	0.16	0.08	0.48	0.31	-0.34	-0.33	0.03	0.15	0.03	-0.29	-0.77	-0.22
1980	0.08	0.24	0.25	0.04	0.15	-0.12	-0.01	-0.06	0.63	0.11	-0.37	-0.63	0.28	0.42	-0.08
1981	0.10	0.17	0.08	0.12	0.12	0.30	-0.41	-0.37	0.03	-0.11	0.48	-0.64	-0.51	-0.14	-0.20
1982	-0.01	-0.17	0.10	-0.22	-0.08	0.35	0.31	0.57	0.52	0.44	0.06	0.16	0.72	0.59	0.38
1983	0.28	0.43	0.29	0.09	0.27	0.00	0.21	-0.29	0.16	0.02	-0.45	-0.18	-0.72	-0.12	-0.37
1984	-0.14	-0.01	-0.09	-0.20	-0.11	-0.12	-0.15	-1.00	-0.49	-0.44	-0.19	-0.25	-0.70	-0.37	-0.38
1985	-0.04	-0.14	-0.34	-0.33	-0.21	-0.42	-0.83	-0.47	0.05	-0.42	-0.33	-0.69	-0.37	-0.19	-0.40
1986	-0.01	-0.02	-0.11	0.00	-0.04	-0.47	-0.28	-1.09	-1.08	-0.73	-0.33	-0.37	-0.85	-0.78	-0.58
1987	0.29	0.08	0.35	0.25	0.24	-0.40	-1.30	-0.77	-0.14	-0.65	-0.32	-0.98	-0.75	-0.10	-0.54
1988	0.26	0.30	0.58	0.12	0.32	-1.48	-0.65	-0.86	-1.20	-1.05	-0.94	-0.45	-0.69	-0.88	-0.74
1989	0.01	0.15	0.10	0.12	0.10	-0.30	-0.60	-0.91	-0.79	-0.65	-0.07	-0.52	-0.72	-0.58	-0.47
1990	0.19	0.50	0.48	0.13	0.33	-1.29	-1.23	-0.72	-0.82	-1.02	-0.89	-1.04	-0.57	-0.62	-0.78
1991	0.18	0.17	0.43	0.14	0.23	-0.60	-0.99	-0.41	0.20	-0.45	-0.33	-0.82	-0.42	0.12	-0.36
1992	0.14	-0.23	-0.31	-0.38	-0.20	0.25	-0.55	-0.46	-0.40	-0.29	-0.10	-0.51	-0.49	-0.39	-0.37

^aTemperature anomalies (in relation to a 1958–77 average) expressed in degrees Celsius for Win (December–February), Spr (March–May), Sum (June–August), and Fall (September–November).

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Temperature

Global, hemispheric, and zonal temperature anomalies
derived from radiosonde records

J.K. Angell (continued)

SOUTHERN HEMISPHERE (0–90° S)

Annual and Seasonal Temperature Anomalies^a

Year	Surface					850–300 mb					300–100 mb				
	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann
1958	0.76	0.58	−0.04	0.38	0.42	0.25	0.00	0.37	0.30	0.23	0.05	−0.37	−0.05	−0.68	−0.26
1959	0.45	0.44	0.34	0.11	0.34	0.08	0.20	0.41	0.20	0.22	−0.35	0.33	0.04	−0.69	−0.17
1960	0.16	0.20	−0.09	0.18	0.11	0.43	0.00	0.16	0.22	0.20	−0.14	0.21	0.49	0.03	0.15
1961	0.13	0.36	0.13	0.50	0.28	0.08	0.20	0.07	0.29	0.16	0.00	0.46	−0.13	−0.70	−0.09
1962	0.24	0.05	0.02	0.19	0.13	0.08	−0.10	0.01	0.09	0.02	−0.44	−0.66	−0.06	0.60	−0.14
1963	0.04	−0.17	0.05	0.13	0.01	0.02	−0.15	−0.20	−0.26	−0.15	−0.16	0.33	0.49	0.51	0.29
1964	−0.21	−0.42	0.03	−0.11	−0.18	−0.24	−0.28	−0.37	−0.53	−0.36	0.38	0.15	0.09	0.44	0.27
1965	−0.01	−0.21	−0.15	−0.04	−0.10	−0.76	−0.54	−0.26	0.01	−0.39	−0.30	−0.37	−0.42	−0.38	−0.37
1966	0.24	0.20	−0.02	0.02	0.11	0.08	0.05	−0.10	−0.22	−0.05	0.11	0.26	0.17	−0.03	0.13
1967	0.16	−0.14	0.03	0.00	0.01	−0.09	−0.05	0.01	0.03	−0.03	0.03	−0.14	−0.06	0.14	−0.01
1968	0.05	0.02	−0.31	−0.28	−0.13	−0.07	0.03	−0.28	−0.31	−0.16	0.04	−0.67	−0.22	0.75	−0.02
1969	−0.18	−0.04	−0.34	0.01	−0.14	0.02	0.28	0.41	0.20	0.23	0.63	0.77	0.07	−0.43	0.26
1970	−0.07	−0.25	−0.23	−0.19	−0.19	0.06	0.26	0.16	0.14	0.16	−0.25	0.33	0.38	0.25	0.17
1971	−0.15	−0.29	−0.23	−0.46	−0.29	0.04	−0.31	−0.39	−0.41	−0.27	0.05	−0.01	−0.24	−0.46	−0.17
1972	−0.37	−0.32	0.22	−0.28	−0.19	−0.31	−0.01	0.36	0.48	0.13	−0.10	−0.51	−0.23	0.12	−0.19
1973	−0.04	0.34	0.05	0.15	0.13	0.66	0.71	0.34	0.19	0.48	0.24	0.12	0.08	0.07	0.13
1974	−0.40	0.15	0.22	0.06	0.01	0.24	−0.01	0.07	−0.03	0.07	−0.14	−0.45	−0.25	−0.12	−0.24
1975	−0.07	0.20	0.05	−0.25	−0.02	0.24	−0.09	−0.29	−0.09	−0.06	0.04	0.04	−0.10	−0.26	−0.07
1976	−0.47	−0.56	−0.15	−0.15	−0.33	0.08	−0.11	−0.15	−0.44	−0.16	−0.25	−0.60	−0.43	−0.10	−0.35
1977	0.04	0.40	0.42	−0.08	0.20	0.27	0.67	0.45	0.20	0.40	−0.11	−0.15	0.09	0.05	−0.03
1978	−0.06	0.21	0.06	0.01	0.06	0.08	0.42	0.36	0.21	0.27	0.27	0.12	−0.29	0.10	0.05
1979	0.06	0.31	0.20	0.33	0.23	0.39	0.75	0.41	0.32	0.47	0.31	0.04	−0.28	0.21	0.07
1980	0.36	0.71	0.58	0.19	0.46	0.54	0.70	0.69	0.42	0.59	−0.01	0.12	0.16	−0.22	0.01
1981	0.02	0.39	0.51	0.11	0.26	0.61	0.40	0.47	0.32	0.45	−0.35	−0.53	−0.41	−0.24	−0.38
1982	0.22	0.22	0.26	0.31	0.25	0.69	0.11	0.43	0.23	0.37	−0.23	−0.37	−0.04	−0.07	−0.18
1983	0.15	0.67	0.25	0.28	0.34	0.47	1.10	0.63	0.31	0.63	−0.09	0.52	−0.06	−0.20	0.04
1984	0.13	0.73	0.05	0.43	0.34	0.23	0.50	0.05	0.22	0.25	−0.99	−0.92	−0.28	−0.60	−0.70
1985	0.16	0.30	0.66	−0.12	0.25	0.37	0.44	0.39	0.16	0.34	−1.02	−0.59	−0.81	−1.41	−0.96
1986	−0.16	0.45	0.27	0.07	0.16	0.51	0.18	0.24	0.15	0.27	−1.41	−0.52	−0.23	−0.40	−0.64
1987	0.25	0.95	0.85	0.37	0.61	0.72	0.67	0.77	0.52	0.67	−0.57	−0.35	0.16	−0.30	−0.27
1988	0.18	0.37	0.23	0.54	0.33	0.64	0.69	0.58	0.40	0.58	−0.26	−0.12	0.35	0.66	0.16
1989	−0.18	0.00	0.02	0.12	−0.01	0.28	0.12	0.31	0.36	0.27	−0.75	−0.66	−0.48	−0.90	−0.70
1990	0.15	0.41	0.25	0.61	0.36	0.40	0.44	0.74	0.86	0.61	−0.40	0.07	−0.15	−0.73	−0.30
1991	0.38	0.44	0.86	0.34	0.51	0.69	0.57	0.79	0.33	0.60	−0.74	−0.47	0.10	−0.33	−0.36
1992	0.07	0.44	−0.03	0.33	0.20	0.05	0.21	0.00	−0.05	0.05	−0.68	−0.12	0.35	−1.02	−0.37

Temperature

Global, hemispheric, and zonal temperature anomalies
derived from radiosonde records

J.K. Angell (continued)

SOUTHERN HEMISPHERE (0–90° S)

Annual and Seasonal Temperature Anomalies^a

Year	Surface–100 mb					100–50 mb					100–30 mb				
	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann	Win	Spr	Sum	Fall	Ann
1958	0.31	–0.11	0.20	0.06	0.12										
1959	0.07	0.28	0.32	0.01	0.17										
1960	0.24	0.09	0.18	0.17	0.17										
1961	0.07	0.29	0.01	0.11	0.12										
1962	–0.01	–0.19	0.01	0.20	0.00										
	–0.15	–0.15	–0.01	–0.03	–0.09										
1963															
1964	0.00	–0.21	–0.20	–0.24	–0.16	1.11	1.00	0.47	1.36	0.99	0.50	0.68	0.99	0.80	0.74
1965	0.54	–0.46	–0.27	–0.12	–0.35	0.77	0.71	0.42	1.36	0.82	0.42	0.14	0.34	1.38	0.57
1966	0.10	0.12	–0.02	–0.14	0.02	–0.64	–0.57	–0.45	–0.06	–0.43	–0.84	–0.24	–0.16	1.15	–0.02
1967	–0.04	–0.09	0.00	0.04	–0.02	0.56	0.48	0.42	0.27	0.43	0.54	0.57	0.04	0.36	0.38
1968	0.07	–0.14	–0.26	–0.07	–0.10	–0.50	0.19	–0.14	0.00	–0.11	–0.24	0.38	0.08	–0.07	0.04
1969	0.19	0.33	0.21	0.03	0.19	0.26	–0.05	–0.44	–0.27	–0.13	–0.07	0.09	0.25	0.34	0.15
1970	–0.09	0.19	0.17	0.12	0.10	–0.13	–0.02	0.72	–0.50	0.02	–0.14	0.25	0.75	0.71	0.39
1971	0.01	–0.26	–0.33	–0.42	–0.25	0.47	0.05	–0.58	–0.14	–0.05	0.71	–0.30	–0.82	–0.58	–0.25
1972	–0.33	–0.28	0.19	0.19	–0.06	0.04	–0.23	0.14	–0.32	–0.09	0.36	0.21	–0.13	–0.19	0.06
1973	0.49	0.53	0.30	0.18	0.38	–0.33	0.14	–0.50	–0.41	–0.28	–0.20	–0.23	–0.79	–0.39	–0.40
1974	0.00	–0.06	0.01	–0.02	–0.02	–0.22	–0.34	–0.36	–0.44	–0.34	–0.36	–0.41	–0.32	–0.86	–0.49
1975	0.05	0.02	–0.17	–0.11	–0.05	–0.15	–0.19	0.36	–0.81	–0.20	–0.35	–0.25	–0.43	–0.90	–0.48
1976	–0.10	–0.29	–0.39	–0.32	–0.28	0.14	–0.02	–0.30	0.61	0.11	–0.31	–0.05	0.39	0.03	0.02
1977	0.14	0.43	0.37	0.12	0.27	–1.21	–0.37	–0.41	0.49	–0.38	–1.52	–0.59	–0.62	0.19	–0.64
1978	0.10	0.31	0.14	0.15	0.18	–0.12	0.65	0.34	–1.01	–0.04	–0.53	–0.02	0.04	–0.69	–0.30
1979	0.29	0.52	0.22	0.31	0.34	–0.04	0.18	–0.15	–0.73	–0.19	–0.51	0.36	–0.29	–0.84	–0.32
1980	0.47	0.67	0.57	0.27	0.50	–0.06	–0.56	–0.43	–0.65	–0.43	0.12	–1.03	–1.00	–0.32	–0.56
1981	0.29	0.17	0.31	0.16	0.23	–0.01	0.12	–0.84	0.09	–0.16	0.09	–0.06	–0.46	–0.09	–0.13
1982	0.39	0.02	0.32	0.17	0.23	–0.16	0.02	–0.40	0.48	–0.02	–0.71	–0.28	–0.77	0.11	–0.41
1983	0.30	0.93	0.43	0.22	0.47	1.22	0.03	–0.29	0.18	0.29	0.82	–0.08	–0.11	0.14	0.19
1984	–0.06	0.22	–0.03	0.07	0.05	0.33	–0.76	–0.17	–0.91	–0.38	–0.42	–0.62	–0.29	–0.98	–0.58
1985	0.07	0.19	0.14	–0.24	0.04	–1.54	–1.24	–2.23	–1.97	–1.75	–1.23	–0.92	–1.85	–1.71	–1.43
1986	–0.03	0.07	0.17	0.02	0.06	–1.59	–1.20	–0.94	–1.92	–1.41	–1.27	–0.86	–0.71	–1.37	–1.05
1987	0.36	0.48	0.59	0.34	0.44	–1.40	–1.28	–1.58	–2.92	–1.80	–1.15	–0.85	–1.77	–2.97	–1.69
1988	0.36	0.46	0.46	0.48	0.44	–1.42	–2.18	–1.48	–1.43	–1.63	–1.36	–1.53	–1.24	–0.84	–1.24
1989	–0.03	–0.07	0.09	0.04	0.01	–1.44	–1.56	–1.24	–2.08	–1.58	–1.22	–1.12	–1.11	–1.99	–1.36
1990	0.18	0.35	0.46	0.46	0.36	–1.63	–1.06	–1.99	–2.54	–1.81	–1.15	–0.84	–1.67	–2.20	–1.47
1991	0.32	0.32	0.61	0.12	0.34	–2.04	–1.32	–1.24	–0.25	–1.21	–1.78	–0.89	–0.91	–0.43	–1.00
1992	–0.12	0.12	–0.02	–0.08	–0.02	0.11	–0.47	–0.18	–1.66	–0.55	–0.13	–0.31	–0.24	–1.43	–0.53

^aTemperature anomalies (in relation to a 1958–77 average) expressed in degrees Celsius for Win (December–February), Spr (March–May), Sum (June–August), and Fall (September–November).

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Global, hemispheric, and zonal temperature anomalies
derived from radiosonde records

J.K. Angell (continued)

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Global and hemispheric temperature anomalies
derived from rawinsonde records

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1958–89

Methods

Surface temperatures and temperatures at various standard pressure levels (950, 900, 850, 700, 500, 300, 200, 100, and 50 mb) from a globally distributed rawinsonde network of approximately 700–800 stations have been used to estimate annual and seasonal global and hemispheric temperature anomalies. The data presented here are the culmination of three separate projects in which the data processing schemes were very similar. The data types and sources for these projects were upper-air data from the Massachusetts Institute of Technology General Circulation Library, daily soundings from the National Meteorological Center (NMC) and the National Center for Atmospheric Research, and more recently the twice-daily soundings from NMC from the Global Telecommunication System Network. Only regularly reporting stations were used in deriving the monthly statistics, which were used to compile the seasonal and annual temperature anomalies presented here. A Conditional Relaxation Analysis Method (Harris et al. 1966) was used to obtain point values at a regular global grid (2.5° latitude, 5° longitude) from the basic station data of the irregular rawinsonde network. The zonal average of the station values in the different latitudinal belts was used as a first guess for the monthly mean temperature fields (Oort and Liu 1993). For detailed information on the data sources, processing, and analysis, see Oort and Liu (1993), Oort (1977, 1983), Oort and Rasmusson (1971), and Rosen et al. (1979).

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Global and hemispheric temperature anomalies
derived from rawinsonde records

A.H. Oort, H. Liu, and M. Rosenstein (continued)

GLOBAL AND HEMISPHERIC ANOMALIES

Trends

Oort and Liu (1993) compared this time series of global and hemispheric mean temperature anomalies for the troposphere and lower stratosphere to those of Angell (1986, 1988, 1990), Angell and Korshover (1983), and Spencer et al. (1990) and found excellent agreement supporting their conclusion that the rawinsonde network can provide reliable estimates of the actual interseasonal hemispheric-scale temperature changes that have occurred between the earth's surface and about 20 km (50 mb) height since the 1950s. Oort and Liu (1993) reported an increase of 0.1 to 0.3°C/10 yr for the surface; a significant rising trend over the last 25 years of 0.1 to 0.3°C/10 yr for the troposphere, especially in the Southern Hemisphere; a cooling on the order of -0.1 to -0.2°C/10 yr in the upper troposphere; and strong downward trends ranging from -0.2 to -0.4°C/10 yr in the Northern Hemisphere to -0.4 to -0.6°C/10 yr for the Southern Hemisphere in the low stratosphere.

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Temperature

Global and hemispheric temperature anomalies derived from rawinsonde records

A.H. Oort, H. Liu, and M. Rosenstein (continued)

GLOBAL AND HEMISPHERIC ANOMALIES

Global annual temperature anomalies, 1964-89.

CITE AS: Oort, A.H., H. Liu, and M. Rosenstein. 1994. Global and hemispheric temperature anomalies derived from rawinsonde records. pp. 673-684. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Temperature

Global and hemispheric temperature anomalies derived from rawinsonde records

A.H. Oort, H. Liu, and M. Rosenstein (continued)

GLOBAL AND HEMISPHERIC ANOMALIES

Northern Hemisphere annual temperature anomalies, 1959-89.

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Global and hemispheric temperature anomalies
derived from rawinsonde records

A.H. Oort, H. Liu, and M. Rosenstein (continued)

GLOBAL AND HEMISPHERIC ANOMALIES

Southern Hemisphere annual temperature anomalies, 1964-89.

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Temperature

Global and hemispheric temperature anomalies
derived from rawinsonde records

A.H. Oort, H. Liu, and M. Rosenstein (continued)

GLOBAL

Annual and Seasonal Temperature Anomalies^a

Year	Surface (950 mb)					850–300 mb				
	Dec–Feb	Mar–May	Jun–Aug	Sept–Nov	Ann	Dec–Feb	Mar–May	Jun–Aug	Sept–Nov	Ann
1958										
1959										
1960										
1961										
1962										
1963			–0.054	–0.722				0.032	–0.116	
1964	–0.363	–0.160	–0.218	–0.445	–0.318	–0.169	–0.060	–0.171	–0.262	–0.204
1965	–0.448	–0.530	0.070	–0.722	–0.423	–0.577	–0.475	–0.346	–0.103	–0.336
1966	–0.821	–0.312	0.055	–0.253	–0.268	–0.047	0.030	0.092	–0.118	–0.004
1967	–0.151	0.052	–0.040	–0.014	–0.016	–0.143	–0.023	0.073	0.011	–0.022
1968	–0.022	–0.129	–0.084	–0.221	–0.152	–0.284	–0.253	–0.154	–0.166	–0.227
1969	–0.121	–0.035	–0.111	0.019	–0.018	–0.135	0.166	0.184	0.088	0.111
1970	0.119	–0.005	0.062	0.161	0.050	0.182	0.127	0.276	0.235	0.181
1971	–0.117	–0.118	–0.011	–0.126	–0.104	–0.013	–0.241	–0.261	–0.280	–0.219
1972	–0.280	–0.095	0.100	–0.157	–0.083	–0.467	–0.176	–0.008	0.081	–0.111
1973	0.043	0.201	0.010	0.252	0.123	0.304	0.370	0.136	0.094	0.206
1974	–0.076	–0.020	0.195	0.037	0.041	–0.197	–0.303	–0.202	–0.142	–0.207
1975	0.070	–0.061	–0.040	–0.165	–0.065	–0.184	–0.046	–0.208	–0.237	–0.185
1976	–0.246	–0.338	–0.164	–0.103	–0.199	–0.341	–0.475	–0.431	–0.281	–0.364
1977	0.086	0.064	0.159	0.000	0.087	0.036	0.138	0.119	0.085	0.110
1978	0.211	0.129	0.210	0.042	0.141	0.097	0.270	0.073	0.080	0.124
1979	–0.071	0.084	0.189	0.391	0.182	0.022	0.243	0.175	0.281	0.208
1980	0.456	0.283	0.422	0.230	0.323	0.351	0.377	0.416	0.290	0.358
1981	0.222	0.230	0.468	0.375	0.339	0.373	0.335	0.310	0.203	0.318
1982	0.203	–0.031	0.001	0.092	0.053	0.258	0.090	0.099	0.085	0.116
1983	0.271	0.287	0.255	0.342	0.293	0.342	0.616	0.360	0.290	0.388
1984	0.234	0.177	0.269	0.273	0.243	0.035	0.201	0.069	0.065	0.093
1985	0.275	0.041	0.299	0.221	0.200	0.088	–0.003	0.073	0.040	0.053
1986	0.225	0.127	0.046	0.284	0.172	0.126	0.085	0.066	0.137	0.130
1987	0.243	0.262	0.291	0.469	0.333	0.522	0.394	0.492	0.457	0.485
1988	0.397	0.217	0.181	0.118	0.215	0.522	0.492	0.529	0.413	0.447
1989	0.061	0.197	0.256	0.169	0.167	0.075	0.155	0.245	0.370	0.224

Temperature

Global and hemispheric temperature anomalies
derived from rawinsonde records

A.H. Oort, H. Liu, and M. Rosenstein (continued)

GLOBAL

Annual and Seasonal Temperature Anomalies^a

Year	300–100 mb					100–50 mb				
	Dec–Feb	Mar–May	Jun–Aug	Sept–Nov	Ann	Dec–Feb	Mar–May	Jun–Aug	Sept–Nov	Ann
1958										
1959										
1960										
1961										
1962										
1963			0.316	0.219				0.769	0.938	
1964	0.275	0.353	0.044	0.230	0.165	0.972	0.929	0.420	0.465	0.633
1965	–0.416	–0.339	–0.264	–0.096	–0.222	0.156	0.126	0.210	0.226	0.190
1966	0.055	0.032	0.272	–0.191	0.026	–0.160	–0.098	–0.056	–0.006	–0.066
1967	–0.072	–0.115	–0.138	0.116	–0.060	0.246	0.367	0.208	0.135	0.220
1968	–0.007	–0.622	–0.201	–0.017	–0.208	–0.071	0.049	–0.209	–0.053	–0.101
1969	0.006	0.346	0.181	–0.132	0.083	–0.394	–0.171	–0.062	0.040	–0.137
1970	–0.119	0.202	0.266	0.152	0.143	–0.265	0.098	0.074	–0.013	0.001
1971	0.011	–0.050	–0.196	–0.311	–0.173	–0.056	–0.368	–0.370	–0.172	–0.269
1972	–0.598	–0.425	–0.159	–0.072	–0.253	–0.245	–0.224	–0.274	–0.613	–0.338
1973	0.462	0.430	0.120	0.008	0.220	–0.277	–0.308	–0.507	–0.181	–0.307
1974	–0.350	–0.345	–0.368	–0.177	–0.292	–0.041	–0.152	–0.263	–0.226	–0.161
1975	–0.003	–0.007	–0.268	–0.264	–0.163	0.103	–0.183	–0.380	–0.476	–0.239
1976	–0.384	–0.395	–0.495	–0.343	–0.396	0.092	–0.111	–0.426	–0.333	–0.228
1977	–0.062	0.104	–0.038	0.004	0.029	–0.572	–0.201	–0.555	–0.499	–0.447
1978	0.036	–0.061	–0.116	–0.120	–0.087	–0.403	–0.501	–0.573	–0.492	–0.490
1979	–0.201	–0.108	–0.167	0.117	–0.066	–0.305	–0.208	–0.521	–0.343	–0.322
1980	0.037	0.426	0.204	–0.051	0.102	–0.114	–0.299	–0.428	–0.320	–0.323
1981	–0.424	–0.280	–0.251	–0.232	–0.254	–0.342	–0.377	–0.470	–0.315	–0.353
1982	–0.072	–0.142	–0.108	0.019	–0.075	–0.123	0.003	0.041	0.333	0.110
1983	0.080	0.299	–0.032	–0.100	0.030	0.582	0.313	–0.260	–0.101	0.084
1984	–0.588	–0.291	–0.199	–0.317	–0.334	–0.287	–0.668	–1.037	–0.940	–0.781
1985	–0.338	–0.231	–0.533	–0.607	–0.470	–0.949	–0.937	–1.215	–0.895	–1.009
1986	–0.653	–0.475	–0.346	–0.266	–0.387	–0.847	–0.758	–1.073	–0.864	–0.880
1987	0.005	–0.098	0.182	0.125	0.099	–0.795	–0.730	–0.881	–0.856	–0.823
1988	–0.054	0.019	0.040	0.109	–0.026	–0.915	–0.815	–0.855	–0.768	–0.836
1989	–0.411	–0.320	–0.361	–0.249	–0.328	–0.760	–0.882	–0.973	–0.883	–0.893

^aTemperature anomalies (in relation to a 1963–73 mean climatology) expressed in degrees Celsius for December–February, March–May, June–August, and September–November. Annual anomalies are in degrees Celsius and represent calendar year averages, not seasonal year averages.

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Temperature

Global and hemispheric temperature anomalies
derived from rawinsonde records

A.H. Oort, H. Liu, and M. Rosenstein (continued)

NORTHERN HEMISPHERE

Annual and Seasonal Temperature Anomalies^a

Year	Surface (950 mb)					850–300 mb				
	Dec–Feb	Mar–May	Jun–Aug	Sept–Nov	Ann	Dec–Feb	Mar–May	Jun–Aug	Sept–Nov	Ann
1958			–0.210	–0.291				0.465	0.392	
1959	–0.116	–0.213	–0.201	–0.124	–0.164	0.385	0.504	0.314	0.468	0.421
1960	0.011	–0.226	–0.027	–0.311	–0.128	0.410	0.049	0.404	0.176	0.265
1961	–0.081	–0.306	–0.301	–0.375	–0.304	0.317	0.226	0.159	0.057	0.148
1962	–0.376	–0.471	–0.319	–0.415	–0.394	0.234	–0.012	–0.153	0.028	0.029
1963	–0.279	–0.495	–0.230	–0.151	–0.257	0.043	–0.209	–0.061	0.124	–0.013
1964	–0.150	–0.274	–0.333	–0.365	–0.323	–0.017	–0.130	–0.121	–0.252	–0.185
1965	–0.364	–0.407	–0.371	–0.106	–0.299	–0.359	–0.389	–0.420	–0.117	–0.275
1966	–0.192	–0.418	0.082	–0.220	–0.151	0.043	0.007	0.200	0.039	0.086
1967	–0.126	–0.149	0.007	–0.077	–0.100	–0.051	–0.166	–0.002	–0.015	–0.080
1968	–0.243	–0.152	–0.180	–0.146	–0.204	–0.364	–0.312	–0.284	–0.271	–0.319
1969	–0.192	–0.176	–0.003	–0.042	–0.057	–0.309	0.043	0.178	–0.010	0.007
1970	0.147	–0.077	–0.040	–0.010	–0.037	0.116	0.044	0.213	0.128	0.072
1971	–0.202	–0.296	–0.348	–0.349	–0.312	–0.327	–0.368	–0.411	–0.511	–0.418
1972	–0.547	–0.379	–0.318	–0.247	–0.358	–0.690	–0.341	–0.267	–0.176	–0.319
1973	–0.179	0.043	–0.059	0.078	–0.005	0.210	0.162	0.074	0.001	0.108
1974	–0.070	–0.080	–0.183	–0.040	–0.105	–0.196	–0.237	–0.288	–0.244	–0.284
1975	–0.066	–0.137	–0.322	–0.181	–0.182	–0.401	–0.034	–0.177	–0.218	–0.191
1976	–0.378	–0.503	–0.336	–0.268	–0.370	–0.380	–0.556	–0.461	–0.228	–0.386
1977	–0.056	–0.049	0.034	0.064	0.023	0.104	0.160	0.072	0.105	0.128
1978	0.008	–0.203	–0.126	–0.170	–0.141	0.041	0.106	0.058	–0.084	0.031
1979	–0.256	–0.154	0.014	0.226	–0.013	–0.028	0.088	0.145	0.299	0.147
1980	0.185	–0.108	0.032	–0.092	–0.021	0.314	0.156	0.345	0.196	0.246
1981	0.133	–0.054	0.080	0.251	0.145	0.311	0.318	0.297	0.206	0.293
1982	0.085	–0.291	–0.205	–0.045	–0.152	0.154	–0.001	–0.002	–0.035	0.023
1983	0.074	0.008	0.034	0.158	0.088	0.367	0.448	0.282	0.219	0.311
1984	0.118	–0.083	0.097	–0.004	0.009	0.039	0.019	0.094	–0.147	–0.022
1985	–0.007	–0.329	–0.132	–0.034	–0.101	–0.038	–0.187	–0.174	–0.095	–0.089
1986	0.084	–0.099	–0.125	–0.096	–0.091	0.144	0.119	0.067	0.054	0.109
1987	–0.039	–0.073	0.136	0.288	0.117	0.504	0.305	0.411	0.467	0.454
1988	0.338	0.208	–0.054	0.032	0.123	0.583	0.429	0.562	0.331	0.424
1989	0.021	0.018	–0.018	0.161	0.066	0.042	0.158	0.127	0.306	0.179

Global and hemispheric temperature anomalies derived from rawinsonde records

A.H. Oort, H. Liu, and M. Rosenstein (continued)

NORTHERN HEMISPHERE

Annual and Seasonal Temperature Anomalies^a

Year	300–100 mb					100–50 mb				
	Dec–Feb	Mar–May	Jun–Aug	Sept–Nov	Ann	Dec–Feb	Mar–May	Jun–Aug	Sept–Nov	Ann
1958			–0.053	0.048				0.415	0.541	
1959	–0.226	0.164	–0.156	–0.093	–0.064	0.519	0.494	0.799	1.132	0.760
1960	–0.070	–0.272	–0.190	–0.117	–0.142	0.580	0.453	0.001	0.404	0.331
1961	–0.180	–0.002	–0.140	–0.246	–0.237	0.108	0.279	0.720	1.112	0.538
1962	–0.857	–0.916	–1.001	–0.368	–0.775	0.529	0.195	–0.223	–0.123	0.081
1963	–0.927	–0.418	0.325	0.300	–0.119	0.143	0.066	0.860	0.681	0.414
1964	0.131	0.526	0.005	–0.069	0.117	0.273	1.194	0.569	–0.028	0.524
1965	–0.336	–0.278	–0.264	0.176	–0.093	0.166	0.525	0.254	0.550	0.393
1966	0.407	0.222	0.460	0.287	0.296	0.162	0.154	0.632	0.876	0.428
1967	–0.138	–0.234	–0.050	–0.129	–0.126	0.150	0.473	0.301	–0.220	0.198
1968	0.020	–0.884	–0.284	–0.204	–0.350	0.261	0.103	0.104	–0.166	0.036
1969	–0.205	0.322	0.112	–0.057	0.037	–0.233	–0.068	–0.165	0.339	–0.024
1970	–0.004	0.270	0.362	0.156	0.175	–0.038	0.190	0.149	–0.254	–0.003
1971	–0.054	–0.031	–0.250	–0.449	–0.216	–0.131	–0.504	–0.141	–0.234	–0.240
1972	–0.827	–0.520	–0.285	–0.063	–0.360	–0.264	–0.083	–0.787	–0.567	–0.465
1973	0.602	0.492	0.074	–0.127	0.213	–0.224	–0.476	–0.431	–0.238	–0.328
1974	–0.647	–0.186	–0.440	–0.302	–0.378	–0.233	0.028	–0.563	–0.684	–0.346
1975	–0.182	–0.030	–0.316	–0.302	–0.239	–0.132	0.026	–0.374	–0.369	–0.203
1976	–0.708	–0.375	–0.463	–0.293	–0.417	–0.173	0.004	–0.070	–0.283	–0.132
1977	0.054	0.147	–0.167	–0.079	0.002	–0.150	0.119	–0.451	–0.672	–0.340
1978	0.050	–0.211	–0.132	–0.315	–0.184	–0.792	–0.739	–0.714	–0.813	–0.770
1979	–0.320	–0.122	–0.176	0.071	–0.118	–0.296	–0.194	–0.450	–0.646	–0.369
1980	–0.154	0.482	0.212	0.010	0.068	–0.478	–0.138	–0.020	–0.137	–0.227
1981	–0.682	–0.258	–0.031	0.013	–0.161	–0.452	–0.382	–0.396	–0.373	–0.360
1982	0.081	0.022	0.099	–0.105	0.025	0.070	0.396	0.515	0.301	0.365
1983	0.055	0.272	0.144	–0.042	0.080	0.365	0.344	–0.166	–0.136	0.089
1984	–0.625	–0.193	–0.340	–0.259	–0.320	–0.206	–0.352	–1.117	–0.815	–0.663
1985	0.078	–0.030	–0.467	–0.261	–0.209	–0.765	–0.831	–0.777	–0.305	–0.672
1986	–0.312	–0.287	–0.427	–0.272	–0.297	–0.447	–0.388	–1.188	–0.793	–0.706
1987	0.312	–0.035	0.221	0.540	0.334	–0.445	–0.569	–0.587	–0.232	–0.468
1988	–0.016	0.131	0.051	–0.142	–0.102	–1.171	–0.454	–0.938	–1.161	–0.931
1989	–0.372	–0.201	–0.370	–0.002	–0.203	–0.525	–0.525	–0.711	–0.581	–0.614

^aTemperature anomalies (in relation to a 1963–73 mean climatology) expressed in degrees Celsius for December–February, March–May, June–August, and September–November. Annual anomalies are in degrees Celsius and represent calendar year averages, not seasonal year averages.

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Temperature

Global and hemispheric temperature anomalies
derived from rawinsonde records

A.H. Oort, H. Liu, and M. Rosenstein (continued)

SOUTHERN HEMISPHERE

Annual and Seasonal Temperature Anomalies^a

Year	Surface (950 mb)					850–300 mb				
	Dec–Feb	Mar–May	Jun–Aug	Sept–Nov	Ann	Dec–Feb	Mar–May	Jun–Aug	Sept–Nov	Ann
1958										
1959										
1960										
1961										
1962										
1963			0.081	–1.162				0.126	–0.356	
1964	–0.527	–0.073	–0.129	–0.507	–0.314	–0.321	0.010	–0.221	–0.273	–0.222
1965	–0.512	–0.624	0.409	–1.196	–0.518	–0.797	–0.561	–0.272	–0.089	–0.396
1966	–1.304	–0.231	0.034	–0.279	–0.357	–0.137	0.052	–0.017	–0.276	–0.094
1967	–0.170	0.207	–0.076	0.034	0.048	–0.235	0.122	0.148	0.038	0.035
1968	0.147	–0.111	–0.010	–0.279	–0.113	–0.203	–0.193	–0.024	–0.060	–0.135
1969	–0.067	0.074	–0.193	0.066	0.012	0.039	0.289	0.190	0.186	0.216
1970	0.097	0.051	0.140	0.293	0.117	0.248	0.210	0.339	0.341	0.291
1971	–0.051	0.019	0.247	0.045	0.057	0.302	–0.113	–0.111	–0.047	–0.020
1972	–0.075	0.122	0.422	–0.088	0.128	–0.244	–0.010	0.252	0.339	0.098
1973	0.213	0.323	0.063	0.385	0.221	0.399	0.579	0.197	0.188	0.306
1974	–0.081	0.026	0.485	0.095	0.154	–0.197	–0.369	–0.115	–0.039	–0.130
1975	0.174	–0.003	0.176	–0.153	0.025	0.033	–0.058	–0.239	–0.255	–0.179
1976	–0.144	–0.212	–0.032	0.023	–0.068	–0.303	–0.394	–0.401	–0.335	–0.342
1977	0.196	0.152	0.254	–0.049	0.136	–0.031	0.116	0.166	0.064	0.091
1978	0.367	0.385	0.468	0.206	0.357	0.152	0.435	0.088	0.244	0.217
1979	0.070	0.267	0.323	0.517	0.333	0.072	0.398	0.205	0.263	0.269
1980	0.664	0.583	0.721	0.478	0.587	0.389	0.600	0.486	0.384	0.470
1981	0.290	0.449	0.767	0.471	0.489	0.435	0.351	0.323	0.200	0.344
1982	0.294	0.168	0.159	0.196	0.210	0.362	0.180	0.202	0.206	0.210
1983	0.423	0.502	0.425	0.484	0.450	0.316	0.786	0.437	0.362	0.466
1984	0.323	0.376	0.401	0.485	0.422	0.030	0.383	0.044	0.277	0.208
1985	0.492	0.326	0.631	0.417	0.431	0.215	0.183	0.322	0.175	0.196
1986	0.333	0.300	0.178	0.577	0.374	0.108	0.052	0.065	0.221	0.151
1987	0.460	0.520	0.410	0.609	0.499	0.541	0.482	0.573	0.448	0.516
1988	0.442	0.223	0.361	0.185	0.286	0.461	0.555	0.496	0.496	0.471
1989	0.092	0.335	0.466	0.175	0.244	0.108	0.150	0.362	0.434	0.270

Global and hemispheric temperature anomalies derived from rawinsonde records

A.H. Oort, H. Liu, and M. Rosenstein (continued)

SOUTHERN HEMISPHERE

Annual and Seasonal Temperature Anomalies^a

Year	300–100 mb					100–50 mb				
	Dec–Feb	Mar–May	Jun–Aug	Sept–Nov	Ann	Dec–Feb	Mar–May	Jun–Aug	Sept–Nov	Ann
1958										
1959										
1960										
1961										
1962										
1963			0.307	0.138				0.678	1.195	
1964	0.419	0.181	0.082	0.530	0.213	1.671	0.664	0.271	0.958	0.741
1965	–0.496	–0.400	–0.263	–0.367	–0.351	0.146	–0.274	0.166	–0.097	–0.013
1966	–0.297	–0.159	0.085	–0.668	–0.243	–0.482	–0.349	–0.745	–0.888	–0.559
1967	–0.006	0.004	–0.226	0.360	0.007	0.342	0.261	0.115	0.490	0.241
1968	–0.034	–0.360	–0.117	0.169	–0.065	–0.402	–0.004	–0.522	0.060	–0.239
1969	0.218	0.369	0.251	–0.207	0.128	–0.555	–0.274	0.041	–0.259	–0.250
1970	–0.234	0.133	0.170	0.147	0.110	–0.492	0.005	–0.001	0.228	0.005
1971	0.075	–0.069	–0.142	–0.173	–0.130	0.018	–0.233	–0.599	–0.110	–0.299
1972	–0.368	–0.329	–0.032	–0.081	–0.145	–0.226	–0.364	0.240	–0.658	–0.211
1973	0.321	0.368	0.166	0.143	0.227	–0.329	–0.140	–0.582	–0.125	–0.287
1974	–0.052	–0.505	–0.296	–0.052	–0.207	0.150	–0.332	0.036	0.232	0.024
1975	0.175	0.016	–0.219	–0.227	–0.087	0.337	–0.393	–0.385	–0.583	–0.275
1976	–0.060	–0.415	–0.527	–0.394	–0.375	0.357	–0.226	–0.781	–0.384	–0.324
1977	–0.178	0.060	0.091	0.087	0.055	–0.993	–0.520	–0.659	–0.326	–0.553
1978	0.022	0.090	–0.100	0.076	0.009	–0.015	–0.262	–0.433	–0.171	–0.210
1979	–0.082	–0.094	–0.159	0.164	–0.013	–0.314	–0.222	–0.592	–0.040	–0.275
1980	0.229	0.371	0.195	–0.112	0.136	0.250	–0.460	–0.836	–0.502	–0.418
1981	–0.167	–0.302	–0.470	–0.478	–0.348	–0.233	–0.371	–0.544	–0.256	–0.346
1982	–0.226	–0.306	–0.315	0.142	–0.176	–0.316	–0.389	–0.434	0.366	–0.144
1983	0.106	0.326	–0.208	–0.158	–0.019	0.798	0.281	–0.353	–0.067	0.079
1984	–0.551	–0.389	–0.058	–0.375	–0.347	–0.368	–0.984	–0.957	–1.065	–0.900
1985	–0.754	–0.433	–0.598	–0.952	–0.731	–1.132	–1.043	–1.653	–1.485	–1.345
1986	–0.993	–0.662	–0.266	–0.261	–0.478	–1.247	–1.129	–0.957	–0.935	–1.053
1987	–0.301	–0.162	0.143	–0.290	–0.135	–1.145	–0.890	–1.175	–1.479	–1.179
1988	–0.092	–0.093	0.029	0.360	0.049	–0.659	–1.175	–0.773	–0.374	–0.740
1989	–0.450	–0.439	–0.352	–0.497	–0.452	–0.994	–1.240	–1.236	–1.185	–1.172

^aTemperature anomalies (in relation to a 1963–73 mean climatology) expressed in degrees Celsius for December–February, March–May, June–August, and September–November. Annual anomalies are in degrees Celsius and represent calendar year averages, not seasonal year averages.

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Global and hemispheric temperature anomalies
derived from rawinsonde records

A.H. Oort, H. Liu, and M. Rosenstein (continued)

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Temperature

U.S. national and regional temperature anomalies

T.R. Karl, D.R. Easterling, R.W. Knight, P.Y. Hughes

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Contiguous United States • North Pacific Coast • South Pacific Coast • North Cascades • California Interior Valleys • East Slope North Cascades • Great Basin • Southern Desert • Northern Rockies • Southern Rockies • Northern Steppes • Southern Steppes • Northern Plains • South Coastal Plain • Gulf Coast • Great Lakes • Eastern Prairies • Northern Appalachians • Southern Appalachians • Northern Piedmont • Southern Piedmont • Coastal Northeast • Coastal Southeast

Period of Record

1900–92 (relative to a 1961–90 reference period for each individual station)

Methods

These national and regional temperature estimates over the contiguous United States were derived by using records from the National Climatic Data Center's (NCDC's) United States Historical Climatology Network (HCN) (Karl et al. 1990). The HCN data described in Karl et al. (1990) extended through 1987 and were from 1219 stations; the updated records used here extend through September 1992 and contain 1221 stations. Data from these stations have been adjusted to account for the "time-of-observation-bias" through procedures described by Karl et al. (1986b), nonclimatic bias (e.g., changes in instrumentation or station location) through a procedure documented by Karl and Williams (1987), and potential heat-island biases through empirical equations developed by Karl et al. (1988b). All 1221 station records were used in this regional analysis.

The contiguous United States. Regions outlined are the 23 climatic regions specified for the contiguous United States in Karl et al. (1988a).

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U.S. national and regional temperature anomalies

T.R. Karl, D.R. Easterling, R.W. Knight, and P.Y. Hughes (continued)

Temperature anomaly time series, relative to the 1961–90 means for each station, were generated for each individual station. These station temperature anomaly time series were then aggregated into regional mean temperature anomaly series. The NCDC compilers divided the nation into 23 regions (subregions) on the basis of terrain, vegetation, and climate characteristics in relation to the rest of the country and the continent as a whole. The compilers also required each subregion to have boundaries that coincide with boundaries of NCDC's climate divisions. Composite values for the contiguous United States were produced by taking an areally weighted average of the regional values.

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CONTIGUOUS UNITED STATES

Trends

National and regional temperature estimates for the United States using the HCN data described in Karl et al. (1990) were presented in Karl et al. (1988a). On the basis of regional seasonal temperatures (i.e., maximum, minimum, average, and diurnal range) for the United States, Karl et al. (1988a) concluded that the climate has changed during the recent century but that the changes for the most part have not been monotonic. Instead, the changes are somewhat unsteady and sometimes occur over a relatively short period of time. If there are any monotonic trends in the data, it may be the decrease in the diurnal temperature range (Karl et al. 1988a). Karl et al. (1993) found the rate of decrease in the diurnal temperature range ($-1.4^{\circ}\text{C}/100$ years) to be comparable to the increase of the mean temperature ($1.3^{\circ}\text{C}/100$ years) for the Northern Hemisphere.

Using data from the HCN, Plantico et al. (1990) reported that the annual mean temperature for the area extending from the eastern United States to the Southern Rockies cooled during the 1948–87 period. Furthermore, the Northern Appalachians and Gulf Coast regions show significant local decreases in temperature whereas significant local increases are evident from the Pacific Coast to the Southern Desert. For the contiguous United States, the mean temperature cooled over the 1948–87 period by -0.06°C and is not consistent with the warming experienced across the Northern Hemisphere as a whole (Plantico et al. 1990).

Annual mean temperature anomalies.

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U.S. national and regional temperature anomalies

T.R. Karl, D.R. Easterling, R.W. Knight, and P.Y. Hughes (continued)

CONTIGUOUS UNITED STATES

Annual and Seasonal Mean Temperature Anomalies (°C)

Year	CY ^a mean	Win	Spr	Sum	Fall	SY ^b mean	Year	CY ^a mean	Win	Spr	Sum	Fall	SY ^b mean
1900	0.46		0.21	0.27	0.85		1947	0.10	0.47	-0.42	0.03	0.85	0.23
1901	-0.21	0.07	-0.46	0.48	-0.28	-0.05	1948	-0.22	-0.67	-0.01	0.02	-0.15	-0.20
1902	-0.14	-0.69	0.48	-0.58	0.12	-0.17	1949	0.05	-0.77	0.39	0.33	0.23	0.05
1903	-0.77	-0.84	0.10	-0.83	-1.02	-0.65	1950	-0.37	0.39	-1.02	-0.86	0.13	-0.34
1904	-0.72	-1.86	-0.39	-0.92	-0.21	-0.85	1951	-0.45	0.05	-0.69	-0.30	-0.70	-0.41
1905	-0.45	-1.86	0.67	-0.32	-0.25	-0.44	1952	0.03	0.68	-0.40	0.49	-1.22	-0.11
1906	-0.04	0.23	-0.69	-0.42	-0.10	-0.25	1953	0.61	1.91	0.03	0.31	0.31	0.64
1907	-0.23	1.09	-0.61	-0.85	-0.39	-0.19	1954	0.57	1.47	-0.22	0.36	0.70	0.58
1908	-0.11	0.73	0.36	-0.64	-0.59	-0.04	1955	-0.25	-0.33	0.12	0.19	-0.60	-0.16
1909	-0.36	0.82	-1.06	0.06	0.01	-0.04	1956	-0.05	-0.16	-0.42	0.01	-0.37	-0.23
1910	-0.14	-2.08	0.95	-0.55	0.13	-0.39	1957	0.45	1.02	0.44	0.25	-0.13	0.40
1911	0.02	0.52	0.20	-0.19	-0.62	-0.02	1958	0.14	0.93	0.06	0.11	0.45	0.39
1912	-0.88	-1.50	-0.75	-0.76	-0.51	-0.88	1959	0.12	-0.60	0.16	0.50	-0.52	-0.12
1913	-0.23	-0.74	-0.65	-0.07	0.22	-0.31	1960	-0.27	0.43	-0.98	0.01	0.56	0.01
1914	-0.05	0.48	0.04	0.14	0.32	0.25	1961	-0.01	-0.02	-0.17	0.18	-0.29	-0.07
1915	-0.11	-0.37	-0.18	-1.16	0.31	-0.35	1962	-0.04	-0.52	-0.09	-0.41	0.65	-0.09
1916	-0.77	-0.29	-0.36	-0.30	-1.23	-0.54	1963	-0.06	-1.35	0.61	0.12	1.38	0.19
1917	-1.34	-1.93	-1.75	-0.73	-1.04	-1.36	1964	-0.27	-1.30	-0.24	-0.08	-0.40	-0.51
1918	-0.14	-2.02	0.30	0.03	-0.09	-0.45	1965	-0.03	-0.07	-0.56	-0.42	0.28	-0.19
1919	-0.16	0.69	0.00	0.12	-0.13	0.17	1966	-0.34	-0.31	-0.25	-0.07	-0.13	-0.19
1920	-0.37	-0.83	-0.96	-0.67	0.02	-0.61	1967	-0.13	0.23	-0.05	-0.37	-0.32	-0.13
1921	0.87	1.56	0.83	0.52	0.32	0.81	1968	-0.28	-0.31	-0.16	-0.12	0.01	-0.15
1922	0.01	-0.44	0.15	0.16	0.41	0.07	1969	-0.06	-0.36	-0.54	0.12	-0.16	-0.23
1923	-0.10	0.23	-1.02	-0.07	-0.09	-0.24	1970	-0.12	-0.17	-0.44	0.32	-0.07	-0.09
1924	-1.01	0.13	-1.27	-0.64	-0.53	-0.58	1971	-0.04	-0.08	-0.99	0.01	0.56	-0.12
1925	0.20	-0.44	0.57	0.05	-0.41	-0.06	1972	-0.13	0.20	0.26	-0.19	0.05	0.08
1926	-0.01	0.97	-0.58	-0.27	0.02	0.04	1973	0.48	-0.23	0.47	0.22	0.90	0.34
1927	0.20	1.11	0.41	-0.83	0.83	0.38	1974	0.16	0.52	0.74	-0.32	-0.39	0.14
1928	-0.08	-0.40	-0.28	-0.43	-0.08	-0.30	1975	-0.09	0.63	-0.79	0.03	-0.20	-0.08
1929	-0.68	-1.94	0.30	-0.39	-0.78	-0.70	1976	-0.62	0.88	-0.09	-0.54	-1.72	-0.37
1930	-0.12	0.07	0.09	-0.07	-0.25	-0.04	1977	0.32	-1.95	1.07	0.60	0.68	0.10
1931	0.81	1.16	-0.71	0.51	1.41	0.59	1978	-0.37	-1.31	0.23	0.09	0.21	-0.19
1932	-0.14	1.75	-0.58	0.26	-0.78	0.16	1979	-0.53	-2.92	0.09	-0.21	-0.07	-0.78
1933	0.35	-0.60	-0.08	0.45	0.54	0.08	1980	0.18	0.72	-0.25	0.43	-0.04	0.22
1934	0.86	1.45	0.77	0.86	0.82	0.97	1981	0.64	0.90	0.80	0.57	0.36	0.66
1935	0.12	0.84	0.12	0.31	-0.47	0.20	1982	-0.08	-0.86	0.03	-0.11	0.06	-0.22
1936	-0.10	-2.23	0.48	1.00	-0.32	-0.27	1983	0.40	2.33	-0.36	0.58	0.94	0.87
1937	-0.13	-0.65	-0.24	0.66	-0.03	-0.07	1984	0.21	-0.78	-0.30	0.31	0.07	-0.17
1938	0.71	1.31	0.98	0.39	0.08	0.69	1985	-0.26	-0.78	1.24	-0.23	0.05	0.07
1939	0.38	0.36	0.34	0.18	0.15	0.26	1986	0.93	0.22	1.22	0.45	0.49	0.59
1940	0.06	0.03	-0.10	0.18	0.12	0.05	1987	0.67	1.52	0.97	0.33	-0.17	0.66
1941	0.79	1.56	0.44	0.28	0.85	0.78	1988	-0.07	-0.26	-0.06	0.57	0.04	0.07
1942	0.01	0.35	0.22	0.08	0.06	0.18	1989	-0.30	-0.28	0.36	0.12	-0.27	-0.02
1943	-0.17	0.20	-0.46	0.54	-0.79	-0.13	1990	0.72	0.41	0.72	0.41	0.66	0.55
1944	0.04	0.61	-0.38	-0.20	0.43	0.11	1991	0.77	0.32	1.36	0.56	-0.31	0.48
1945	-0.02	0.30	0.25	-0.47	0.08	0.04	1992		2.48	0.82	-0.70		
1946	0.53	-0.26	1.21	-0.21	0.18	0.23							

^aCalendar year mean (January–December).^bSeasonal year mean, calculated from four seasons in the following sequence: Win (December–February), Spr (March–May), Sum (June–August), and Fall (September–November).

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Temperature

U.S. national and regional temperature anomalies

T.R. Karl, D.R. Easterling, R.W. Knight, and P.Y. Hughes (continued)

NORTH PACIFIC COAST

Annual mean temperature anomalies.

CITE AS: Karl, T.R., D.R. Easterling, R.W. Knight, and P.Y. Hughes. 1994. U.S. national and regional temperature anomalies. pp. 686-736. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

U.S. national and regional temperature anomalies

T.R. Karl, D.R. Easterling, R.W. Knight, and P.Y. Hughes (continued)

NORTH PACIFIC COAST

Annual and Seasonal Mean Temperature Anomalies (°C)

Year	CY ^a mean	Win	Spr	Sum	Fall	SY ^b mean	Year	CY ^a mean	Win	Spr	Sum	Fall	SY ^b mean
1900	0.32		0.83	-0.22	-0.52		1947	0.28	-0.20	1.05	0.13	0.09	0.27
1901	-0.30	0.24	-0.42	-1.17	0.78	-0.14	1948	-0.81	-0.65	-0.89	0.25	-0.99	-0.57
1902	0.03	0.40	0.19	-0.62	-0.11	-0.04	1949	-0.81	-3.26	0.42	-0.74	-0.13	-0.93
1903	-0.11	-0.18	-0.72	0.03	0.43	-0.11	1950	-0.20	-2.08	-0.86	0.00	0.58	-0.59
1904	0.21	0.01	0.18	-0.57	1.05	0.17	1951	-0.34	1.09	-0.77	-0.37	0.21	0.04
1905	0.03	0.67	0.96	0.04	-1.09	0.14	1952	-0.32	-0.74	-0.58	-0.22	-0.42	-0.49
1906	0.38	0.80	0.22	0.05	-0.12	0.24	1953	0.48	1.38	-0.45	-0.19	1.16	0.47
1907	0.04	0.36	-0.11	-0.39	0.27	0.03	1954	-0.13	0.44	-0.66	-0.43	0.46	-0.05
1908	-0.57	0.60	-0.84	-0.64	-0.67	-0.39	1955	-0.94	-0.74	-1.67	-0.83	-0.69	-0.98
1909	-0.82	-0.30	-1.06	-1.16	-0.26	-0.70	1956	-0.38	-0.09	-0.20	0.01	-0.70	-0.24
1910	-0.34	-1.62	0.60	-1.26	-0.27	-0.63	1957	0.21	-1.41	1.04	0.16	0.33	0.03
1911	-1.00	-0.52	-1.01	-0.75	-1.12	-0.85	1958	1.39	2.34	0.44	1.81	0.57	1.29
1912	-0.08	0.67	-0.47	-0.13	-0.58	-0.13	1959	0.09	1.26	0.12	0.19	-0.08	0.37
1913	-0.34	-1.32	-0.57	0.48	-0.09	-0.38	1960	0.11	-0.33	0.40	0.01	-0.00	0.02
1914	0.13	0.94	0.85	-0.52	-0.04	0.31	1961	0.32	1.20	0.34	0.86	-1.05	0.34
1915	0.32	-0.20	1.18	0.34	-0.69	0.16	1962	-0.02	-0.45	-0.34	-0.49	0.82	-0.12
1916	-1.00	-0.67	-0.22	-0.48	-1.89	-0.82	1963	0.50	0.64	0.08	-0.06	1.42	0.52
1917	-0.61	-1.98	-1.33	-0.81	0.40	-0.93	1964	-0.43	0.00	-1.07	-0.07	-0.39	-0.38
1918	-0.30	0.86	-1.03	-0.36	0.37	-0.04	1965	0.02	0.22	-0.36	-0.03	0.69	0.13
1919	-0.80	-0.45	-0.19	-1.09	-1.41	-0.79	1966	0.15	-0.55	-0.16	-0.37	0.62	-0.11
1920	-0.38	-1.08	-1.26	-0.21	0.17	-0.59	1967	0.21	0.96	-0.97	0.59	1.23	0.45
1921	-0.07	0.77	-0.14	-0.26	-0.05	0.08	1968	0.32	0.31	0.13	0.32	0.58	0.33
1922	-0.92	-1.64	-1.02	-0.30	-0.65	-0.90	1969	0.04	-1.39	0.00	0.51	0.08	-0.20
1923	-0.50	-1.13	-0.55	-0.23	-0.04	-0.49	1970	-0.04	1.53	-0.67	-0.07	-0.26	0.13
1924	-0.66	-0.00	-0.73	-0.79	-0.62	-0.53	1971	-0.36	-0.14	-0.60	0.21	-0.54	-0.27
1925	0.18	0.11	0.25	-0.29	-0.64	-0.14	1972	-0.13	-0.82	0.35	0.40	-0.27	-0.08
1926	0.69	1.42	1.34	0.22	0.35	0.83	1973	0.29	-0.45	-0.02	-0.15	0.35	-0.07
1927	-0.13	0.42	-0.78	0.01	0.40	0.01	1974	0.07	0.54	0.10	0.12	-0.05	0.18
1928	0.06	-0.32	0.81	-0.20	-0.40	-0.03	1975	-0.24	0.15	-0.93	-0.05	0.05	-0.20
1929	-1.12	-2.19	-1.01	-0.62	-1.55	-1.34	1976	-0.16	0.08	-0.89	-0.03	0.63	-0.05
1930	-0.59	-0.29	0.08	-0.64	-0.64	-0.37	1977	0.16	-0.41	-0.47	0.64	0.13	-0.03
1931	0.14	0.58	0.82	-0.11	-0.92	0.09	1978	0.44	1.92	0.78	0.83	-0.39	0.78
1932	-0.35	-0.87	0.31	-0.39	0.24	-0.18	1979	0.56	-1.67	0.82	0.40	1.27	0.20
1933	-0.54	-1.99	-0.75	-0.49	-0.30	-0.88	1980	0.50	0.97	0.42	0.12	0.51	0.51
1934	1.07	2.06	1.83	-0.15	0.85	1.15	1981	0.99	1.55	0.86	0.82	0.67	0.98
1935	-0.53	0.37	-0.94	-0.50	-0.94	-0.50	1982	-0.05	0.30	-0.66	0.53	0.19	0.09
1936	-0.11	0.06	0.40	0.40	-1.16	-0.08	1983	1.18	1.56	1.12	1.12	1.04	1.21
1937	-0.14	-2.20	0.14	0.16	0.94	-0.24	1984	0.41	0.56	0.76	0.49	0.25	0.51
1938	-0.10	0.65	-0.14	-0.39	-0.26	-0.03	1985	-0.69	-1.44	-0.20	0.30	-1.20	-0.64
1939	0.03	-0.28	0.15	-0.27	-0.15	-0.14	1986	0.91	0.63	0.87	0.82	0.46	0.70
1940	1.00	2.12	1.27	0.25	0.71	1.09	1987	0.72	0.49	1.24	0.43	0.88	0.76
1941	1.09	1.87	1.32	0.94	0.37	1.12	1988	0.43	0.10	0.31	0.28	1.08	0.44
1942	0.18	0.35	-0.14	0.65	-0.23	0.16	1989	0.20	-1.31	1.06	0.68	0.34	0.19
1943	-0.18	-0.21	0.12	-0.47	0.36	-0.05	1990	0.35	-0.27	1.05	1.22	0.61	0.65
1944	-0.14	-0.28	-0.56	-0.34	0.51	-0.17	1991	0.43	-0.87	-0.12	0.65	0.61	0.07
1945	-0.01	0.46	-0.20	-0.44	-0.11	-0.08	1992		1.46	2.04	1.46		
1946	-0.40	0.11	-0.09	-0.07	-1.37	-0.35							

^aCalendar year mean (January–December).^bSeasonal year mean, calculated from four seasons in the following sequence: Win (December–February), Spr (March–May), Sum (June–August), and Fall (September–November).

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Temperature

U.S. national and regional temperature anomalies

T.R. Karl, D.R. Easterling, R.W. Knight, and P.Y. Hughes (continued)

SOUTH PACIFIC COAST

Annual mean temperature anomalies.

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U.S. national and regional temperature anomalies

T.R. Karl, D.R. Easterling, R.W. Knight, and P.Y. Hughes (continued)

SOUTH PACIFIC COAST

Annual and Seasonal Mean Temperature Anomalies (°C)

Year	CY ^a mean	Win	Spr	Sum	Fall	SY ^b mean	Year	CY ^a mean	Win	Spr	Sum	Fall	SY ^b mean
1900	0.69		0.80	-0.03	0.70		1947	-0.23	-0.43	0.92	-0.24	-0.58	-0.08
1901	0.15	1.12	-0.28	-0.52	0.59	0.23	1948	-1.15	-1.08	-0.95	-0.90	-1.26	-1.05
1902	-0.38	0.00	-0.85	-0.62	0.03	-0.36	1949	-0.74	-3.15	0.13	-0.28	-0.01	-0.83
1903	-0.41	-1.09	-0.55	-0.92	0.88	-0.42	1950	0.03	-1.12	-0.17	-0.52	0.73	-0.27
1904	0.32	-0.23	0.68	-0.27	1.08	0.32	1951	-0.23	0.44	-0.25	-0.27	0.04	-0.01
1905	-0.40	0.69	0.41	-1.24	-1.00	-0.29	1952	-0.41	-0.45	-0.25	-0.81	-0.27	-0.45
1906	0.25	0.37	0.34	-0.02	-0.57	0.03	1953	-0.48	0.28	-1.37	-0.58	-0.03	-0.43
1907	0.28	1.23	0.28	-0.55	0.18	0.29	1954	-0.11	-0.01	0.25	-0.11	-0.56	-0.11
1908	-0.78	0.32	-0.89	-0.97	-0.88	-0.60	1955	-0.80	-1.57	-1.10	-0.89	-0.45	-1.00
1909	-0.30	0.51	-1.08	-0.91	0.07	-0.35	1956	-0.72	0.10	-0.64	-0.70	-0.70	-0.48
1910	-0.05	-0.96	0.95	-0.98	0.50	-0.12	1957	0.33	0.21	0.36	0.49	-0.30	0.19
1911	-0.57	0.02	0.39	-0.83	-1.08	-0.37	1958	0.75	1.20	0.21	0.74	0.70	0.71
1912	-0.77	-0.49	-0.66	-1.13	-0.65	-0.73	1959	0.77	0.58	0.76	1.17	0.75	0.82
1913	-0.41	-1.73	-1.13	-0.02	0.62	-0.57	1960	0.06	-0.18	0.45	0.58	-0.17	0.17
1914	0.29	0.71	1.04	-0.78	0.28	0.31	1961	0.00	-0.10	-0.47	1.08	-0.67	-0.04
1915	-0.13	0.08	0.51	-0.44	-0.88	-0.18	1962	-0.29	-0.27	-0.64	-0.53	0.01	-0.36
1916	-0.87	0.37	-0.17	-1.44	-1.57	-0.70	1963	0.15	0.87	-0.50	-0.40	1.13	0.28
1917	-0.71	-1.97	-2.45	0.04	0.72	-0.91	1964	-0.40	-1.33	-1.35	-0.15	0.12	-0.68
1918	0.03	-0.29	-0.49	0.22	1.43	0.22	1965	-0.09	0.86	-0.10	-0.33	0.20	0.16
1919	-0.70	-1.16	-0.13	-0.56	-1.33	-0.80	1966	0.20	-1.12	0.56	0.28	0.51	0.06
1920	-0.54	0.17	-0.77	-0.59	-0.94	-0.53	1967	0.34	0.42	-0.85	0.76	1.68	0.50
1921	-0.26	-0.69	-0.61	-0.27	-0.19	-0.44	1968	0.12	0.61	-0.17	0.04	0.06	0.13
1922	-0.64	-0.51	-1.36	-0.20	-0.50	-0.64	1969	0.36	0.18	-0.14	0.51	0.11	0.16
1923	-0.62	-0.03	-0.44	-1.46	0.12	-0.45	1970	0.17	1.40	-0.56	0.53	-0.37	0.25
1924	-0.83	-0.41	-0.05	-1.02	-1.45	-0.73	1971	-0.59	-0.20	-1.05	0.49	-0.99	-0.44
1925	-0.18	-0.51	0.10	-0.12	-0.95	-0.37	1972	0.12	-0.96	0.37	0.82	0.04	0.07
1926	0.68	0.28	2.22	0.33	0.24	0.77	1973	0.12	0.02	-0.22	0.30	-0.33	-0.06
1927	-0.09	0.54	-0.58	-0.56	0.23	-0.09	1974	0.14	0.19	-0.14	0.54	0.47	0.27
1928	-0.01	-0.18	1.27	-0.49	-0.43	0.04	1975	-0.63	-0.34	-1.17	-0.48	-0.48	-0.62
1929	-0.28	-1.49	-0.99	0.37	0.06	-0.52	1976	0.21	-0.16	-0.62	0.25	1.43	0.23
1930	0.03	1.12	0.26	0.20	-0.27	0.33	1977	0.59	0.38	-0.96	0.86	0.62	0.22
1931	1.01	0.36	1.94	1.80	-0.34	0.94	1978	1.00	3.01	1.57	0.75	0.46	1.45
1932	-0.40	-1.09	-0.22	-0.57	0.66	-0.30	1979	0.54	-0.59	0.77	0.41	0.77	0.34
1933	-0.72	-2.27	-1.02	-0.42	0.14	-0.89	1980	0.79	2.34	0.22	0.43	-0.02	0.74
1934	0.97	0.64	2.07	0.19	0.62	0.88	1981	1.10	1.72	0.88	1.44	0.26	1.08
1935	-0.46	0.55	-0.46	-0.26	-1.10	-0.32	1982	0.03	0.78	0.05	-0.08	-0.12	0.16
1936	0.28	0.06	0.47	0.82	-0.25	0.28	1983	1.32	0.99	0.49	1.06	1.95	1.12
1937	-0.27	-2.11	-0.56	0.34	0.56	-0.44	1984	0.98	1.29	0.86	1.78	0.89	1.21
1938	-0.05	0.74	-0.18	0.09	-0.86	-0.05	1985	-0.00	-0.42	0.02	0.87	-0.58	-0.03
1939	-0.04	-0.53	0.09	-0.13	0.42	-0.04	1986	0.69	1.76	0.88	0.45	-0.37	0.68
1940	0.65	1.70	1.09	-0.06	-0.44	0.57	1987	0.49	-0.18	1.02	0.12	1.15	0.53
1941	0.62	2.16	1.09	-0.04	-0.44	0.69	1988	0.43	0.21	0.38	0.59	0.52	0.43
1942	-0.41	0.18	-0.83	-0.04	-0.52	-0.30	1989	0.19	-0.88	1.40	0.34	-0.05	0.20
1943	0.06	0.20	0.81	-0.96	-0.12	-0.02	1990	0.15	-0.71	0.83	1.02	0.26	0.35
1944	-0.47	-0.02	-0.62	-1.10	0.07	-0.42	1991	0.26	-0.36	-0.62	0.20	0.82	0.01
1945	-0.13	-0.08	-1.15	0.35	0.36	-0.13	1992		0.81	2.60	1.47		
1946	-0.68	-1.15	-0.39	-0.25	-1.10	-0.72							

^aCalendar year mean (January–December).^bSeasonal year mean, calculated from four seasons in the following sequence: Win (December–February), Spr (March–May), Sum (June–August), and Fall (September–November).

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Temperature

U.S. national and regional temperature anomalies

T.R. Karl, D.R. Easterling, R.W. Knight, and P.Y. Hughes (continued)

NORTH CASCADES

Annual mean temperature anomalies.

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U.S. national and regional temperature anomalies

T.R. Karl, D.R. Easterling, R.W. Knight, and P.Y. Hughes (continued)

NORTH CASCADES

Annual and Seasonal Mean Temperature Anomalies (°C)

Year	CY ^a mean	Win	Spr	Sum	Fall	SY ^b mean	Year	CY ^a mean	Win	Spr	Sum	Fall	SY ^b mean
1900	0.14		0.49	-0.66	-0.56		1947	0.39	-0.15	1.01	-0.15	0.67	0.35
1901	-0.47	0.22	-0.42	-1.36	0.36	-0.30	1948	-0.50	-0.32	-0.43	0.52	-0.71	-0.23
1902	-0.30	0.21	0.40	-1.31	-0.56	-0.31	1949	-0.86	-3.50	0.52	-0.96	0.00	-0.98
1903	-0.50	-0.74	-0.96	-0.21	-0.13	-0.51	1950	-0.41	-2.40	-0.99	0.03	0.34	-0.76
1904	-0.06	0.02	-0.15	-1.11	0.69	-0.14	1951	-0.60	1.05	-1.06	-0.81	0.07	-0.19
1905	-0.40	0.33	0.56	-0.57	-1.45	-0.28	1952	-0.46	-1.04	-0.47	-0.19	-0.73	-0.61
1906	0.03	0.50	-0.53	-0.46	0.16	-0.08	1953	0.57	1.40	-0.21	-0.32	1.01	0.47
1907	-0.46	-0.39	-0.85	-0.92	0.25	-0.48	1954	-0.30	0.49	-0.96	-0.67	0.40	-0.19
1908	-0.92	0.41	-1.21	-0.99	-1.03	-0.70	1955	-0.91	-0.58	-1.71	-0.74	-0.60	-0.91
1909	-1.17	-1.07	-1.23	-1.74	-0.13	-1.04	1956	-0.34	-0.58	-0.06	-0.00	-0.72	-0.34
1910	-0.56	-1.96	0.40	-1.73	-0.23	-0.88	1957	-0.10	-1.37	1.22	-0.38	-0.31	-0.21
1911	-1.25	-0.90	-1.58	-0.96	-1.14	-1.14	1958	1.42	2.42	0.45	1.88	0.39	1.28
1912	-0.20	0.77	-0.74	-0.22	-0.69	-0.22	1959	0.08	1.62	-0.05	0.02	-0.19	0.35
1913	-0.46	-1.37	-0.58	0.36	-0.27	-0.47	1960	0.07	-0.12	0.30	-0.09	0.14	0.06
1914	0.14	0.89	0.89	-0.56	0.43	0.41	1961	0.45	1.51	0.62	0.98	-1.41	0.43
1915	0.33	-0.86	1.10	0.33	-0.46	0.03	1962	0.00	-0.43	-0.12	-0.74	0.94	-0.09
1916	-1.27	-1.19	-0.47	-0.58	-2.15	-1.10	1963	0.51	0.59	0.12	0.01	1.60	0.58
1917	-0.46	-1.52	-1.17	-0.92	0.32	-0.82	1964	-0.48	0.03	-1.11	-0.09	-0.48	-0.41
1918	-0.10	1.42	-1.15	-0.19	0.64	0.18	1965	0.12	0.51	-0.58	0.14	0.58	0.16
1919	-0.84	-0.10	-0.27	-1.15	-1.00	-0.63	1966	0.26	-0.07	-0.24	-0.33	0.66	0.01
1920	-0.53	-1.91	-1.56	-0.24	0.08	-0.91	1967	0.37	1.56	-0.94	0.77	0.96	0.59
1921	-0.16	0.97	-0.18	-0.41	-0.12	0.07	1968	0.32	0.65	0.07	0.35	0.46	0.38
1922	-0.94	-2.04	-1.24	-0.20	-0.29	-0.94	1969	-0.02	-1.39	-0.04	0.40	0.10	-0.23
1923	-0.12	-1.11	-0.27	0.39	0.22	-0.19	1970	-0.19	1.44	-0.77	0.01	-0.77	-0.02
1924	-0.59	0.41	-0.61	-0.62	-0.44	-0.32	1971	-0.37	-0.07	-0.72	0.22	-0.69	-0.31
1925	0.47	0.14	0.67	-0.18	-0.56	0.02	1972	-0.34	-0.70	0.19	0.34	-0.73	-0.23
1926	0.63	1.57	1.12	0.12	0.34	0.79	1973	0.18	-0.64	0.00	-0.42	0.10	-0.24
1927	-0.09	-0.02	-0.80	0.28	0.84	0.08	1974	0.05	0.55	-0.05	0.21	-0.12	0.15
1928	0.10	-0.70	0.82	0.01	-0.02	0.03	1975	-0.16	0.58	-1.20	-0.02	0.07	-0.14
1929	-1.21	-2.87	-0.74	-0.69	-1.48	-1.44	1976	-0.08	0.67	-0.84	-0.26	0.58	0.04
1930	-0.68	-1.00	0.17	-0.63	-0.61	-0.52	1977	0.17	-0.27	-0.42	0.88	-0.12	0.02
1931	0.06	0.48	0.72	-0.17	-0.82	0.05	1978	0.44	2.07	0.65	1.13	-0.76	0.77
1932	-0.22	-0.91	0.60	-0.29	0.50	-0.02	1979	0.43	-1.75	0.82	0.22	0.95	0.06
1933	-0.33	-2.05	-0.65	-0.27	-0.10	-0.77	1980	0.38	0.65	0.61	-0.18	0.50	0.40
1934	1.43	2.58	2.39	0.11	1.10	1.54	1981	0.90	1.71	0.85	0.67	0.38	0.90
1935	-0.53	0.45	-1.12	-0.25	-0.92	-0.46	1982	-0.04	0.49	-0.90	0.85	-0.07	0.09
1936	0.03	-0.34	0.72	0.59	-1.06	-0.02	1983	0.90	1.78	1.11	0.81	0.40	1.03
1937	0.17	-2.02	0.43	0.55	1.49	0.11	1984	0.18	0.39	0.61	-0.11	-0.15	0.18
1938	0.10	0.76	0.10	-0.25	0.20	0.20	1985	-0.94	-1.44	-0.24	0.29	-1.90	-0.82
1939	0.44	0.17	0.23	-0.01	0.56	0.24	1986	0.96	0.45	0.93	0.89	0.50	0.69
1940	1.11	2.09	1.47	0.32	1.17	1.26	1987	0.62	0.62	1.33	0.40	0.41	0.69
1941	1.09	1.36	1.07	1.17	0.71	1.08	1988	0.44	0.05	0.45	0.06	1.02	0.40
1942	0.35	0.13	0.17	0.93	0.06	0.32	1989	0.23	-1.04	0.99	0.62	0.23	0.20
1943	-0.35	-0.44	-0.16	-0.51	0.47	-0.16	1990	0.56	0.43	1.01	1.50	0.69	0.91
1944	-0.18	-0.51	-0.60	-0.28	0.71	-0.17	1991	0.62	-0.57	0.04	0.76	0.53	0.19
1945	0.07	0.37	0.16	-0.53	-0.15	-0.04	1992		2.13	1.86	1.37		
1946	-0.15	0.36	0.21	0.03	-1.21	-0.15							

^aCalendar year mean (January–December).^bSeasonal year mean, calculated from four seasons in the following sequence: Win (December–February), Spr (March–May), Sum (June–August), and Fall (September–November).

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Temperature

U.S. national and regional temperature anomalies

T.R. Karl, D.R. Easterling, R.W. Knight, and P.Y. Hughes (continued)

CALIFORNIA INTERIOR VALLEYS

Annual mean temperature anomalies.

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U.S. national and regional temperature anomalies

T.R. Karl, D.R. Easterling, R.W. Knight, and P.Y. Hughes (continued)

CALIFORNIA INTERIOR VALLEYS

Annual and Seasonal Mean Temperature Anomalies (°C)

Year	CY ^a					SY ^b	Year	CY ^a					SY ^b
	mean	Win	Spr	Sum	Fall	mean		mean	Win	Spr	Sum	Fall	mean
1900	0.27		0.71	-0.43	-0.52		1947	-0.04	0.02	1.53	-0.75	-0.21	0.15
1901	-0.31	0.56	-0.94	-0.54	0.16	-0.19	1948	-1.12	-0.90	-1.56	-0.76	-0.98	-1.05
1902	-0.44	0.11	-1.14	-0.49	-0.62	-0.53	1949	-0.81	-3.22	0.35	-0.43	-0.03	-0.83
1903	-0.96	-1.62	-1.01	-0.94	-0.04	-0.90	1950	0.58	-1.08	-0.06	0.12	1.60	0.14
1904	0.19	-0.78	0.30	0.16	0.81	0.12	1951	0.09	1.52	0.15	-0.25	0.31	0.43
1905	-0.76	0.99	0.06	-1.18	-2.07	-0.55	1952	0.03	-0.44	-0.17	-0.23	0.41	-0.11
1906	-0.35	0.11	-0.41	-0.62	-1.52	-0.61	1953	-0.08	1.14	-1.23	-0.72	0.88	0.02
1907	-0.24	1.12	-0.30	-2.09	-0.02	-0.32	1954	-0.04	0.42	0.58	-0.53	-0.57	-0.02
1908	-0.89	0.86	-1.63	-0.70	-1.08	-0.64	1955	-0.65	-1.34	-1.13	-0.74	-0.42	-0.91
1909	-0.49	0.92	-1.04	-1.49	-0.34	-0.49	1956	-0.48	0.83	-0.19	-0.34	-0.57	-0.07
1910	-0.33	-1.68	0.86	-1.08	-0.19	-0.53	1957	0.33	-0.48	0.87	-0.05	0.10	0.11
1911	-1.67	-0.57	-1.20	-1.25	-2.49	-1.38	1958	1.16	1.70	0.20	1.31	1.18	1.10
1912	-1.03	-0.77	-1.30	-0.92	-1.26	-1.06	1959	0.55	1.28	0.73	0.86	0.23	0.78
1913	-0.63	-2.29	-1.37	0.15	0.48	-0.76	1960	0.57	-0.20	0.46	1.29	0.27	0.46
1914	-0.35	0.32	0.63	-1.04	-0.92	-0.26	1961	0.41	0.52	-0.27	1.81	-0.44	0.41
1915	-0.22	-0.37	0.40	-0.59	-1.02	-0.40	1962	0.07	-0.51	-0.33	-0.09	0.94	0.00
1916	-0.79	0.55	0.07	-0.91	-2.06	-0.58	1963	0.24	0.85	-0.29	-0.60	1.49	0.36
1917	-0.80	-2.19	-2.56	0.24	0.32	-1.05	1964	-0.21	-0.90	-1.16	0.13	0.06	-0.47
1918	-0.52	0.04	-1.30	-0.33	0.42	-0.29	1965	0.01	1.06	0.35	-0.23	0.18	0.34
1919	-0.94	-1.22	-0.21	-0.71	-1.87	-1.00	1966	0.47	-1.17	1.11	0.19	0.87	0.25
1920	-0.85	-0.88	-1.37	-0.95	-0.75	-0.99	1967	0.47	0.57	-1.02	1.52	1.90	0.74
1921	-0.24	0.24	-0.58	-0.43	-0.36	-0.28	1968	0.48	0.25	0.37	0.50	0.51	0.41
1922	-0.84	-0.94	-1.62	-0.41	-0.50	-0.87	1969	0.28	-0.20	0.05	0.50	0.03	0.10
1923	-0.81	-0.32	-0.81	-1.60	0.43	-0.57	1970	0.59	1.92	-0.23	0.60	0.22	0.63
1924	-0.78	-0.67	-0.23	-1.30	-0.96	-0.79	1971	-0.38	-0.00	-0.74	0.70	-0.70	-0.19
1925	-0.00	0.37	0.42	-0.02	-1.39	-0.15	1972	0.23	-0.79	0.91	0.86	0.09	0.27
1926	0.65	0.38	1.99	0.33	0.23	0.73	1973	0.61	-0.17	0.55	0.54	0.15	0.27
1927	-0.21	0.77	-0.82	-0.55	-0.09	-0.17	1974	0.43	0.61	0.23	0.76	0.82	0.61
1928	-0.13	-0.27	1.06	-0.51	-0.60	-0.08	1975	-0.42	-0.27	-0.79	-0.18	-0.20	-0.36
1929	-0.81	-1.85	-1.22	-0.38	-1.14	-1.15	1976	-0.16	-0.60	-0.59	-0.05	1.14	-0.03
1930	-0.54	1.13	-0.21	-0.35	-1.03	-0.12	1977	0.46	-0.92	-0.70	1.19	0.56	0.03
1931	0.39	-0.17	1.29	0.94	-1.14	0.23	1978	0.81	2.82	1.33	0.58	0.26	1.25
1932	-0.57	-1.14	-0.24	-0.47	0.45	-0.35	1979	0.66	-0.87	0.98	0.43	1.21	0.44
1933	-0.63	-2.75	-1.18	0.30	-0.12	-0.94	1980	0.57	1.72	0.08	-0.11	0.42	0.52
1934	1.16	1.31	2.15	-0.01	1.00	1.11	1981	1.29	1.29	0.98	1.30	0.93	1.13
1935	-0.39	0.61	-0.81	0.11	-0.99	-0.27	1982	0.08	0.60	0.11	0.26	0.27	0.31
1936	0.40	0.62	0.66	0.66	-0.22	0.43	1983	1.29	1.03	0.65	0.59	1.92	1.05
1937	-0.19	-2.12	-0.07	0.11	0.57	-0.38	1984	0.96	1.09	1.23	1.67	0.95	1.24
1938	0.13	1.00	-0.14	0.33	-0.60	0.15	1985	0.02	-0.74	0.03	1.28	-0.40	0.04
1939	-0.06	-0.54	0.70	-0.23	-0.28	-0.09	1986	1.10	1.97	1.41	0.84	-0.14	1.02
1940	0.98	2.20	1.28	0.39	-0.05	0.95	1987	0.75	-0.04	1.56	0.15	1.31	0.75
1941	0.58	2.44	0.56	-0.18	-0.47	0.59	1988	0.73	0.10	0.47	1.53	1.15	0.82
1942	-0.23	0.46	-1.12	0.04	-0.06	-0.17	1989	-0.05	-1.54	1.62	0.28	-0.14	0.06
1943	0.14	0.61	0.97	-1.04	0.17	0.18	1990	0.03	-1.73	1.22	1.25	0.19	0.23
1944	-0.27	-0.07	-0.81	-0.94	0.66	-0.29	1991	0.40	-1.20	-0.74	0.51	1.78	0.09
1945	0.31	0.43	-0.87	0.44	1.13	0.28	1992		0.49	2.48	1.09		
1946	-0.43	-0.65	-0.08	-0.18	-0.87	-0.45							

^aCalendar year mean (January–December).^bSeasonal year mean, calculated from four seasons in the following sequence: Win (December–February), Spr (March–May), Sum (June–August), and Fall (September–November).

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Temperature

U.S. national and regional temperature anomalies

T.R. Karl, D.R. Easterling, R.W. Knight, and P.Y. Hughes (continued)

EAST SLOPE NORTH CASCADES

Annual mean temperature anomalies.

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U.S. national and regional temperature anomalies

T.R. Karl, D.R. Easterling, R.W. Knight, and P.Y. Hughes (continued)

EAST SLOPE NORTH CASCADES

Annual and Seasonal Mean Temperature Anomalies (°C)

Year	CY ^a mean	Win	Spr	Sum	Fall	SY ^b mean	Year	CY ^a mean	Win	Spr	Sum	Fall	SY ^b mean
1900	0.96		1.03	-0.02	-0.16		1947	0.64	0.05	1.17	-0.27	1.42	0.59
1901	0.01	1.80	-0.35	-1.04	0.82	0.31	1948	-0.72	0.12	-0.45	0.12	-0.86	-0.27
1902	-0.57	1.02	0.17	-1.72	-0.82	-0.34	1949	-1.04	-5.56	0.73	-0.70	0.14	-1.35
1903	-0.83	-1.82	-1.30	-0.38	-0.56	-1.01	1950	-0.36	-3.17	-0.85	0.30	0.93	-0.70
1904	-0.02	0.32	-0.46	-0.82	0.73	-0.06	1951	-0.42	1.64	-0.99	-0.25	0.12	0.13
1905	-0.47	-0.02	0.25	-0.47	-1.06	-0.32	1952	-0.22	-1.53	0.00	-0.11	-0.59	-0.56
1906	0.19	0.61	-0.56	-0.01	-0.00	0.01	1953	0.95	3.35	-0.27	-0.79	1.11	0.85
1907	-0.55	-1.21	-0.47	-0.86	0.33	-0.55	1954	-0.26	1.94	-1.05	-1.27	0.30	-0.02
1908	-0.35	0.64	-0.55	-0.54	-0.01	-0.11	1955	-0.95	-0.27	-1.98	-0.50	-0.79	-0.88
1909	-1.11	-1.43	-1.12	-1.55	0.52	-0.89	1956	-0.15	-1.16	0.43	-0.01	-0.42	-0.29
1910	-0.20	-3.04	1.31	-1.56	0.51	-0.70	1957	-0.15	-2.31	1.51	-0.59	0.09	-0.33
1911	-1.21	-0.59	-1.17	-0.56	-1.59	-0.98	1958	1.69	4.01	0.72	2.06	0.02	1.70
1912	-0.46	0.08	-0.67	-0.51	-0.94	-0.51	1959	-0.05	1.89	-0.31	-0.33	-0.54	0.13
1913	-0.92	-2.47	-0.64	-0.10	-0.39	-0.90	1960	-0.26	-0.60	-0.20	0.03	-0.04	-0.20
1914	-0.03	1.02	0.59	-0.52	0.37	0.37	1961	0.69	2.08	0.68	1.59	-1.87	0.62
1915	0.17	-1.55	1.06	0.11	-0.50	-0.22	1962	0.14	-0.12	-0.13	-0.82	0.85	-0.06
1916	-1.96	-2.81	-0.45	-1.18	-2.37	-1.70	1963	0.50	0.87	0.18	-0.15	1.90	0.70
1917	-0.52	-2.43	-1.70	-0.79	0.52	-1.10	1964	-0.59	0.57	-1.14	-0.58	-0.75	-0.48
1918	0.12	1.84	-1.05	-0.06	0.92	0.41	1965	0.33	1.02	-0.92	0.34	0.48	0.23
1919	-1.29	0.06	-0.57	-1.14	-1.48	-0.78	1966	0.57	0.85	-0.34	-0.48	1.19	0.31
1920	-0.35	-2.23	-1.26	-0.27	-0.20	-0.99	1967	0.89	3.38	-0.82	1.06	1.17	1.20
1921	-0.31	-1.12	-0.23	-0.34	-0.75	-0.05	1968	0.37	1.17	-0.12	0.32	0.34	0.43
1922	-1.37	-3.77	-1.64	0.68	-0.02	-1.19	1969	-0.33	-2.20	0.08	-0.04	-0.13	-0.57
1923	-0.07	-1.79	-0.29	0.35	0.35	-0.35	1970	-0.05	1.81	-0.93	0.86	-1.07	0.17
1924	-0.59	0.24	-0.46	-0.43	-0.12	-0.19	1971	-0.08	0.80	-0.62	0.41	-0.79	-0.05
1925	0.83	0.13	0.80	0.19	-0.57	0.14	1972	-0.19	-0.59	0.22	0.51	-0.30	-0.04
1926	0.65	2.99	0.66	0.46	-0.13	1.00	1973	0.60	-0.69	0.14	-0.03	0.76	0.04
1927	-0.18	0.03	-0.87	0.23	1.07	0.11	1974	0.34	1.60	0.06	0.25	0.01	0.48
1928	-0.11	-1.40	0.35	-0.09	-0.30	-0.36	1975	-0.08	0.43	-1.19	0.33	0.15	-0.07
1929	-1.71	-4.80	-0.58	-0.55	-2.00	-1.98	1976	-0.17	1.51	-0.94	-0.56	0.16	0.04
1930	-0.69	-1.84	0.57	-0.17	-0.44	-0.47	1977	0.20	-0.52	-0.30	1.22	-0.34	0.01
1931	0.05	0.75	0.62	0.09	-0.88	0.15	1978	0.06	2.43	0.64	0.39	-1.40	0.52
1932	-0.44	-1.91	0.57	-0.34	0.51	-0.29	1979	0.02	-3.75	0.44	0.50	0.60	-0.55
1933	-0.20	-2.76	-0.66	-0.01	0.09	-0.84	1980	0.39	0.92	1.02	-0.82	0.60	0.43
1934	1.69	3.74	2.16	0.10	1.56	1.89	1981	0.79	3.02	0.59	-0.34	0.30	0.89
1935	-0.43	0.97	-1.14	-0.41	-0.87	-0.36	1982	-0.25	0.29	-1.06	0.69	-0.51	-0.15
1936	-0.36	-1.60	1.06	0.64	-1.72	-0.41	1983	0.74	2.81	1.01	0.22	0.46	1.12
1937	-0.31	-3.89	0.36	0.30	1.65	-0.40	1984	-0.08	-0.57	0.42	0.03	-0.42	-0.14
1938	0.56	1.71	0.20	0.43	0.57	0.73	1985	-1.34	-2.87	0.02	0.48	-2.72	-1.27
1939	0.51	0.45	0.57	0.02	-0.03	0.26	1986	1.00	-0.23	1.07	0.95	0.44	0.56
1940	1.34	2.57	1.66	0.70	1.28	1.55	1987	0.84	0.95	1.84	0.28	0.48	0.89
1941	1.20	1.70	1.02	1.17	0.58	1.12	1988	0.65	0.22	0.70	0.19	1.48	0.65
1942	0.14	0.00	0.10	0.39	0.23	0.18	1989	0.19	-1.28	0.75	0.35	0.58	0.10
1943	-0.31	-0.57	-0.33	-0.76	0.90	-0.19	1990	0.67	1.50	0.79	1.32	0.99	1.15
1944	0.07	-0.14	-0.24	-0.05	0.98	0.14	1991	0.68	-0.65	-0.10	0.44	0.57	0.07
1945	0.41	1.39	0.07	-0.15	0.02	0.33	1992		3.68	1.70	1.39		
1946	0.04	0.52	0.51	-0.20	-1.04	-0.05							

^aCalendar year mean (January–December).^bSeasonal year mean, calculated from four seasons in the following sequence: Win (December–February), Spr (March–May), Sum (June–August), and Fall (September–November).

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Temperature

U.S. national and regional temperature anomalies

T.R. Karl, D.R. Easterling, R.W. Knight, and P.Y. Hughes (continued)

GREAT BASIN

Annual mean temperature anomalies.

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U.S. national and regional temperature anomalies

T.R. Karl, D.R. Easterling, R.W. Knight, and P.Y. Hughes (continued)

GREAT BASIN

Annual and Seasonal Mean Temperature Anomalies (°C)

Year	CY ^a mean	Win	Spr	Sum	Fall	SY ^b mean	Year	CY ^a mean	Win	Spr	Sum	Fall	SY ^b mean
1900	0.66		0.58	-0.10	-0.14		1947	0.24	0.94	1.08	-0.57	0.57	0.51
1901	0.41	1.27	-0.05	0.43	0.31	0.49	1948	-0.68	-0.06	-0.92	-0.32	-0.47	-0.44
1902	-0.02	0.91	-0.46	-0.36	-0.32	-0.06	1949	-1.26	-5.83	0.73	-0.53	0.21	-1.36
1903	-1.11	-2.15	-0.58	-0.32	-0.49	-0.89	1950	0.32	-0.83	-0.85	-0.73	1.74	-0.17
1904	-0.05	-1.03	0.52	0.03	-0.15	-0.16	1951	-0.23	1.98	-0.27	-0.38	-0.35	0.25
1905	-0.57	0.83	0.32	-0.57	-1.75	-0.29	1952	-0.40	-1.37	-0.33	-0.08	-0.75	-0.63
1906	0.29	-0.32	-0.17	-0.06	-0.62	-0.29	1953	0.24	2.37	-1.34	-0.50	1.12	0.41
1907	0.51	2.75	0.65	-1.38	0.21	0.56	1954	0.28	1.34	0.37	-0.45	-0.01	0.31
1908	-0.63	2.02	-1.06	-0.86	-1.12	-0.25	1955	-0.85	-2.92	-1.61	-0.05	-0.17	-1.19
1909	-0.31	1.30	-1.43	-0.38	-0.13	-0.16	1956	-0.40	1.15	0.28	-0.53	-1.10	-0.05
1910	0.07	-3.08	1.27	-0.42	0.49	-0.44	1957	0.19	-0.53	0.70	-0.11	-0.29	-0.06
1911	-1.08	1.00	-0.72	-0.65	-2.02	-0.60	1958	0.79	2.23	0.08	0.48	0.16	0.74
1912	-0.91	-0.65	-0.75	-1.23	-1.46	-1.02	1959	0.05	2.06	-0.58	0.61	-0.56	0.38
1913	-0.91	-2.57	-0.86	-0.14	-0.13	-0.93	1960	0.20	-1.08	0.21	0.38	1.06	0.14
1914	-0.06	0.62	0.96	-0.30	-0.61	0.17	1961	0.28	0.28	-0.05	1.73	-1.09	0.22
1915	-0.20	-1.46	0.71	-1.10	-0.71	-0.64	1962	-0.22	-0.90	-0.25	-0.80	1.06	-0.22
1916	-1.24	0.10	-0.34	-1.56	-2.10	-0.98	1963	0.39	0.09	-0.24	-0.52	2.48	0.45
1917	-1.18	-3.92	-2.46	-0.40	-0.05	-1.71	1964	-0.97	-2.17	-1.65	-0.33	-0.89	-1.26
1918	-0.18	1.36	-0.92	0.27	0.31	0.26	1965	-0.02	2.02	-0.69	-0.68	0.12	0.19
1919	-0.41	-0.68	0.52	0.33	-1.24	-0.27	1966	0.18	-0.33	-0.02	-0.01	0.95	0.15
1920	-0.28	-0.69	-0.87	-0.48	-0.29	-0.59	1967	0.46	1.16	-0.50	0.82	1.44	0.73
1921	0.50	1.22	0.36	0.12	-0.20	0.38	1968	0.16	-0.02	-0.45	0.01	0.36	-0.03
1922	-0.75	-1.74	-1.77	0.65	-0.13	-0.75	1969	0.54	1.14	0.05	0.44	-0.18	0.36
1923	-0.64	0.13	-0.65	-0.64	-0.26	-0.36	1970	0.31	2.48	-1.26	0.88	-0.37	0.43
1924	-1.00	-1.02	-0.60	-0.64	-0.66	-0.73	1971	-0.15	0.90	-0.55	0.71	-1.01	0.01
1925	0.48	-1.04	1.16	0.04	-0.56	-0.10	1972	0.29	-0.10	0.40	0.61	0.79	0.43
1926	0.66	1.63	1.39	0.71	-0.13	0.90	1973	0.29	-1.30	0.14	0.13	0.24	-0.20
1927	0.36	1.28	-0.35	0.14	1.06	0.53	1974	0.15	0.46	0.52	0.01	0.52	0.38
1928	-0.06	-0.41	1.14	-0.76	-0.05	-0.02	1975	-0.51	-0.45	-1.33	-0.49	-0.21	-0.62
1929	-0.98	-3.32	-0.82	0.30	-1.87	-1.42	1976	-0.46	0.67	-0.76	-0.72	0.21	-0.15
1930	-0.81	0.07	0.42	0.39	-1.69	-0.20	1977	0.54	-1.55	-0.92	1.55	0.83	-0.02
1931	-0.06	-1.50	-0.09	1.29	-0.61	-0.23	1978	0.59	3.86	1.29	-0.64	0.09	1.15
1932	-1.03	-3.08	0.33	-0.35	-0.25	-0.84	1979	0.09	-1.82	0.46	-0.02	0.54	-0.21
1933	-0.70	-5.41	-1.36	0.81	0.24	-1.43	1980	0.68	2.36	0.17	-0.55	0.33	0.58
1934	1.77	3.61	2.60	0.60	0.96	1.94	1981	1.27	2.00	0.84	0.57	1.38	1.20
1935	-0.11	1.38	-0.41	0.02	-0.86	0.03	1982	-0.14	0.42	-0.45	0.15	0.14	0.07
1936	0.37	0.50	0.77	1.39	-1.59	0.27	1983	1.27	2.23	0.34	0.20	1.88	1.16
1937	-0.36	-3.62	0.09	0.40	0.99	-0.53	1984	-0.12	-0.39	0.15	0.64	0.36	0.19
1938	0.72	2.82	0.33	0.22	-0.05	0.83	1985	-0.61	-2.41	0.45	0.68	-0.96	-0.56
1939	0.42	-0.30	1.02	0.11	0.38	0.30	1986	1.15	1.61	1.42	0.94	-0.09	0.97
1940	1.49	3.13	1.52	0.91	0.87	1.61	1987	0.62	0.01	1.39	-0.03	1.05	0.61
1941	0.74	2.67	0.45	-0.04	-0.53	0.64	1988	0.33	-0.58	0.15	1.06	1.22	0.46
1942	-0.38	-0.04	-1.01	-0.27	-0.08	-0.35	1989	-0.24	-2.95	1.53	0.19	-0.04	-0.31
1943	0.42	1.58	0.67	-0.71	0.54	0.52	1990	0.26	-0.22	1.32	0.61	1.04	0.69
1944	-0.88	-0.77	-0.90	-1.63	0.36	-0.73	1991	0.25	-1.81	-0.65	0.35	1.13	-0.24
1945	0.03	1.00	-0.77	-0.65	0.34	-0.02	1992		1.18	2.46	0.07		
1946	0.26	-0.53	0.54	0.33	-0.38	-0.01							

^aCalendar year mean (January–December).^bSeasonal year mean, calculated from four seasons in the following sequence: Win (December–February), Spr (March–May), Sum (June–August), and Fall (September–November).

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Temperature

U.S. national and regional temperature anomalies

T.R. Karl, D.R. Easterling, R.W. Knight, and P.Y. Hughes (continued)

SOUTHERN DESERT

Annual mean temperature anomalies.

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U.S. national and regional temperature anomalies

T.R. Karl, D.R. Easterling, R.W. Knight, and P.Y. Hughes (continued)

SOUTHERN DESERT

Annual and Seasonal Mean Temperature Anomalies (°C)

Year	CY ^a mean	Win	Spr	Sum	Fall	SY ^b mean	Year	CY ^a mean	Win	Spr	Sum	Fall	SY ^b mean
1900	0.16		0.54	-0.39	0.33		1947	0.10	0.18	0.74	0.17	0.15	0.31
1901	0.21	0.68	-0.90	0.28	0.75	0.20	1948	-0.41	-1.04	-0.42	0.05	-0.52	-0.48
1902	-0.11	-0.40	-0.43	-0.29	0.26	-0.21	1949	-0.27	-1.50	0.09	-0.10	0.68	-0.21
1903	-0.65	-1.07	-0.70	0.02	-0.23	-0.50	1950	0.27	-0.06	0.34	-0.35	0.52	0.11
1904	-0.02	-1.12	0.72	0.07	-0.15	-0.12	1951	-0.10	-0.06	-0.08	-0.12	0.09	-0.04
1905	0.29	1.06	0.40	-0.73	0.85	0.40	1952	-0.11	0.11	-0.11	0.06	-0.20	-0.04
1906	0.01	0.26	-0.18	-0.35	-0.97	-0.31	1953	-0.33	-0.12	-0.72	0.32	-0.17	-0.17
1907	0.35	2.26	-0.02	-0.94	0.78	0.52	1954	0.56	-0.11	0.83	-0.03	0.88	0.39
1908	-0.41	0.59	-0.19	-0.66	-1.41	-0.42	1955	-0.49	-1.29	-0.73	-0.55	0.08	-0.62
1909	-0.20	1.09	-0.92	0.33	-0.40	0.02	1956	-0.35	0.12	-0.24	-0.06	-0.58	-0.19
1910	0.48	-1.18	1.26	0.23	0.78	0.27	1957	0.74	1.88	0.10	0.80	-0.31	0.62
1911	-0.26	0.94	0.47	-0.39	-0.66	0.09	1958	0.72	0.89	0.31	0.76	1.14	0.78
1912	-1.31	-2.28	-1.03	-0.84	-1.50	-1.41	1959	0.38	-0.07	0.38	1.15	-0.27	0.30
1913	-0.79	-2.05	-1.22	-0.88	0.34	-0.95	1960	0.04	-0.64	0.33	0.72	0.44	0.21
1914	0.53	0.46	0.68	-0.00	0.97	0.53	1961	0.03	-0.13	-0.07	0.74	-0.78	-0.06
1915	-0.65	-0.31	-0.65	-0.84	-0.77	-0.64	1962	0.31	0.34	-0.33	-0.26	1.19	0.24
1916	-0.42	0.95	0.36	-0.79	-1.54	-0.25	1963	0.18	0.36	-0.01	-0.04	1.31	0.40
1917	-0.74	-1.34	-2.49	-0.13	0.20	-0.94	1964	-0.65	-2.58	-0.99	0.17	0.11	-0.82
1918	-0.19	-0.51	-0.02	0.21	-0.18	-0.12	1965	-0.13	0.42	-0.75	-0.78	0.27	-0.21
1919	-0.42	-1.53	0.07	-0.28	-0.34	-0.52	1966	0.07	-0.83	0.79	0.55	0.35	0.21
1920	-0.77	1.23	-1.07	-0.77	-1.43	-0.51	1967	-0.02	-0.50	-0.24	0.18	0.79	0.05
1921	-0.04	-1.00	-0.53	-0.12	-0.15	-0.45	1968	-0.17	0.67	0.02	-0.51	-0.47	-0.07
1922	-0.14	-0.09	-1.07	0.66	0.06	-0.11	1969	0.44	0.07	-0.47	0.71	0.30	0.15
1923	-0.15	1.07	-0.20	-0.76	-0.41	-0.08	1970	-0.26	0.59	-0.88	0.65	-1.15	-0.20
1924	-0.62	-0.56	-0.69	0.13	-0.66	-0.45	1971	-0.46	-0.26	-0.86	0.16	-0.71	-0.42
1925	-0.01	-0.91	0.93	0.12	-0.56	-0.11	1972	0.09	-0.40	0.92	0.35	-0.25	0.15
1926	0.42	-0.31	1.13	-0.18	0.82	0.37	1973	-0.47	-0.25	-0.74	-0.19	-0.82	-0.50
1927	0.35	1.47	-0.21	-0.02	0.62	0.46	1974	0.17	-0.54	0.88	0.08	0.56	0.24
1928	-0.09	-0.40	0.12	-0.29	0.27	-0.08	1975	-0.95	-0.88	-1.74	-0.67	-0.91	-1.05
1929	-0.39	-1.29	-0.24	0.17	-0.46	-0.46	1976	-0.52	0.37	-0.32	-0.83	-0.80	-0.40
1930	-0.24	0.30	0.04	-0.13	-0.52	-0.08	1977	0.49	-0.35	-0.94	0.95	1.00	0.17
1931	0.44	-0.06	0.38	0.65	0.50	0.37	1978	0.71	1.78	0.78	0.33	1.14	1.01
1932	-0.64	-0.64	-0.57	-0.51	-0.56	-0.57	1979	-0.41	-0.84	-0.19	-0.70	-0.31	-0.51
1933	-0.45	-2.29	-1.61	0.33	1.11	-0.62	1980	0.36	1.67	-0.85	0.36	-0.40	0.20
1934	0.92	0.31	2.27	0.27	0.40	0.81	1981	1.12	1.78	1.09	1.18	0.63	1.17
1935	0.09	1.21	-0.10	0.19	-0.59	0.18	1982	0.18	1.01	0.43	-0.17	-0.21	0.27
1936	0.30	-0.08	0.98	0.61	-0.28	0.31	1983	0.42	0.89	-0.65	-0.40	1.62	0.36
1937	-0.09	-1.75	-0.40	0.35	0.83	-0.24	1984	0.44	0.46	0.87	0.39	-0.16	0.39
1938	-0.16	1.28	-0.31	-0.29	-0.95	-0.06	1985	0.27	0.33	1.15	0.41	-0.27	0.41
1939	-0.05	-0.94	0.36	-0.04	0.25	-0.09	1986	0.86	1.46	1.66	0.65	-0.56	0.80
1940	0.53	0.68	0.82	0.03	0.10	0.40	1987	-0.04	0.14	0.20	-0.50	0.52	0.09
1941	0.21	2.53	0.14	-0.87	-0.40	0.35	1988	0.21	-0.07	-0.08	0.40	0.49	0.19
1942	-0.20	0.13	-0.79	-0.06	-0.00	-0.18	1989	0.42	-0.15	2.04	0.23	-0.25	0.47
1943	0.49	0.87	1.09	0.21	-0.14	0.51	1990	0.31	-0.87	1.27	0.42	0.50	0.33
1944	-0.53	-0.15	-0.94	-1.08	0.36	-0.45	1991	0.09	0.37	-0.69	-0.53	0.25	-0.15
1945	-0.43	0.04	-0.97	-0.36	0.00	-0.32	1992		1.34	1.75	-0.25		
1946	0.08	-1.44	0.64	0.48	-0.38	-0.18							

^aCalendar year mean (January–December).^bSeasonal year mean, calculated from four seasons in the following sequence: Win (December–February), Spr (March–May), Sum (June–August), and Fall (September–November).

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Temperature

U.S. national and regional temperature anomalies

T.R. Karl, D.R. Easterling, R.W. Knight, and P.Y. Hughes (continued)

NORTHERN ROCKIES

Annual mean temperature anomalies.

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U.S. national and regional temperature anomalies

T.R. Karl, D.R. Easterling, R.W. Knight, and P.Y. Hughes (continued)

NORTHERN ROCKIES

Annual and Seasonal Mean Temperature Anomalies (°C)

Year	CY ^a mean	Win	Spr	Sum	Fall	SY ^b mean	Year	CY ^a mean	Win	Spr	Sum	Fall	SY ^b mean
1900	0.98		1.38	-0.00	-0.08		1947	0.41	0.98	0.74	-0.36	0.88	0.56
1901	0.55	1.39	0.43	0.21	0.89	0.73	1948	-0.54	0.28	-0.64	0.20	-0.41	-0.14
1902	-0.26	1.70	-0.05	-1.60	-0.49	-0.11	1949	-0.88	-5.65	0.89	-0.37	0.59	-1.14
1903	-0.86	-1.27	-1.39	-0.36	-0.69	-0.93	1950	-0.24	-1.33	-1.06	-1.04	0.94	-0.62
1904	0.02	0.46	-0.19	-0.93	0.67	0.00	1951	-0.74	1.64	-1.05	-0.82	-0.59	-0.21
1905	-0.41	-0.30	0.58	-0.36	-0.90	-0.24	1952	-0.62	-1.92	-0.57	-0.13	-1.09	-0.93
1906	0.16	0.46	-0.85	-0.34	-0.04	-0.19	1953	1.07	3.59	-0.65	-0.04	1.30	1.05
1907	-0.06	1.10	0.14	-1.35	0.55	0.11	1954	0.43	2.39	-0.29	-0.32	0.59	0.59
1908	-0.43	0.50	-0.31	-0.82	-0.46	-0.27	1955	-0.98	-1.53	-2.06	0.13	-0.84	-1.07
1909	-0.57	-0.03	-1.40	-0.24	0.61	-0.26	1956	-0.27	-0.23	0.27	-0.31	-0.71	-0.25
1910	0.24	-3.17	1.87	-0.80	0.91	-0.30	1957	-0.00	-1.23	0.75	0.19	-0.50	-0.20
1911	-1.13	0.02	-0.57	-0.86	-1.90	-0.83	1958	1.07	2.93	0.46	0.69	0.01	1.02
1912	-0.75	-0.11	-1.55	-0.74	-1.02	-0.85	1959	0.08	1.92	-0.21	0.06	-0.52	0.31
1913	-1.01	-2.49	-0.82	-0.07	-0.23	-0.90	1960	-0.13	-0.81	-0.02	0.06	0.65	-0.03
1914	0.10	0.35	0.86	-0.29	0.36	0.32	1961	0.64	1.71	0.46	1.65	-1.21	0.65
1915	0.22	-0.89	1.37	-1.12	-0.00	-0.16	1962	0.08	-0.98	-0.07	-0.69	1.05	-0.17
1916	-1.60	-1.82	-0.15	-1.06	-2.08	-1.28	1963	0.70	0.98	0.32	0.11	2.42	0.96
1917	-0.77	-2.90	-2.64	-0.81	0.59	-1.44	1964	-0.66	-0.98	-1.24	-0.16	-0.52	-0.72
1918	0.07	1.41	-0.54	0.27	0.59	0.43	1965	0.23	1.42	-1.33	0.06	0.43	0.14
1919	-0.73	0.20	0.15	0.10	-1.65	-0.30	1966	0.24	0.41	-0.39	-0.07	1.01	0.24
1920	-0.26	-1.23	-1.16	-0.52	-0.18	-0.77	1967	0.72	2.37	-0.25	0.61	1.17	0.97
1921	0.41	1.38	0.34	0.38	-0.23	0.47	1968	-0.01	-0.09	-0.13	-0.10	0.10	-0.05
1922	-1.14	-2.92	-1.67	0.66	-0.07	-1.00	1969	0.03	-0.54	-0.29	-0.03	-0.08	-0.24
1923	-0.46	-1.07	-1.02	0.19	0.02	-0.47	1970	0.24	2.48	-0.89	0.90	-0.82	0.42
1924	-0.96	-0.38	-0.84	-1.14	-0.32	-0.67	1971	0.02	1.26	-0.27	0.44	-0.88	0.14
1925	0.97	0.27	1.26	0.05	-0.55	0.26	1972	0.18	-0.13	0.82	0.44	0.14	0.32
1926	0.63	2.63	0.96	0.31	0.03	0.98	1973	0.07	-2.00	-0.38	0.16	0.49	-0.43
1927	-0.09	0.56	-0.61	-0.25	1.34	0.26	1974	0.32	1.08	0.46	0.27	0.12	0.48
1928	-0.40	-1.39	0.45	-1.01	-0.31	-0.57	1975	-0.40	-0.11	-1.29	0.01	-0.67	-0.51
1929	-1.27	-4.43	-0.81	0.03	-1.63	-1.71	1976	-0.15	1.45	-0.66	-0.37	-0.28	0.04
1930	-0.57	-0.42	0.72	0.35	-1.04	-0.09	1977	0.37	-0.06	-0.25	0.95	0.16	0.20
1931	-0.14	-0.32	-0.27	0.61	-0.86	-0.21	1978	-0.13	2.00	1.01	-0.39	-0.96	0.41
1932	-0.95	-2.18	-0.27	-0.14	-0.18	-0.69	1979	-0.43	-4.06	0.17	0.12	-0.16	-0.98
1933	-0.17	-3.62	-1.04	0.43	0.48	-0.94	1980	0.68	1.23	0.77	-0.35	0.60	0.56
1934	1.77	4.43	2.42	0.11	0.98	1.99	1981	1.43	3.42	1.47	0.20	0.99	1.52
1935	-0.53	1.01	-0.97	-0.57	-1.16	-0.42	1982	-0.13	0.16	-0.52	0.55	-0.08	0.03
1936	-0.19	-1.60	0.16	1.66	-1.33	-0.28	1983	0.90	2.80	0.45	0.87	1.05	1.29
1937	-0.50	-3.70	-0.27	0.34	1.36	-0.57	1984	-0.24	-1.58	0.21	0.52	-0.53	-0.35
1938	0.74	1.81	0.37	0.27	0.54	0.75	1985	-1.23	-3.25	0.15	0.28	-2.06	-1.22
1939	0.37	0.21	0.78	-0.48	0.32	0.21	1986	1.17	0.89	1.68	0.84	0.12	0.88
1940	1.22	2.26	1.59	0.65	1.08	1.39	1987	0.79	1.08	1.80	0.04	0.27	0.80
1941	0.95	1.65	1.01	0.99	0.04	0.92	1988	0.62	0.01	0.76	0.88	1.05	0.67
1942	-0.59	-1.35	-0.63	-0.42	0.11	-0.57	1989	0.18	-1.94	0.96	0.56	0.81	0.10
1943	-0.10	0.43	-0.53	-0.55	0.65	-0.00	1990	0.74	1.60	1.11	0.72	1.52	1.24
1944	-0.60	-0.51	-0.46	-1.00	0.31	-0.42	1991	0.55	-0.77	0.28	0.62	0.01	0.03
1945	0.05	1.00	-0.67	-0.42	-0.08	-0.04	1992		2.18	2.38	0.19		
1946	0.38	0.08	0.87	0.00	-0.66	0.07							

^aCalendar year mean (January–December).^bSeasonal year mean, calculated from four seasons in the following sequence: Win (December–February), Spr (March–May), Sum (June–August), and Fall (September–November).

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Temperature

U.S. national and regional temperature anomalies

T.R. Karl, D.R. Easterling, R.W. Knight, and P.Y. Hughes (continued)

SOUTHERN ROCKIES

Annual mean temperature anomalies.

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U.S. national and regional temperature anomalies

T.R. Karl, D.R. Easterling, R.W. Knight, and P.Y. Hughes (continued)

SOUTHERN ROCKIES

Annual and Seasonal Mean Temperature Anomalies (°C)

Year	CY ^a mean	Win	Spr	Sum	Fall	SY ^b mean	Year	CY ^a mean	Win	Spr	Sum	Fall	SY ^b mean
1900	0.32		0.85	-0.67	0.12		1947	0.01	0.73	0.35	-0.10	0.28	0.31
1901	0.26	1.04	-0.26	-0.01	0.22	0.25	1948	-0.50	-0.83	-0.63	-0.40	-0.75	-0.65
1902	-0.21	0.41	-0.27	-0.70	-0.10	-0.17	1949	-0.46	-1.61	0.36	-0.26	0.21	-0.32
1903	-1.13	-1.82	-0.68	-0.47	-1.02	-1.00	1950	0.03	0.12	-0.30	-1.13	0.54	-0.19
1904	-0.19	-0.76	0.52	-0.55	-0.62	-0.35	1951	-0.29	0.62	-0.27	-0.11	-0.74	-0.13
1905	0.05	0.54	0.94	-0.78	0.16	0.22	1952	-0.16	0.14	-0.23	0.50	-0.91	-0.13
1906	0.24	-0.26	-0.04	-0.85	-0.10	-0.31	1953	0.03	0.44	-0.58	0.41	0.11	0.09
1907	0.61	4.14	0.30	-0.87	0.15	0.93	1954	0.94	0.86	0.84	0.42	1.37	0.87
1908	-0.90	0.23	-0.49	-0.95	-1.86	-0.77	1955	-0.44	-1.91	-0.88	0.01	-0.04	-0.70
1909	-0.33	0.77	-1.58	0.61	-0.05	-0.06	1956	-0.34	1.53	-0.21	-0.04	-1.24	0.01
1910	0.41	-1.86	0.90	0.07	0.69	-0.05	1957	0.88	1.93	0.21	0.61	-0.14	0.65
1911	0.18	2.25	0.84	-0.38	-0.34	0.59	1958	0.70	1.38	0.18	0.61	0.54	0.68
1912	-1.21	-1.85	-0.59	-0.73	-1.75	-1.23	1959	0.34	0.87	-0.03	0.93	-0.43	0.33
1913	-0.91	-2.70	-1.06	-0.43	0.15	-1.01	1960	-0.01	-0.41	0.23	0.13	0.71	0.17
1914	0.34	-0.27	0.58	0.20	0.41	0.23	1961	-0.12	-0.31	0.24	0.68	-0.76	-0.04
1915	-0.57	-0.96	0.08	-1.12	-0.77	-0.69	1962	0.13	-0.08	-0.61	-0.78	1.10	-0.09
1916	-0.19	1.05	0.20	-0.53	-0.84	-0.03	1963	0.29	-0.16	0.18	0.36	1.67	0.51
1917	-0.92	-1.49	-2.48	-0.50	-0.24	-1.18	1964	-0.74	-2.59	-1.11	0.11	-0.15	-0.94
1918	-0.14	0.08	0.13	0.46	-0.12	0.14	1965	0.10	0.78	-0.67	-0.53	0.51	0.02
1919	-0.63	-3.03	0.30	-0.00	-0.16	-0.72	1966	-0.10	-0.94	0.13	0.47	0.43	0.02
1920	-0.43	0.88	-0.79	-0.64	-0.75	-0.33	1967	-0.01	-0.04	0.21	0.14	0.34	0.16
1921	0.76	0.14	0.29	0.32	0.39	0.29	1968	-0.47	-0.50	-0.54	-0.46	-0.40	-0.47
1922	-0.16	0.45	-0.92	0.64	-0.31	-0.04	1969	0.59	0.63	-0.38	0.76	0.13	0.29
1923	-0.27	0.97	-0.53	-0.19	-0.61	-0.09	1970	-0.06	1.37	-1.17	0.50	-0.56	0.04
1924	-1.10	-0.85	-1.24	-0.62	-0.72	-0.86	1971	-0.27	0.29	-0.82	0.34	-0.52	-0.18
1925	0.09	-1.97	1.02	0.53	-0.24	-0.17	1972	0.27	0.06	0.41	0.19	0.78	0.36
1926	0.26	0.03	1.02	-0.26	0.44	0.31	1973	-0.67	-1.44	-0.75	-0.54	-0.45	-0.80
1927	0.57	1.76	0.11	-0.05	0.92	0.68	1974	-0.29	-1.46	0.49	-0.19	0.47	-0.17
1928	0.05	-0.35	0.81	-0.62	0.46	0.07	1975	-1.00	-1.10	-1.28	-0.85	-1.16	-1.10
1929	-0.65	-2.07	-0.62	0.30	-0.86	-0.81	1976	-0.64	0.23	-0.26	-0.60	-1.19	-0.46
1930	-0.74	-0.48	-0.30	0.15	-1.26	-0.47	1977	0.33	-1.36	-0.78	0.90	0.79	-0.11
1931	-0.09	-0.76	-0.55	0.50	0.47	-0.08	1978	0.39	2.11	0.82	-0.44	0.81	0.83
1932	-0.73	-1.62	-0.41	-0.06	-0.94	-0.76	1979	-0.72	-2.18	-0.12	-0.79	-0.59	-0.92
1933	-0.54	-3.72	-1.59	0.61	1.04	-0.91	1980	0.45	2.01	-0.83	0.01	-0.55	0.16
1934	1.11	1.98	1.95	0.43	0.16	1.13	1981	1.22	2.19	1.11	1.03	1.14	1.37
1935	0.31	1.43	0.06	0.43	-0.36	0.39	1982	0.34	0.83	0.31	0.18	0.24	0.39
1936	0.52	0.70	0.56	1.10	-0.41	0.49	1983	0.82	1.75	-0.40	0.32	1.38	0.76
1937	-0.05	-2.26	0.05	0.40	0.99	-0.21	1984	0.16	-0.53	0.11	0.55	0.32	0.11
1938	0.38	1.95	0.35	0.20	-0.50	0.50	1985	0.43	0.74	1.38	0.16	0.15	0.61
1939	-0.10	-1.24	0.67	-0.27	0.41	-0.11	1986	1.06	1.96	1.35	0.54	0.07	0.98
1940	0.85	1.00	0.97	0.37	0.75	0.77	1987	0.07	0.94	0.13	-0.48	0.14	0.18
1941	0.77	2.29	0.86	-0.49	0.47	0.78	1988	-0.00	-0.54	-0.28	0.78	0.26	0.05
1942	-0.14	-0.01	-0.67	-0.31	0.48	-0.13	1989	-0.04	-0.80	1.70	-0.28	-0.63	-0.00
1943	0.75	1.58	1.04	0.73	-0.03	0.83	1990	0.33	-0.40	1.37	0.28	0.69	0.48
1944	-0.19	0.16	-0.86	-0.63	0.86	-0.12	1991	-0.05	-0.96	-0.39	-0.16	0.15	-0.34
1945	-0.01	1.28	-0.75	-0.07	0.08	0.14	1992		0.31	2.04	-0.69		
1946	0.37	-1.39	0.89	0.53	0.08	0.03							

^aCalendar year mean (January–December).^bSeasonal year mean, calculated from four seasons in the following sequence: Win (December–February), Spr (March–May), Sum (June–August), and Fall (September–November).

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Temperature

U.S. national and regional temperature anomalies

T.R. Karl, D.R. Easterling, R.W. Knight, and P.Y. Hughes (continued)

NORTHERN STEPPES

Annual mean temperature anomalies.

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U.S. national and regional temperature anomalies

T.R. Karl, D.R. Easterling, R.W. Knight, and P.Y. Hughes (continued)

NORTHERN STEPPES

Annual and Seasonal Mean Temperature Anomalies (°C)

CY ^a							SY ^b						
Year	mean	Win	Spr	Sum	Fall	mean	Year	mean	Win	Spr	Sum	Fall	mean
1900	0.83		1.38	0.62	0.12		1947	0.14	0.67	-0.76	-0.03	0.52	0.10
1901	0.29	-0.17	0.75	0.64	0.57	0.45	1948	-0.23	0.55	-0.45	0.19	0.37	0.17
1902	-0.13	0.78	0.63	-0.70	-0.72	-0.01	1949	-0.67	-4.77	0.86	0.17	0.95	-0.70
1903	-0.52	-0.97	-0.94	-0.31	-0.78	-0.75	1950	-1.01	-2.42	-1.78	-1.57	0.18	-1.40
1904	-0.26	0.31	-0.55	-0.98	0.37	-0.21	1951	-1.57	0.29	-2.34	-1.36	-0.96	-1.09
1905	-0.62	-1.57	0.52	-0.37	-0.60	-0.51	1952	-0.13	-1.02	-0.41	-0.13	-0.67	-0.56
1906	-0.27	0.61	-1.26	-1.18	-0.13	-0.49	1953	1.12	3.24	-0.78	0.40	1.51	1.09
1907	-0.48	0.59	-0.72	-1.16	-0.23	-0.38	1954	0.65	2.29	-1.41	0.21	1.33	0.61
1908	-0.25	1.03	-0.40	-1.09	-0.24	-0.18	1955	-0.78	0.14	-1.07	0.41	-1.44	-0.49
1909	-0.77	-0.38	-1.69	0.50	0.42	-0.29	1956	0.07	-0.81	-0.41	0.19	0.25	-0.20
1910	0.54	-2.93	2.37	-0.31	0.74	-0.03	1957	0.20	-0.60	0.08	0.36	0.18	0.01
1911	-0.67	-0.28	0.50	-0.52	-1.37	-0.42	1958	0.65	3.23	0.42	-0.28	0.32	0.92
1912	-0.81	-0.89	-1.93	-0.77	-0.65	-1.06	1959	-0.26	-0.66	-0.10	0.30	-1.40	-0.46
1913	-0.78	-1.77	-0.86	0.13	0.10	-0.60	1960	-0.12	0.74	-0.46	0.06	0.34	0.17
1914	0.04	0.07	0.51	-0.13	0.96	0.35	1961	0.45	2.29	0.46	1.15	-1.40	0.63
1915	-0.02	-1.22	0.52	-1.67	0.52	-0.46	1962	0.16	-1.29	-0.12	-0.62	1.33	-0.18
1916	-1.66	-2.77	-0.05	-0.48	-1.30	-1.15	1963	0.72	0.15	0.81	0.70	2.47	1.03
1917	-1.31	-3.46	-2.31	-1.03	0.58	-1.56	1964	-0.39	0.69	-0.67	-0.14	-0.91	-0.26
1918	-0.03	-2.01	0.26	0.29	-0.11	-0.39	1965	-0.30	-0.72	-1.90	-0.16	-0.15	-0.73
1919	-0.26	1.52	-0.11	0.89	-1.93	0.09	1966	-0.31	-0.82	-0.21	0.02	0.22	-0.20
1920	-0.15	0.08	-1.27	-0.36	-0.07	-0.40	1967	0.16	1.95	-0.55	-0.48	0.73	0.41
1921	0.77	2.29	0.11	0.70	0.03	0.78	1968	-0.29	-0.03	-0.19	-0.70	0.07	-0.21
1922	-0.71	-2.49	-0.29	0.43	0.30	-0.51	1969	-0.28	-2.65	-0.08	-0.28	0.17	-0.71
1923	0.00	-0.53	-0.97	0.54	0.27	-0.17	1970	-0.31	1.29	-0.95	0.59	-1.16	-0.06
1924	-1.07	0.41	-1.74	-1.39	0.30	-0.61	1971	-0.27	-0.22	-0.05	-0.02	-0.37	-0.17
1925	0.56	-0.35	1.35	-0.27	-0.92	-0.05	1972	-0.50	-1.57	0.83	-0.11	-0.71	-0.39
1926	0.59	3.29	0.62	-0.22	-0.31	0.84	1973	0.23	-0.76	-0.06	-0.03	0.09	-0.19
1927	-0.72	0.00	-0.25	-1.01	0.16	-0.27	1974	0.25	1.18	0.46	-0.33	-0.28	0.26
1928	-0.08	-1.09	0.29	-1.37	-0.34	-0.63	1975	-0.63	-0.41	-1.47	-0.20	-0.78	-0.72
1929	-1.15	-3.62	-0.33	0.24	-0.86	-1.14	1976	0.36	2.60	0.11	-0.06	-1.00	0.41
1930	0.07	-0.84	0.42	0.46	-0.38	-0.09	1977	0.51	0.98	1.26	0.48	0.18	0.73
1931	0.94	3.42	-0.57	0.97	0.25	1.02	1978	-0.93	-2.54	1.11	-0.49	-0.69	-0.65
1932	-0.26	0.39	-0.34	0.63	-0.15	0.13	1979	-0.61	-5.00	0.09	0.01	0.23	-1.17
1933	0.67	-1.75	-0.01	1.37	1.34	0.24	1980	0.47	0.60	0.47	0.02	0.78	0.47
1934	1.52	3.31	1.87	0.59	0.60	1.59	1981	1.49	3.03	1.81	0.22	1.36	1.61
1935	-0.18	1.23	-1.35	0.13	-0.84	-0.21	1982	-0.68	-1.73	-0.61	-0.01	-0.49	-0.71
1936	-0.32	-4.12	0.59	2.21	0.17	-0.29	1983	0.45	3.82	-0.33	0.99	0.65	1.28
1937	-0.54	-3.68	0.18	0.73	0.83	-0.49	1984	0.34	-0.61	0.32	0.68	-0.82	-0.11
1938	0.90	0.52	0.91	0.48	1.22	0.78	1985	-0.87	-2.24	1.39	-0.37	-2.91	-1.03
1939	0.62	0.22	0.88	-0.30	0.71	0.38	1986	1.21	1.53	1.98	0.39	-0.05	0.96
1940	0.94	0.76	1.18	0.94	1.32	1.05	1987	1.21	3.10	1.94	-0.07	0.10	1.27
1941	1.02	2.28	1.12	0.73	0.36	1.12	1988	0.70	-0.00	0.87	1.51	0.45	0.70
1942	0.05	0.00	0.40	-0.37	0.12	0.04	1989	-0.07	-0.76	0.07	0.31	0.77	0.10
1943	-0.22	0.55	-1.17	-0.13	-0.09	-0.21	1990	0.67	1.72	0.51	0.31	1.21	0.94
1944	-0.35	0.99	-0.69	-0.89	0.04	-0.14	1991	1.07	0.18	1.20	0.94	-0.46	0.46
1945	-0.36	0.65	-0.92	-0.69	-0.32	-0.32	1992		4.10	1.90	-0.98		
1946	0.71	1.15	1.49	-0.14	-0.69	0.45							

^aCalendar year mean (January–December).^bSeasonal year mean, calculated from four seasons in the following sequence: Win (December–February), Spr (March–May), Sum (June–August), and Fall (September–November).

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Temperature

U.S. national and regional temperature anomalies

T.R. Karl, D.R. Easterling, R.W. Knight, and P.Y. Hughes (continued)

SOUTHERN STEPPES

Annual mean temperature anomalies.

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U.S. national and regional temperature anomalies

T.R. Karl, D.R. Easterling, R.W. Knight, and P.Y. Hughes (continued)

SOUTHERN STEPPES

Annual and Seasonal Mean Temperature Anomalies (°C)

Year	CY ^a mean	Win	Spr	Sum	Fall	SY ^b mean	Year	CY ^a mean	Win	Spr	Sum	Fall	SY ^b mean
1900	0.18		0.24	-0.21	0.79		1947	-0.20	0.20	-0.99	0.02	0.58	-0.05
1901	-0.29	-0.91	-1.10	0.44	0.63	-0.23	1948	-0.29	-0.58	-0.07	0.18	-0.89	-0.34
1902	0.06	-1.03	0.97	0.01	-0.12	-0.04	1949	-0.03	-0.25	0.50	-0.16	0.09	0.05
1903	-1.02	-0.68	-0.76	-1.01	-1.26	-0.93	1950	-0.22	0.84	-0.76	-0.65	0.13	-0.11
1904	-0.52	-0.97	-0.09	-1.01	-0.07	-0.54	1951	-0.37	-0.42	-0.88	0.40	-0.85	-0.44
1905	-0.67	-2.82	1.03	-0.50	0.02	-0.57	1952	0.20	1.49	-0.70	1.46	-1.49	0.19
1906	-0.76	-0.75	-1.24	-1.70	-1.10	-1.20	1953	0.74	1.11	0.19	1.24	0.48	0.75
1907	-0.11	2.07	-0.64	-0.74	-0.32	0.09	1954	1.27	1.39	0.34	1.56	1.43	1.18
1908	-0.28	0.65	0.16	-0.75	-1.28	-0.30	1955	0.08	0.26	0.56	0.06	-0.27	0.15
1909	-0.46	0.59	-1.54	0.43	0.17	-0.09	1956	0.31	-0.08	0.19	0.73	0.04	0.22
1910	-0.12	-1.91	0.48	-0.19	0.03	-0.40	1957	0.57	1.92	0.13	0.50	-0.47	0.52
1911	0.30	0.97	0.93	0.15	-0.12	0.48	1958	0.33	1.15	-0.42	0.50	0.79	0.51
1912	-1.35	-2.52	-1.07	-1.09	-1.01	-1.42	1959	-0.28	-0.50	-0.21	0.13	-1.45	-0.51
1913	-0.52	-1.98	-0.78	-0.12	0.22	-0.66	1960	-0.28	-0.04	-0.83	-0.11	0.61	-0.09
1914	-0.02	0.44	-0.27	0.12	0.42	0.18	1961	-0.52	-0.08	-0.24	-0.77	-0.75	-0.46
1915	-0.57	-0.41	-1.01	-1.72	0.07	-0.77	1962	0.29	-0.58	0.24	-0.30	1.14	0.13
1916	-0.52	-0.01	0.01	-0.33	-1.05	-0.34	1963	0.48	-1.20	1.68	0.94	1.85	0.82
1917	-1.26	-0.91	-2.14	-0.89	-0.89	-1.21	1964	0.01	-1.55	-0.11	0.40	0.39	-0.22
1918	-0.23	-2.38	0.41	0.54	-0.29	-0.43	1965	0.39	0.29	-0.36	-0.10	0.77	0.15
1919	-0.50	-0.77	0.18	-0.89	-0.04	-0.38	1966	-0.47	-0.43	-0.02	0.47	-0.23	-0.05
1920	-0.61	-0.19	-1.27	-1.27	-0.13	-0.72	1967	0.05	-0.72	1.31	-0.60	-0.39	-0.10
1921	0.49	1.00	0.40	-0.07	0.19	0.38	1968	-0.29	0.18	-0.30	-0.25	-0.43	-0.20
1922	-0.14	-0.59	-0.18	-0.00	0.23	-0.14	1969	0.51	0.84	-0.38	0.56	0.08	0.28
1923	0.05	0.79	-0.81	0.13	0.05	0.04	1970	-0.24	0.57	-0.67	0.02	-0.83	-0.23
1924	-1.18	-0.29	-2.38	-0.07	-0.43	-0.79	1971	0.15	0.29	-0.57	-0.08	0.60	0.06
1925	0.20	-1.57	1.40	0.50	-0.51	-0.04	1972	0.06	0.60	1.14	-0.19	0.07	0.40
1926	-0.27	0.31	-0.79	-0.98	0.25	-0.30	1973	-0.02	-0.36	-0.28	-0.70	0.82	-0.13
1927	0.05	0.78	0.54	-0.78	0.50	0.26	1974	0.09	-0.43	1.68	-0.47	-0.37	0.10
1928	-0.27	-0.77	-0.49	-0.72	-0.22	-0.55	1975	-0.42	-0.08	-0.67	-0.45	-1.03	-0.56
1929	-0.77	-1.54	0.21	-0.18	-1.23	-0.69	1976	-0.60	1.20	0.09	-0.77	-2.08	-0.39
1930	-0.21	-1.11	-0.30	0.15	0.50	-0.19	1977	0.73	-0.98	1.37	0.99	0.84	0.55
1931	0.56	1.27	-1.83	-0.07	2.01	0.35	1978	-0.08	-1.58	0.63	0.46	1.01	0.13
1932	-0.39	1.93	-0.88	0.36	-1.44	-0.01	1979	-0.64	-2.44	0.34	-0.62	-0.66	-0.85
1933	0.66	-1.24	-0.23	0.61	1.75	0.22	1980	0.36	0.56	-1.05	1.62	-0.22	0.23
1934	1.22	1.59	0.73	2.02	1.02	1.34	1981	1.02	1.41	1.49	0.55	1.08	1.14
1935	0.81	1.68	1.05	0.63	-0.07	0.82	1982	-0.02	-0.46	0.37	0.01	-0.01	-0.02
1936	0.21	-1.24	0.91	1.05	-0.24	0.12	1983	-0.14	1.14	-1.27	-0.01	1.57	0.36
1937	0.19	-0.35	0.23	1.04	0.28	0.30	1984	0.11	-1.89	-0.53	0.25	0.01	-0.54
1938	0.87	1.62	1.23	0.62	0.00	0.87	1985	0.16	0.22	1.88	-0.22	0.31	0.55
1939	0.32	0.30	0.58	0.08	0.13	0.27	1986	0.98	0.61	1.59	0.29	0.38	0.72
1940	-0.09	-0.74	-0.00	-0.50	0.48	-0.19	1987	0.03	1.61	-0.27	-0.24	-0.44	0.17
1941	0.83	2.38	0.70	-0.68	1.08	0.87	1988	-0.53	-0.96	-0.90	-0.09	-0.27	-0.56
1942	-0.26	-0.09	-0.31	-0.26	-0.03	-0.17	1989	-0.55	-0.29	1.04	-0.69	-0.95	-0.22
1943	-0.27	0.73	-0.56	0.93	-1.50	-0.10	1990	0.45	-0.29	0.66	0.23	0.74	0.33
1944	0.09	0.46	-0.91	0.17	0.36	0.02	1991	0.47	-0.15	1.31	0.03	-0.99	0.05
1945	-0.33	0.65	-0.42	-0.74	-0.26	-0.19	1992		2.60	0.95	-1.41		
1946	0.83	-0.23	0.92	0.27	0.85	0.45							

^aCalendar year mean (January–December).^bSeasonal year mean, calculated from four seasons in the following sequence: Win (December–February), Spr (March–May), Sum (June–August), and Fall (September–November).

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Temperature

U.S. national and regional temperature anomalies

T.R. Karl, D.R. Easterling, R.W. Knight, and P.Y. Hughes (continued)

NORTHERN PLAINS

Annual mean temperature anomalies.

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U.S. national and regional temperature anomalies

T.R. Karl, D.R. Easterling, R.W. Knight, and P.Y. Hughes (continued)

NORTHERN PLAINS

Annual and Seasonal Mean Temperature Anomalies (°C)

CY ^a						SY ^b							
Year	mean	Win	Spr	Sum	Fall	mean	Year	mean	Win	Spr	Sum	Fall	mean
1900	0.30		0.10	0.47	0.42		1947	0.22	1.07	-1.41	0.48	0.98	0.28
1901	-0.15	0.17	0.36	0.71	-0.68	0.14	1948	-0.13	-0.83	-0.49	0.22	0.99	-0.03
1902	-0.42	0.10	0.80	-1.51	-0.64	-0.31	1949	-0.13	-2.38	0.45	0.82	0.61	-0.13
1903	-1.15	-1.66	0.30	-1.67	-1.35	-1.09	1950	-1.89	-2.72	-2.44	-1.59	-0.35	-1.77
1904	-1.51	-3.98	-1.36	-2.02	0.39	-1.74	1951	-1.40	-1.05	-1.75	-1.07	-1.51	-1.34
1905	-0.79	-3.08	-0.06	-0.64	0.01	-0.94	1952	0.23	0.08	-0.34	0.23	-0.85	-0.22
1906	-0.18	1.30	-0.78	-1.04	0.35	-0.04	1953	1.15	2.70	-0.30	0.83	1.54	1.19
1907	-1.43	-1.24	-2.88	-1.15	-1.31	-1.65	1954	1.01	2.66	-1.26	0.68	1.41	0.87
1908	0.24	2.35	-0.57	-1.18	0.88	0.37	1955	-0.29	0.97	0.52	1.40	-1.52	0.34
1909	-0.69	0.17	-1.79	0.51	-0.14	-0.31	1956	-0.25	-2.23	-1.52	0.36	0.31	-0.77
1910	-0.34	-2.64	1.55	-0.98	-0.39	-0.61	1957	0.48	0.17	-0.07	0.74	0.48	0.33
1911	-0.47	-0.99	0.84	-0.57	-2.00	-0.68	1958	0.05	2.58	0.48	-1.24	0.49	0.58
1912	-1.34	-2.16	-1.53	-1.36	-0.26	-1.33	1959	0.02	-2.51	0.54	0.95	-1.72	-0.69
1913	-0.25	-1.01	-1.22	0.18	0.26	-0.45	1960	-0.35	2.27	-1.92	-0.11	0.55	0.20
1914	-0.17	1.00	0.09	0.09	1.06	0.56	1961	0.21	1.40	-0.10	0.19	-0.04	0.36
1915	-0.10	-0.41	0.09	-2.72	0.60	-0.61	1962	0.14	-1.49	-0.10	-0.18	1.16	-0.15
1916	-1.65	-2.04	-1.04	0.07	-1.19	-1.05	1963	0.64	-1.04	1.17	1.10	2.88	1.03
1917	-2.33	-5.07	-1.84	-1.68	-0.69	-2.32	1964	0.07	1.04	-0.21	-0.06	-0.52	0.06
1918	-0.13	-3.98	0.67	-0.22	-0.33	-0.96	1965	-0.56	-2.65	-1.50	-0.15	-0.65	-1.23
1919	-0.15	3.15	-0.18	0.89	-1.90	0.49	1966	-0.79	-0.71	-0.41	0.33	-0.88	-0.42
1920	-0.07	-1.31	-1.40	-0.61	1.26	-0.51	1967	-0.53	-0.29	-0.66	-1.21	-0.12	-0.57
1921	1.34	3.53	0.87	1.36	-0.26	1.37	1968	0.13	0.31	0.30	-0.26	0.87	0.30
1922	0.16	-1.32	1.27	0.02	1.78	0.44	1969	-0.23	-0.92	-0.71	-0.51	0.24	-0.48
1923	0.01	-1.04	-2.08	0.36	0.82	-0.49	1970	-0.40	-0.50	-0.90	0.64	0.28	-0.12
1924	-1.39	0.88	-1.55	-1.80	0.20	-0.57	1971	-0.05	-1.40	-0.36	-0.07	1.17	-0.17
1925	-0.15	-1.27	0.57	-0.62	-1.27	-0.65	1972	-0.74	-1.93	0.46	-0.25	-0.23	-0.49
1926	-0.20	2.62	-0.64	-0.82	-1.21	-0.01	1973	1.40	1.04	1.61	0.72	1.22	1.15
1927	-0.49	0.57	0.80	-1.85	0.09	-0.10	1974	0.24	0.20	0.22	-0.23	-0.30	-0.03
1928	0.21	-0.50	-0.69	-1.19	-0.24	-0.65	1975	0.18	1.53	-1.07	0.72	0.10	0.32
1929	-1.43	-2.95	0.09	-0.76	-0.90	-1.13	1976	-0.13	2.58	0.41	0.43	-2.43	0.25
1930	0.54	0.35	0.32	0.50	-0.09	0.27	1977	0.77	-1.63	3.79	0.00	0.39	0.64
1931	2.28	5.54	-0.50	1.11	2.38	2.13	1978	-0.85	-3.64	0.59	-0.01	0.15	-0.73
1932	-0.25	2.39	-0.52	0.88	-1.51	0.31	1979	-1.02	-5.21	-1.20	0.00	0.07	-1.58
1933	0.37	-0.09	0.27	1.07	0.04	0.32	1980	0.47	1.68	0.10	0.49	0.61	0.72
1934	0.98	1.54	0.78	0.48	0.90	0.93	1981	1.40	2.71	1.56	0.48	1.07	1.45
1935	0.10	1.35	-0.16	0.63	-1.76	0.01	1982	-0.36	-2.45	0.22	-0.46	0.09	-0.65
1936	-1.09	-5.92	0.11	1.68	-0.54	-1.17	1983	1.17	5.23	0.08	1.88	1.53	2.18
1937	-0.72	-2.86	0.10	1.13	-0.44	-0.52	1984	0.80	0.31	-0.26	0.85	-0.01	0.22
1938	1.04	0.05	1.39	0.74	0.99	0.79	1985	-0.67	-1.07	2.66	-1.25	-1.71	-0.34
1939	0.53	0.30	0.20	0.21	0.29	0.25	1986	1.33	-0.07	2.25	0.38	-0.12	0.61
1940	0.16	1.05	-0.92	0.30	0.91	0.34	1987	2.54	5.60	2.94	0.82	0.42	2.45
1941	1.63	1.91	1.91	0.91	1.36	1.52	1988	0.42	0.31	1.21	1.70	-0.39	0.71
1942	0.53	3.21	1.42	-0.12	-0.48	1.01	1989	-0.64	0.04	-0.38	0.41	-0.80	-0.19
1943	-0.48	-1.24	-1.90	0.80	-0.57	-0.73	1990	1.06	1.75	0.67	0.53	0.65	0.90
1944	0.69	2.62	-0.47	-0.03	1.04	0.79	1991	1.35	0.63	2.55	1.57	-1.24	0.88
1945	-0.39	1.46	-0.12	-1.09	-0.80	-0.14	1992		5.66	1.18	-1.91		
1946	0.55	-0.29	2.06	-0.43	-0.35	0.25							

^aCalendar year mean (January–December).^bSeasonal year mean, calculated from four seasons in the following sequence: Win (December–February), Spr (March–May), Sum (June–August), and Fall (September–November).

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SOUTHERN PLAINS

Annual mean temperature anomalies.

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U.S. national and regional temperature anomalies

T.R. Karl, D.R. Easterling, R.W. Knight, and P.Y. Hughes (continued)

SOUTHERN PLAINS

Annual and Seasonal Mean Temperature Anomalies (°C)

Year	CY ^a mean	Win	Spr	Sum	Fall	SY ^b mean	Year	CY ^a mean	Win	Spr	Sum	Fall	SY ^b mean
1900	0.27		0.01	0.09	1.03		1947	0.13	0.52	-1.40	0.32	1.59	0.25
1901	-0.49	-0.07	-1.15	0.64	-0.27	-0.22	1948	-0.21	-0.31	0.18	-0.05	-0.55	-0.18
1902	-0.46	-2.21	0.91	-0.71	-0.06	-0.52	1949	0.06	-0.30	0.57	0.48	-0.41	0.08
1903	-1.02	-0.89	0.13	-1.74	-1.40	-0.98	1950	-0.84	0.62	-1.25	-1.37	-0.45	-0.61
1904	-1.17	-1.83	-1.32	-1.63	-0.28	-1.27	1951	-0.77	-0.52	-1.31	-0.32	-1.28	-0.86
1905	-1.04	-4.02	0.76	-0.58	-0.29	-1.03	1952	-0.01	1.49	-1.02	1.22	-2.22	-0.13
1906	-0.51	0.09	-1.06	-1.66	-0.53	-0.79	1953	0.70	1.71	-0.09	0.81	0.19	0.66
1907	-0.34	1.56	-1.12	-0.54	-1.02	-0.28	1954	1.09	1.60	-0.34	1.79	1.20	1.06
1908	0.13	1.43	0.62	-0.89	-0.47	0.17	1955	0.00	0.42	1.06	0.25	-0.83	0.23
1909	-0.50	0.80	-1.54	0.22	0.48	-0.01	1956	0.30	-0.59	-0.20	0.61	0.24	0.02
1910	-0.40	-2.35	0.67	-0.98	-0.26	-0.73	1957	0.36	1.14	0.22	0.55	-0.81	0.28
1911	0.45	0.99	0.40	0.12	-0.22	0.32	1958	-0.25	0.53	-0.54	-0.27	0.66	0.10
1912	-1.21	-2.15	-1.07	-0.87	-0.56	-1.16	1959	-0.12	-1.12	0.53	0.18	-1.57	-0.49
1913	0.15	-1.00	-0.75	0.51	0.89	-0.09	1960	-0.53	0.62	-1.89	-0.23	0.63	-0.22
1914	0.29	1.43	-0.16	1.05	1.01	0.83	1961	-0.52	-0.05	-0.52	-0.78	-0.34	-0.42
1915	-0.15	-0.18	-0.61	-2.05	0.80	-0.51	1962	0.10	-1.03	0.18	-0.24	0.84	-0.06
1916	-0.68	-0.43	-0.18	-0.23	-0.62	-0.36	1963	0.17	-1.99	1.55	0.90	1.87	0.58
1917	-1.79	-1.88	-1.75	-1.46	-1.58	-1.67	1964	0.08	-1.31	0.37	0.01	0.00	-0.23
1918	-0.21	-4.07	0.48	0.55	-0.19	-0.81	1965	0.16	-0.65	-0.46	-0.26	0.46	-0.23
1919	-0.14	1.43	-0.13	0.07	-0.06	0.33	1966	-0.71	0.25	-0.72	-0.07	-0.75	-0.32
1920	-0.24	-0.46	-0.83	-1.33	0.41	-0.55	1967	-0.32	-0.34	0.78	-1.43	-0.94	-0.48
1921	1.39	2.68	1.35	0.86	0.60	1.37	1968	-0.38	0.04	-0.39	0.13	-0.44	-0.17
1922	0.29	0.05	0.76	-0.02	0.66	0.36	1969	-0.07	0.00	-0.62	-0.04	-0.30	-0.24
1923	0.25	0.90	-1.33	0.46	0.03	0.01	1970	-0.08	-0.60	-0.00	0.10	-0.11	-0.15
1924	-1.24	0.23	-2.02	-0.38	-0.41	-0.65	1971	0.15	-0.21	-0.85	-0.22	1.24	-0.01
1925	0.16	-0.98	0.87	0.32	-0.61	-0.10	1972	-0.19	0.81	0.41	-0.52	0.33	0.26
1926	0.03	1.38	-1.24	-0.55	0.23	-0.04	1973	0.78	-0.15	0.71	0.05	1.90	0.63
1927	0.25	1.42	1.16	-1.38	0.94	0.53	1974	0.27	0.32	1.73	-0.76	-0.51	0.20
1928	0.05	-0.07	-0.51	-0.60	-0.19	-0.34	1975	0.04	0.65	-0.47	0.08	-0.38	-0.03
1929	-0.65	-2.01	0.80	-0.23	-0.90	-0.59	1976	-0.71	1.94	0.21	-0.87	-2.74	-0.37
1930	0.08	0.05	-0.03	-0.10	0.29	0.05	1977	0.66	-2.39	2.56	0.83	1.04	0.51
1931	1.42	2.52	-1.60	0.32	3.27	1.13	1978	-0.79	-3.63	-0.09	0.30	0.48	-0.74
1932	-0.16	3.28	-0.61	0.72	-1.86	0.38	1979	-1.15	-4.35	-0.09	-0.35	-0.72	-1.38
1933	0.89	0.12	0.26	0.63	1.04	0.51	1980	0.22	0.28	-0.85	1.66	-0.13	0.24
1934	1.01	1.67	-0.05	2.40	0.79	1.20	1981	0.64	0.82	1.15	0.58	0.43	0.75
1935	0.59	1.51	0.66	0.58	-0.34	0.60	1982	-0.37	-1.91	0.06	-0.26	-0.23	-0.58
1936	0.00	-3.24	0.50	1.75	0.12	-0.22	1983	0.06	2.52	-1.06	0.82	1.30	0.89
1937	-0.24	-0.33	-0.30	1.07	-0.61	-0.04	1984	0.13	-1.83	-0.94	-0.01	0.07	-0.68
1938	1.14	1.57	1.71	0.75	0.40	1.11	1985	-0.50	-1.09	1.92	-0.82	0.07	0.02
1939	0.73	0.78	0.54	0.41	0.63	0.59	1986	1.04	-0.28	1.56	0.49	0.51	0.57
1940	-0.57	-1.53	-0.62	-0.25	0.11	-0.57	1987	0.87	2.26	1.22	0.45	-0.56	0.84
1941	1.22	1.88	0.83	0.22	1.70	1.16	1988	-0.39	-0.50	-0.40	0.33	-0.58	-0.29
1942	0.25	0.88	0.64	0.16	0.18	0.46	1989	-0.99	0.00	-0.16	-0.68	-0.97	-0.45
1943	-0.27	0.46	-0.87	1.35	-1.54	-0.15	1990	0.76	0.11	0.32	0.36	0.86	0.41
1944	0.48	1.07	-0.34	0.35	0.85	0.48	1991	0.84	-0.05	2.18	0.46	-0.88	0.43
1945	-0.15	0.66	0.43	-0.97	-0.05	0.02	1992		3.91	0.44	-1.74		
1946	1.20	0.43	1.88	-0.02	0.61	0.73							

^aCalendar year mean (January–December).^bSeasonal year mean, calculated from four seasons in the following sequence: Win (December–February), Spr (March–May), Sum (June–August), and Fall (September–November).

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SOUTH COASTAL PLAIN

Annual mean temperature anomalies.

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U.S. national and regional temperature anomalies

T.R. Karl, D.R. Easterling, R.W. Knight, and P.Y. Hughes (continued)

SOUTH COASTAL PLAIN

Annual and Seasonal Mean Temperature Anomalies (°C)

Year	cy ^a					sy ^b mean	Year	cy ^a					sy ^b mean
	mean	Win	Spr	Sum	Fall			mean	Win	Spr	Sum	Fall	
1900	0.52		0.07	0.53	2.10		1947	-0.08	-0.15	-0.73	-0.28	1.33	0.04
1901	-0.87	-0.18	-1.35	0.31	-1.42	-0.66	1948	0.11	-0.78	1.13	0.08	-0.72	-0.07
1902	0.29	-2.22	1.07	0.77	0.75	0.09	1949	0.82	2.77	0.10	0.27	0.41	0.89
1903	-0.59	0.15	0.83	-0.69	-1.55	-0.32	1950	0.19	3.74	-0.50	-0.60	-0.68	0.49
1904	-0.44	-1.54	-0.22	-0.70	-0.36	-0.71	1951	0.01	-0.77	-0.61	0.50	-0.34	-0.30
1905	0.04	-2.46	1.94	0.32	0.92	0.18	1952	-0.12	2.92	-0.99	0.75	-2.52	0.04
1906	-0.01	-0.95	-0.49	-0.07	0.15	-0.34	1953	0.18	0.78	0.79	0.44	-1.15	0.21
1907	0.53	2.63	0.58	-0.14	-0.46	0.65	1954	0.22	0.50	-0.15	0.71	-0.09	0.24
1908	0.52	0.03	2.54	-0.05	-0.86	0.41	1955	0.05	-0.24	1.43	-0.69	-0.56	-0.02
1909	0.20	1.78	-0.02	0.66	0.13	0.64	1956	0.08	0.36	-0.01	-0.30	-0.80	-0.19
1910	-0.30	-1.79	-0.06	-0.22	0.19	-0.47	1957	0.79	3.29	0.33	0.16	0.18	0.99
1911	1.27	2.17	0.77	0.24	1.02	1.05	1958	-0.60	-1.91	-0.37	0.31	0.55	-0.36
1912	-0.39	-1.40	0.31	-0.18	-0.02	-0.33	1959	0.03	-1.01	-0.19	0.01	0.43	-0.19
1913	0.08	1.08	-0.58	-0.25	-0.08	0.04	1960	-0.65	-0.46	-1.89	0.04	0.65	-0.41
1914	-0.12	0.21	-0.73	0.67	-0.04	0.03	1961	-0.51	-1.24	-0.50	-1.07	-0.15	-0.74
1915	-0.08	-0.10	-1.00	-0.23	0.84	-0.12	1962	-0.07	0.48	-0.66	0.07	0.36	0.06
1916	-0.02	0.99	-0.18	0.08	-1.04	-0.04	1963	-0.71	-3.06	1.22	0.11	0.06	-0.42
1917	-1.10	0.98	-0.93	-0.57	-2.78	-0.82	1964	-0.17	-2.98	0.36	0.17	-0.14	-0.65
1918	0.19	-1.90	1.06	-0.16	-0.09	-0.27	1965	0.15	0.03	0.19	-0.36	1.00	0.22
1919	0.35	0.43	-0.33	-0.03	2.26	0.58	1966	-0.53	-0.89	-0.23	-0.64	-0.27	-0.51
1920	-0.27	0.19	-0.06	-0.56	-0.61	-0.26	1967	-0.51	-0.72	1.08	-0.91	-2.10	-0.67
1921	0.96	0.89	0.89	0.34	0.96	0.77	1968	-1.01	-1.02	-0.58	-0.30	-0.96	-0.72
1922	0.92	1.83	1.00	-0.27	0.43	0.75	1969	-0.58	-0.71	-1.14	-0.02	-0.75	-0.65
1923	0.33	2.20	-0.37	-0.14	-0.56	0.28	1970	-0.34	-2.18	0.18	-0.22	-0.05	-0.57
1924	-0.77	0.30	-1.40	0.31	-0.91	-0.42	1971	0.08	0.27	-2.03	-0.08	1.02	-0.20
1925	0.54	0.81	0.44	0.44	1.08	0.69	1972	0.07	2.24	-0.10	-0.81	0.45	0.45
1926	-0.13	-0.15	-1.65	-0.27	0.51	-0.39	1973	0.22	-0.72	0.17	-0.22	2.11	0.34
1927	1.12	2.63	1.56	-0.17	1.22	1.31	1974	0.07	1.04	1.11	-1.00	-1.25	-0.02
1928	-0.21	-0.41	-0.63	0.25	0.03	-0.19	1975	0.06	1.02	-0.09	-0.12	-0.28	0.13
1929	0.22	-0.59	1.70	-0.39	0.18	0.23	1976	-1.35	-0.39	-0.36	-1.20	-2.78	-1.18
1930	0.05	0.25	0.17	-0.53	0.39	0.07	1977	-0.12	-3.50	0.72	0.56	1.07	-0.29
1931	0.30	-0.29	-2.25	-0.35	2.16	-0.18	1978	-0.70	-3.30	-0.66	0.45	0.79	-0.68
1932	0.61	4.44	-0.66	0.86	-1.10	0.88	1979	-0.78	-2.17	0.17	-0.23	-0.84	-0.77
1933	1.16	1.91	0.97	-0.11	1.01	0.95	1980	-0.29	-0.82	-0.83	0.75	-0.25	-0.29
1934	0.42	1.36	-0.17	1.12	0.74	0.76	1981	-0.49	-1.66	-0.35	0.73	-0.60	-0.47
1935	0.45	0.32	1.70	0.26	0.37	0.66	1982	0.39	-1.04	0.72	0.22	0.05	-0.01
1936	0.10	-2.26	0.37	0.44	0.33	-0.28	1983	-0.78	0.78	-1.66	0.02	-0.12	-0.25
1937	0.23	2.48	-0.58	0.38	-0.85	0.36	1984	-0.12	-2.19	-0.71	-0.57	0.42	-0.76
1938	0.62	1.51	1.59	0.12	-0.48	0.69	1985	0.21	-0.25	1.08	-0.02	2.62	0.86
1939	0.40	0.79	0.11	0.40	-0.04	0.31	1986	0.74	-0.95	-0.15	0.53	2.24	0.42
1940	-1.07	-2.49	-0.98	-0.34	-1.02	-1.21	1987	-0.30	0.25	-0.54	0.38	-1.54	-0.36
1941	0.31	0.21	-0.57	0.39	1.50	0.38	1988	-0.77	-0.88	-1.42	-0.28	0.25	-0.58
1942	-0.40	-0.97	-0.46	0.16	-0.05	-0.33	1989	-0.37	0.50	-0.18	-0.16	-0.21	-0.01
1943	-0.30	0.26	-0.08	0.93	-1.99	-0.22	1990	0.54	0.21	0.02	0.01	-0.06	0.04
1944	0.26	1.12	0.14	0.28	-0.11	0.36	1991	0.71	0.94	1.95	0.30	-0.76	0.61
1945	0.35	0.01	1.16	-0.08	0.58	0.42	1992		1.36	-0.80	-0.52		
1946	0.74	-0.31	1.27	-0.32	1.00	0.41							

^aCalendar year mean (January–December).^bSeasonal year mean, calculated from four seasons in the following sequence: Win (December–February), Spr (March–May), Sum (June–August), and Fall (September–November).

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Temperature

U.S. national and regional temperature anomalies

T.R. Karl, D.R. Easterling, R.W. Knight, and P.Y. Hughes (continued)

GULF COAST

Annual mean temperature anomalies.

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U.S. national and regional temperature anomalies

T.R. Karl, D.R. Easterling, R.W. Knight, and P.Y. Hughes (continued)

GULF COAST

Annual and Seasonal Mean Temperature Anomalies (°C)

Year	CY ^a					SY ^b	Year	CY ^a					SY ^b
	mean	Win	Spr	Sum	Fall	mean		mean	Win	Spr	Sum	Fall	mean
1900	0.36		0.04	0.25	1.51		1947	-0.21	-0.57	-0.69	-0.01	0.72	-0.14
1901	-0.77	-0.14	-1.70	0.23	-0.77	-0.59	1948	0.16	-0.67	0.87	0.43	-0.60	0.01
1902	0.44	-1.96	1.18	0.62	1.07	0.23	1949	0.88	2.72	0.33	0.08	0.39	0.88
1903	-0.85	0.02	0.04	-0.78	-1.66	-0.60	1950	0.40	4.14	-0.25	-0.18	-0.67	0.76
1904	-0.34	-1.24	-0.09	-0.76	-0.04	-0.53	1951	0.16	-0.88	-0.41	0.69	0.12	-0.12
1905	-0.03	-2.51	1.52	0.08	1.34	0.11	1952	-0.36	2.77	-1.30	0.31	-2.48	-0.18
1906	-0.01	-1.49	-0.46	0.32	0.02	-0.40	1953	0.23	0.21	1.42	0.54	-1.02	0.29
1907	0.83	2.97	1.19	-0.09	0.01	1.02	1954	0.15	0.25	-0.19	0.34	-0.07	0.08
1908	0.57	0.07	2.37	0.11	-0.88	0.42	1955	0.12	0.05	1.20	-0.65	-0.26	0.08
1909	0.38	1.74	0.07	0.62	0.65	0.77	1956	-0.01	0.36	-0.02	-0.36	-0.68	-0.18
1910	-0.07	-1.41	-0.14	-0.10	0.45	-0.30	1957	0.69	3.30	0.44	0.28	-0.55	0.87
1911	1.38	3.00	1.27	0.36	0.62	1.31	1958	-0.51	-2.00	-0.71	0.29	0.93	-0.37
1912	-0.25	-1.43	0.31	-0.05	0.36	-0.20	1959	-0.25	-0.86	-0.59	-0.01	-0.07	-0.38
1913	0.01	0.86	-1.04	-0.42	0.37	-0.06	1960	-0.54	-1.21	-1.36	0.14	0.68	-0.44
1914	-0.10	0.37	-0.69	0.54	0.20	0.11	1961	-0.47	-1.11	-0.30	-0.86	-0.28	-0.64
1915	-0.04	-0.55	-1.41	0.41	0.91	-0.16	1962	-0.01	0.51	-0.89	0.28	0.54	0.11
1916	0.14	1.39	-0.11	0.36	-1.04	0.15	1963	-0.45	-2.66	1.46	0.19	0.39	-0.16
1917	-0.65	1.15	-0.47	-0.17	-2.37	-0.46	1964	-0.14	-2.87	0.51	0.18	0.00	-0.54
1918	0.08	-1.58	0.92	0.05	-0.19	-0.20	1965	0.22	-0.01	0.23	-0.55	1.01	0.17
1919	0.23	-0.08	-0.63	-0.09	2.32	0.38	1966	-0.62	-0.93	0.11	-0.56	-0.37	-0.44
1920	-0.21	0.21	-0.10	-0.26	-0.48	-0.16	1967	-0.29	-1.16	1.48	-0.62	-1.51	-0.45
1921	0.95	0.70	0.70	0.22	1.09	0.68	1968	-0.98	-1.28	-0.39	-0.46	-0.94	-0.77
1922	0.97	1.78	0.85	-0.01	0.74	0.84	1969	-0.35	-0.20	-1.30	0.15	-0.52	-0.47
1923	0.50	2.58	-0.20	-0.01	-0.40	0.49	1970	-0.51	-1.53	-0.38	-0.27	-0.81	-0.75
1924	-0.53	0.12	-1.20	0.25	-0.18	-0.25	1971	0.21	0.99	-1.25	-0.32	0.77	0.05
1925	0.24	0.43	0.36	0.31	0.78	0.47	1972	0.07	2.16	0.49	-0.62	0.08	0.53
1926	-0.09	-0.91	-1.39	0.01	0.45	-0.46	1973	-0.04	-1.66	0.05	-0.31	2.01	0.02
1927	1.15	2.63	1.49	0.12	1.33	1.40	1974	0.03	0.30	1.34	-0.93	-1.08	-0.09
1928	-0.27	-0.51	-1.00	0.40	0.14	-0.24	1975	-0.03	0.62	0.32	-0.21	-0.61	0.03
1929	0.02	-0.65	1.55	-0.29	-0.46	0.04	1976	-1.33	-0.65	-0.01	-1.18	-2.99	-1.21
1930	-0.11	-0.25	-0.13	-0.49	0.44	-0.11	1977	-0.32	-2.92	0.08	0.29	0.70	-0.46
1931	0.05	-0.26	-2.75	-0.54	2.18	-0.34	1978	-0.69	-3.12	-0.46	0.07	0.78	-0.68
1932	0.23	3.94	-1.18	0.65	-1.70	0.43	1979	-0.96	-2.04	0.05	-0.32	-1.35	-0.91
1933	1.26	1.69	1.22	-0.22	1.37	1.02	1980	-0.32	-0.67	-0.61	0.55	-0.69	-0.35
1934	0.39	1.69	-0.58	0.56	1.06	0.68	1981	-0.28	-1.35	0.05	0.45	-0.21	-0.26
1935	0.59	0.64	1.65	0.27	0.41	0.74	1982	0.23	-1.03	0.72	0.18	0.08	-0.01
1936	-0.21	-1.48	-0.07	0.16	-0.28	-0.42	1983	-1.10	-0.14	-1.80	-0.22	-0.33	-0.63
1937	0.18	2.03	-0.95	0.36	-0.62	0.21	1984	-0.07	-2.48	-0.50	-0.69	0.41	-0.82
1938	0.65	1.86	1.60	0.27	-0.76	0.74	1985	0.04	-0.21	1.11	-0.22	2.14	0.70
1939	0.38	0.76	0.28	0.31	-0.16	0.30	1986	0.36	-0.89	-0.28	0.04	1.53	0.10
1940	-0.80	-2.25	-0.80	-0.10	-0.69	-0.96	1987	-0.74	-0.15	-1.63	0.07	-1.59	-0.82
1941	0.47	0.82	-0.60	0.46	1.57	0.56	1988	-0.61	-0.91	-1.17	-0.33	0.46	-0.49
1942	-0.29	-0.71	-0.55	0.28	0.11	-0.22	1989	-0.39	0.90	0.07	-0.23	-0.54	0.05
1943	-0.30	0.27	0.07	0.57	-1.71	-0.20	1990	0.45	-0.13	0.55	-0.06	-0.55	-0.05
1944	0.27	1.03	-0.03	0.43	-0.16	0.32	1991	0.45	0.55	1.82	-0.05	-1.13	0.30
1945	0.53	0.26	1.28	0.49	0.36	0.60	1992		1.34	-0.61	-0.50		
1946	0.73	-0.61	0.97	-0.15	1.51	0.43							

^aCalendar year mean (January–December).^bSeasonal year mean, calculated from four seasons in the following sequence: Win (December–February), Spr (March–May), Sum (June–August), and Fall (September–November).

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GREAT LAKES

Annual mean temperature anomalies.

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U.S. national and regional temperature anomalies

T.R. Karl, D.R. Easterling, R.W. Knight, and P.Y. Hughes (continued)

GREAT LAKES

Annual and Seasonal Mean Temperature Anomalies (°C)

Year	CY ^a mean	Win	Spr	Sum	Fall	SY ^b mean	Year	CY ^a mean	Win	Spr	Sum	Fall	SY ^b mean
1900	0.40		-0.69	0.76	1.33		1947	0.12	0.57	-1.33	0.44	0.99	0.17
1901	-0.39	-0.95	-0.19	1.21	-0.75	-0.17	1948	-0.09	-1.36	-0.01	0.00	0.82	-0.14
1902	0.01	-1.16	0.99	-0.83	0.78	-0.06	1949	0.85	1.87	0.06	1.58	-0.22	0.82
1903	-0.59	-0.32	1.76	-1.36	-1.24	-0.29	1950	-0.96	1.15	-1.82	-1.36	-0.28	-0.58
1904	-1.85	-5.04	-1.08	-1.49	-0.52	-2.03	1951	-0.47	-0.69	0.34	-0.76	-1.51	-0.66
1905	-0.85	-3.51	-0.14	-0.16	-0.72	-1.13	1952	0.56	1.28	0.01	0.80	-1.33	0.19
1906	0.08	1.20	-1.07	0.15	0.29	0.14	1953	1.00	3.09	0.50	0.42	0.39	1.10
1907	-1.08	-0.50	-1.95	-0.98	-1.21	-1.16	1954	0.67	2.59	-0.64	0.22	0.76	0.73
1908	0.03	0.66	0.55	-0.58	0.01	0.16	1955	0.42	0.79	1.08	1.47	-0.58	0.69
1909	-0.29	1.07	-1.04	0.01	-0.39	-0.09	1956	0.04	-0.05	-1.27	0.18	-0.20	-0.33
1910	-0.45	-1.74	0.99	-0.60	-0.51	-0.46	1957	0.21	0.82	0.43	0.23	-0.54	0.23
1911	0.52	0.24	0.56	0.36	-1.05	0.03	1958	-0.50	0.65	0.08	-1.02	0.61	0.08
1912	-1.23	-2.61	-1.31	-0.81	0.34	-1.10	1959	0.23	-3.07	0.56	1.21	-0.61	-0.48
1913	0.28	0.39	-0.62	0.07	0.57	0.10	1960	-0.16	2.63	-1.43	-0.57	0.85	0.37
1914	-0.36	0.66	-0.25	0.05	0.32	0.20	1961	0.25	-0.23	-0.37	-0.17	1.14	0.09
1915	-0.00	0.10	0.04	-1.88	0.73	-0.25	1962	-0.41	-1.24	0.89	-0.70	-0.06	-0.28
1916	-0.65	-0.11	-1.05	0.45	-0.81	-0.38	1963	-1.02	-3.80	-0.12	-0.65	1.32	-0.81
1917	-2.19	-3.43	-1.45	-1.00	-2.21	-2.02	1964	0.20	-0.46	0.90	-0.28	-0.58	-0.11
1918	-0.44	-4.55	0.50	-0.32	-0.51	-1.22	1965	-0.19	-0.94	-0.46	-1.23	0.14	-0.63
1919	0.32	3.28	-0.10	1.00	0.15	1.09	1966	-0.43	0.74	-0.54	0.04	-0.66	-0.11
1920	-0.50	-3.64	-1.10	-0.83	1.18	-1.10	1967	-0.52	-0.11	-0.68	-0.66	-1.02	-0.62
1921	1.99	3.30	2.53	1.84	0.76	2.11	1968	0.19	-0.40	0.71	0.11	0.97	0.35
1922	0.47	-0.16	1.55	-0.10	1.25	0.64	1969	-0.15	0.39	-0.48	-0.29	-0.33	-0.18
1923	-0.34	-0.72	-2.39	-0.11	-0.22	-0.86	1970	0.06	-1.64	0.25	0.45	1.14	0.05
1924	-1.41	0.68	-1.23	-1.32	-0.73	-0.65	1971	0.04	-0.64	-1.50	-0.41	2.00	-0.14
1925	-0.46	-1.00	-0.48	-0.06	-1.11	-0.66	1972	-0.73	-0.43	-0.86	-0.60	-0.18	-0.52
1926	-0.98	0.32	-2.66	-0.73	-0.69	-0.94	1973	1.59	1.18	2.00	1.48	1.56	1.55
1927	0.07	0.33	0.83	-2.24	1.19	0.03	1974	0.07	0.15	0.37	-0.24	-0.74	-0.11
1928	0.02	0.40	-1.20	-0.48	0.07	-0.30	1975	0.60	2.21	-0.57	0.87	0.45	0.74
1929	-1.06	-1.84	0.77	-1.21	-1.09	-0.84	1976	-1.05	0.73	0.49	-0.29	-2.97	-0.51
1930	0.15	0.57	0.02	-0.17	-0.10	0.08	1977	0.16	-4.16	2.94	-0.19	0.55	-0.22
1931	2.14	2.99	-0.16	0.98	3.27	1.77	1978	-0.94	-3.27	-0.81	-0.05	0.25	-0.97
1932	0.28	5.00	-1.31	0.37	-1.09	0.74	1979	-0.67	-3.52	-0.07	-0.26	0.10	-0.94
1933	0.58	1.40	0.73	0.69	-0.51	0.58	1980	-0.22	0.55	-0.16	0.54	-0.66	0.07
1934	0.09	-0.40	-0.75	0.55	1.23	0.16	1981	0.31	-0.04	0.54	0.58	-0.36	0.18
1935	0.00	-0.01	-0.34	0.82	-0.50	-0.01	1982	-0.27	-2.13	0.12	-0.99	0.49	-0.63
1936	-0.64	-3.37	0.28	0.12	-0.58	-0.89	1983	0.79	4.15	-0.05	1.46	0.82	1.60
1937	-0.15	1.03	-0.49	0.85	-1.13	0.06	1984	0.41	-0.60	-1.07	0.59	0.39	-0.17
1938	1.10	1.14	1.53	0.71	0.40	0.94	1985	-0.12	-0.33	2.12	-0.92	0.84	0.43
1939	0.54	1.04	-0.31	0.63	-0.02	0.33	1986	0.79	-1.07	1.68	-0.08	0.23	0.19
1940	-0.36	0.61	-1.64	0.38	-0.38	-0.26	1987	1.75	2.98	2.01	1.58	0.01	1.64
1941	1.08	1.46	0.39	0.32	1.51	0.92	1988	0.06	0.44	0.47	1.13	-0.35	0.42
1942	0.38	1.70	1.71	0.34	-0.21	0.89	1989	-0.64	0.75	-0.72	0.37	-0.89	-0.12
1943	-0.62	-0.99	-1.62	1.26	-1.46	-0.70	1990	1.33	0.73	1.03	0.45	0.70	0.73
1944	0.61	1.54	-0.01	0.60	0.74	0.72	1991	1.30	1.37	2.92	1.21	-0.55	1.24
1945	-0.32	-1.26	1.28	-0.99	-0.17	-0.28	1992		3.34	0.06	-1.58		
1946	0.47	-0.34	1.45	-1.01	0.54	0.16							

^aCalendar year mean (January–December).^bSeasonal year mean, calculated from four seasons in the following sequence: Win (December–February), Spr (March–May), Sum (June–August), and Fall (September–November).

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Temperature

U.S. national and regional temperature anomalies

T.R. Karl, D.R. Easterling, R.W. Knight, and P.Y. Hughes (continued)

EASTERN PRAIRIES

Annual mean temperature anomalies.

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U.S. national and regional temperature anomalies

T.R. Karl, D.R. Easterling, R.W. Knight, and P.Y. Hughes (continued)

EASTERN PRAIRIES

Annual and Seasonal Mean Temperature Anomalies (°C)

Year	CY ^a mean	Win	Spr	Sum	Fall	SY ^b mean	Year	CY ^a mean	Win	Spr	Sum	Fall	SY ^b mean
1900	0.74		-0.40	1.32	2.06		1947	-0.14	0.44	-1.51	0.13	1.06	0.03
1901	-0.58	-0.29	-0.78	1.20	-1.33	-0.30	1948	-0.02	-1.23	0.80	-0.26	0.02	-0.17
1902	0.06	-2.51	0.94	-0.27	1.26	-0.14	1949	0.85	2.77	-0.16	1.26	-0.29	0.90
1903	-0.52	-0.07	1.67	-0.93	-1.36	-0.17	1950	-0.34	2.76	-0.96	-1.15	-0.31	0.09
1904	-1.10	-3.23	-0.64	-0.92	-0.70	-1.37	1951	-0.35	-0.68	-0.56	-0.12	-1.31	-0.66
1905	-0.24	-3.22	1.43	0.41	-0.09	-0.37	1952	0.31	2.14	-0.26	0.88	-2.21	0.14
1906	0.24	0.39	-0.73	0.22	0.62	0.13	1953	0.41	2.58	0.63	0.33	-1.14	0.60
1907	-0.12	1.68	-0.55	-0.52	-1.00	-0.10	1954	0.69	1.54	-0.41	0.76	0.55	0.61
1908	0.40	0.73	1.87	-0.28	-0.65	0.42	1955	0.18	0.55	1.34	0.24	-0.63	0.38
1909	0.08	2.05	-0.41	0.34	0.11	0.52	1956	0.28	0.18	-0.30	-0.06	-0.63	-0.20
1910	-0.51	-2.04	0.44	-0.76	-0.14	-0.62	1957	0.51	2.33	0.69	0.12	-0.48	0.66
1911	1.02	1.08	0.30	0.15	0.71	0.56	1958	-0.91	-0.75	-0.47	-0.34	0.05	-0.38
1912	-0.80	-1.99	0.01	-0.42	0.02	-0.59	1959	0.26	-1.87	0.56	0.41	-0.33	-0.31
1913	0.64	0.77	-0.19	0.50	0.75	0.46	1960	-0.71	1.52	-2.46	-0.30	0.46	-0.20
1914	0.03	0.91	-0.31	0.75	0.32	0.41	1961	-0.29	-1.27	-0.75	-0.77	0.54	-0.56
1915	0.13	0.12	-0.52	-0.97	1.13	-0.06	1962	-0.36	-0.34	0.32	-0.50	0.04	-0.12
1916	-0.32	0.54	-0.33	0.27	-1.03	-0.14	1963	-1.39	-4.28	0.56	-0.88	0.03	-1.14
1917	-1.75	-1.29	-1.28	-0.91	-2.25	-1.43	1964	-0.15	-2.45	0.83	-0.16	-1.07	-0.71
1918	-0.18	-4.57	1.11	-0.02	-0.53	-1.00	1965	0.10	-0.25	0.18	-0.69	0.48	-0.07
1919	0.46	2.07	-0.06	0.59	1.49	1.02	1966	-0.74	0.02	-0.75	-0.59	-0.90	-0.56
1920	-0.36	-1.47	-0.68	-0.90	0.33	-0.68	1967	-0.52	-0.10	0.47	-1.20	-1.60	-0.61
1921	1.79	2.47	1.95	1.24	1.21	1.72	1968	-0.58	-1.36	-0.31	0.17	-0.05	-0.39
1922	0.72	1.19	1.70	-0.26	0.59	0.81	1969	-0.60	-0.16	-1.10	-0.12	-0.86	-0.56
1923	0.12	1.02	-1.39	-0.04	-0.43	-0.21	1970	-0.04	-2.33	0.31	-0.17	1.14	-0.26
1924	-1.15	0.69	-1.49	-0.59	-0.82	-0.55	1971	0.08	-0.27	-2.13	-0.29	2.04	-0.16
1925	0.05	0.19	-0.39	-0.03	0.23	0.00	1972	-0.16	0.99	-0.19	-0.90	0.60	0.13
1926	-0.32	0.18	-2.35	-0.23	0.56	-0.46	1973	1.02	0.62	1.16	0.60	2.02	1.10
1927	0.54	1.61	1.29	-1.76	1.39	0.63	1974	0.22	1.16	1.03	-0.73	-1.05	0.11
1928	-0.23	0.01	-1.34	-0.03	-0.08	-0.36	1975	0.50	1.73	-0.52	0.44	0.38	0.51
1929	-0.44	-1.42	1.30	-1.09	-0.49	-0.43	1976	-1.38	0.90	-0.06	-1.16	-3.36	-0.92
1930	0.13	1.20	0.04	-0.66	0.03	0.15	1977	-0.24	-5.04	1.92	0.39	0.95	-0.44
1931	1.45	1.58	-1.13	0.53	3.11	1.02	1978	-1.08	-4.75	-0.84	0.25	0.45	-1.22
1932	0.38	5.09	-1.15	0.36	-0.88	0.86	1979	-0.91	-3.42	-0.11	-0.07	-0.30	-0.97
1933	0.99	1.41	0.84	0.24	0.45	0.73	1980	-0.39	-0.45	-0.99	0.86	-0.62	-0.30
1934	0.32	0.63	-0.84	1.75	0.71	0.56	1981	-0.34	-0.93	-0.07	0.61	-0.55	-0.23
1935	0.35	0.88	0.85	0.50	0.09	0.58	1982	-0.15	-2.34	0.05	-0.68	0.32	-0.66
1936	-0.17	-3.53	0.02	1.01	0.29	-0.55	1983	0.11	2.62	-0.72	0.89	0.66	0.86
1937	-0.11	1.83	-0.72	0.43	-1.34	0.05	1984	0.16	-1.58	-1.28	0.04	0.66	-0.54
1938	1.01	1.78	1.74	0.42	-0.05	0.97	1985	-0.13	-0.80	1.50	-0.40	1.96	0.57
1939	0.50	1.27	0.01	0.49	-0.10	0.42	1986	0.75	-1.15	0.67	0.27	1.39	0.30
1940	-0.88	-1.84	-1.29	0.03	-1.06	-1.04	1987	0.61	1.18	0.82	0.93	-0.93	0.50
1941	0.68	1.11	-0.41	0.40	1.57	0.67	1988	-0.86	-0.39	-0.93	0.11	-1.14	-0.59
1942	0.18	0.44	0.75	0.53	0.38	0.53	1989	-0.55	0.64	-0.60	0.29	-0.40	-0.02
1943	-0.33	0.09	-0.77	1.36	-1.84	-0.29	1990	0.87	0.35	0.26	-0.25	0.41	0.19
1944	0.30	0.74	0.38	0.27	0.18	0.39	1991	1.28	1.19	2.80	0.85	-0.11	1.18
1945	0.05	-0.94	1.50	-0.77	0.53	0.08	1992		2.40	-0.29	-1.08		
1946	0.73	-0.21	1.96	-0.87	0.40	0.32							

^aCalendar year mean (January–December).^bSeasonal year mean, calculated from four seasons in the following sequence: Win (December–February), Spr (March–May), Sum (June–August), and Fall (September–November).

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Temperature

U.S. national and regional temperature anomalies

T.R. Karl, D.R. Easterling, R.W. Knight, and P.Y. Hughes (continued)

NORTHERN APPALACHIANS

Annual mean temperature anomalies.

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U.S. national and regional temperature anomalies

T.R. Karl, D.R. Easterling, R.W. Knight, and P.Y. Hughes (continued)

NORTHERN APPALACHIANS

Annual and Seasonal Mean Temperature Anomalies (°C)

Year	cy ^a mean	Win	Spr	Sum	Fall	sy ^b mean	Year	cy ^a mean	Win	Spr	Sum	Fall	sy ^b mean
1900	0.44		-1.29	1.04	1.90		1947	0.33	0.86	-0.47	1.14	0.50	0.51
1901	0.06	-1.09	0.60	1.72	-0.92	0.08	1948	-0.06	-2.31	-0.16	0.20	0.81	-0.36
1902	0.01	-0.92	1.34	-0.72	0.82	0.13	1949	1.27	3.34	0.33	1.65	-0.09	1.31
1903	-0.17	-0.03	1.88	-1.15	-0.82	-0.03	1950	0.01	2.35	-1.55	-0.47	0.36	0.17
1904	-1.77	-4.34	-0.16	-0.48	-1.84	-1.71	1951	0.53	1.61	1.21	-0.13	-0.68	0.50
1905	-0.80	-3.80	-0.54	0.21	-0.84	-1.24	1952	0.97	1.93	0.45	0.79	-0.10	0.77
1906	-0.05	1.27	-1.13	0.73	-0.06	0.20	1953	1.54	3.64	1.79	-0.07	0.45	1.45
1907	-1.06	-2.40	-1.48	-1.05	-0.69	-1.40	1954	0.57	2.45	0.15	-0.32	1.14	0.85
1908	-0.30	-0.48	0.28	-0.10	-0.00	-0.08	1955	0.42	0.34	1.33	1.32	-0.14	0.71
1909	-0.29	0.74	-0.71	-0.80	-0.42	-0.30	1956	-0.22	0.43	-2.15	-0.40	-0.59	-0.68
1910	-0.26	-0.47	1.48	-0.60	-0.21	0.05	1957	0.32	0.70	0.65	-0.44	0.17	0.27
1911	0.06	-1.39	-0.66	0.47	-1.07	-0.66	1958	-0.50	0.79	0.58	-0.68	0.32	0.25
1912	-0.88	-1.21	-1.15	-1.30	0.71	-0.74	1959	0.40	-3.10	-0.04	1.31	0.64	-0.30
1913	0.50	2.01	0.48	-1.06	0.68	0.53	1960	-0.00	2.35	-0.29	-0.75	0.49	0.45
1914	-1.07	-1.27	-0.47	-0.64	-0.66	-0.76	1961	0.36	-1.99	-0.37	0.32	1.92	-0.03
1915	0.34	0.81	-0.45	-0.71	0.91	0.14	1962	-0.65	-0.32	0.50	-0.72	-0.75	-0.32
1916	-0.50	0.48	-1.39	0.43	-1.02	-0.38	1963	-0.97	-2.47	-0.59	-0.51	0.20	-0.84
1917	-1.78	-1.80	-1.15	0.50	-2.64	-1.27	1964	-0.06	-0.77	0.66	-0.67	-1.01	-0.45
1918	-0.59	-4.86	0.39	-0.68	-0.19	-1.34	1965	-0.38	-0.30	-0.55	-1.34	-0.11	-0.58
1919	0.33	2.36	0.23	0.47	0.32	0.84	1966	-0.26	1.01	-0.63	-0.40	-0.38	-0.10
1920	-0.46	-3.78	-0.67	-0.10	0.75	-0.95	1967	-0.22	0.64	-1.77	0.77	-0.71	-0.27
1921	1.19	1.92	2.64	0.78	0.41	1.44	1968	-0.32	-1.43	0.30	-0.14	0.93	-0.08
1922	0.21	-0.79	0.98	0.25	0.28	0.18	1969	0.08	0.41	-0.72	0.24	0.32	0.06
1923	-0.89	-1.76	-2.43	-1.17	-0.18	-1.38	1970	-0.12	-2.24	0.01	0.13	1.84	-0.06
1924	-1.06	0.92	-0.52	-1.09	-1.11	-0.45	1971	-0.15	-1.02	-1.66	-0.59	1.72	-0.39
1925	-0.38	-0.42	-0.21	-0.26	-1.27	-0.54	1972	-0.56	0.08	-1.42	-0.02	-0.83	-0.55
1926	-1.43	-0.30	-3.12	-0.97	-0.40	-1.20	1973	1.40	0.72	2.16	1.67	0.79	1.34
1927	0.27	0.12	0.38	-1.69	0.98	-0.05	1974	-0.01	1.06	-0.35	0.01	-1.09	-0.09
1928	0.20	0.77	-1.07	0.65	-0.21	0.03	1975	0.68	2.59	-0.54	0.93	1.06	1.01
1929	-0.20	0.72	0.92	-1.14	-0.18	0.08	1976	-0.79	-0.73	0.37	0.10	-1.68	-0.48
1930	0.22	0.70	-0.20	-0.11	0.12	0.13	1977	0.26	-2.75	1.35	-0.16	1.11	-0.11
1931	1.22	0.58	0.90	0.64	2.31	1.11	1978	-0.97	-2.06	-0.91	-0.01	-1.16	-1.04
1932	0.61	3.93	-1.10	-0.20	-0.16	0.62	1979	0.41	-1.42	1.42	-0.02	0.96	0.24
1933	0.37	3.43	0.76	0.25	-1.41	0.76	1980	-0.47	1.08	0.04	0.17	-0.81	0.12
1934	-0.75	-3.42	-0.79	-0.13	1.17	-0.79	1981	0.42	-1.21	0.89	0.24	-0.38	-0.11
1935	-0.44	-1.80	-0.67	0.82	-0.19	-0.46	1982	-0.30	-0.79	-0.52	-1.14	0.64	-0.45
1936	-0.31	-2.13	1.23	-0.39	-0.91	-0.55	1983	0.66	2.78	0.79	0.26	0.54	1.09
1937	0.69	2.90	-0.63	1.36	-0.37	0.81	1984	0.40	0.87	-1.25	0.48	-0.11	-0.00
1938	0.56	0.51	0.79	0.93	-0.68	0.39	1985	-0.01	1.06	0.50	-0.84	0.86	0.40
1939	-0.15	0.80	-1.04	0.66	-0.98	-0.14	1986	0.40	-0.13	1.49	-0.57	-0.48	0.08
1940	-0.83	-0.94	-0.96	-0.10	-1.12	-0.78	1987	0.56	0.49	1.29	0.52	-0.41	0.47
1941	0.08	0.21	-0.71	-0.06	0.56	-0.00	1988	-0.08	1.01	0.32	0.25	-0.43	0.29
1942	0.59	0.34	2.53	0.57	0.08	0.88	1989	-0.62	0.57	-0.54	0.36	-0.23	0.04
1943	-0.52	-0.81	-1.12	1.04	-0.80	-0.42	1990	1.50	-0.05	0.63	0.59	0.95	0.53
1944	0.15	-0.30	-0.36	0.70	0.42	0.12	1991	1.07	2.36	2.39	0.52	-0.19	1.27
1945	0.30	-1.82	2.17	0.16	0.55	0.27	1992		1.05	-0.98	-0.86		
1946	0.34	-0.88	1.28	-1.07	1.01	0.08							

^aCalendar year mean (January–December).^bSeasonal year mean, calculated from four seasons in the following sequence: Win (December–February), Spr (March–May), Sum (June–August), and Fall (September–November).

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Temperature

U.S. national and regional temperature anomalies

T.R. Karl, D.R. Easterling, R.W. Knight, and P.Y. Hughes (continued)

SOUTHERN APPALACHIANS

Annual mean temperature anomalies.

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U.S. national and regional temperature anomalies

T.R. Karl, D.R. Easterling, R.W. Knight, and P.Y. Hughes (continued)

SOUTHERN APPALACHIANS

Annual and Seasonal Mean Temperature Anomalies (°C)

Year	CY ^a mean	Win	Spr	Sum	Fall	SY ^b mean	Year	CY ^a mean	Win	Spr	Sum	Fall	SY ^b mean
1900	0.25		-0.82	0.83	1.99		1947	-0.13	0.09	-0.99	-0.35	1.41	0.04
1901	-1.03	-1.10	-1.05	0.74	-2.06	-0.87	1948	0.44	-0.88	1.47	0.10	0.10	0.20
1902	-0.27	-2.14	0.17	-0.48	0.59	-0.46	1949	1.20	3.79	-0.10	1.11	0.29	1.27
1903	-0.53	0.00	1.52	-0.70	-1.58	-0.19	1950	0.24	3.40	-0.62	-0.40	-0.29	0.52
1904	-1.35	-3.08	-0.83	-0.92	-1.62	-1.61	1951	-0.07	-0.49	-0.14	0.04	-0.56	-0.29
1905	-0.26	-2.52	1.21	0.22	-0.24	-0.33	1952	0.30	2.04	-0.01	0.89	-1.66	0.32
1906	0.39	0.31	-0.75	0.78	0.81	0.29	1953	0.37	1.59	1.24	0.06	-1.25	0.41
1907	-0.26	1.20	-0.21	-0.85	-0.82	-0.17	1954	0.03	0.76	-0.11	0.07	-0.36	0.09
1908	-0.04	-1.16	1.94	-0.24	-1.16	-0.15	1955	-0.02	-0.44	1.35	-0.04	-0.55	0.08
1909	-0.15	2.00	-0.20	-0.26	-0.65	0.22	1956	0.31	-0.08	-0.43	-0.34	-0.12	-0.25
1910	-0.52	-1.73	0.27	-0.46	-0.03	-0.49	1957	0.76	3.11	0.97	-0.30	0.49	1.07
1911	0.79	0.54	-0.45	0.01	1.24	0.33	1958	-0.74	-1.80	0.11	0.24	-0.25	-0.42
1912	-0.44	-1.49	0.50	-0.53	0.30	-0.30	1959	0.28	-1.11	0.28	0.15	0.49	-0.05
1913	0.46	1.50	0.40	0.13	-0.51	0.38	1960	-0.75	0.64	-2.35	0.07	0.45	-0.29
1914	-0.18	0.33	-0.69	0.47	-0.25	-0.04	1961	-0.31	-1.87	-0.78	-0.74	0.67	-0.68
1915	0.03	0.52	-0.81	-0.50	1.06	0.07	1962	-0.28	0.50	0.04	-0.52	-0.20	-0.04
1916	-0.13	0.73	-0.35	0.23	-1.03	-0.10	1963	-1.31	-3.40	0.39	-0.94	-0.76	-1.18
1917	-1.26	-0.13	-0.55	-0.60	-2.24	-0.88	1964	-0.43	-2.50	0.21	-0.33	-0.94	-0.89
1918	0.15	-3.12	1.35	-0.44	-0.26	-0.62	1965	-0.08	0.00	0.59	-0.61	0.05	0.01
1919	0.59	1.17	0.31	0.36	2.08	0.98	1966	-0.78	-0.77	-0.51	-0.87	-0.85	-0.75
1920	-0.39	-0.78	-1.00	-0.36	-0.08	-0.55	1967	-0.71	-0.37	0.21	-1.08	-2.21	-0.86
1921	1.22	1.16	1.54	0.56	1.22	1.12	1968	-0.90	-1.76	-0.55	-0.01	-0.03	-0.58
1922	0.81	1.78	1.44	0.06	-0.18	0.78	1969	-0.62	-1.13	-1.13	0.23	-0.72	-0.69
1923	0.22	1.29	-0.60	0.00	-0.42	0.07	1970	-0.02	-2.18	0.20	-0.07	1.26	-0.20
1924	-0.86	0.32	-1.27	0.03	-1.06	-0.49	1971	0.14	-0.40	-2.20	-0.02	2.06	-0.14
1925	0.36	0.90	-0.16	-0.07	0.83	0.38	1972	-0.06	1.50	-0.62	-1.11	0.25	0.00
1926	-0.21	-0.02	-2.09	0.06	0.75	-0.32	1973	0.58	0.66	0.77	0.56	1.36	0.84
1927	0.76	2.13	1.17	-0.94	1.07	0.86	1974	0.25	2.24	0.86	-0.78	-1.37	0.24
1928	-0.31	-0.38	-1.05	0.39	-0.01	-0.26	1975	0.53	1.48	0.09	0.17	0.59	0.58
1929	0.13	-0.55	1.21	-0.93	0.48	0.05	1976	-1.19	-0.01	-0.42	-1.10	-2.25	-0.95
1930	-0.39	0.95	-0.29	-1.22	-0.33	-0.22	1977	-0.05	-4.03	1.45	0.32	1.42	-0.21
1931	0.68	-0.39	-1.05	0.34	1.70	0.15	1978	-0.59	-3.31	-0.42	0.38	0.70	-0.66
1932	0.63	4.65	-0.94	0.26	-0.37	0.90	1979	-0.22	-1.70	0.58	-0.43	0.65	-0.23
1933	0.79	1.69	0.63	0.05	0.27	0.66	1980	-0.24	-0.47	-0.35	0.31	-0.07	-0.15
1934	0.12	0.17	-0.59	1.52	0.47	0.39	1981	-0.76	-1.80	-0.57	0.61	-1.20	-0.74
1935	0.39	0.36	1.13	0.51	0.51	0.63	1982	0.26	-1.04	0.14	-0.05	0.41	-0.14
1936	0.23	-2.73	0.19	0.63	1.12	-0.20	1983	-0.38	1.05	-0.56	-0.15	-0.15	0.05
1937	0.30	3.15	-0.79	0.76	-1.19	0.48	1984	0.15	-0.79	-0.80	0.06	0.24	-0.32
1938	0.76	1.32	1.50	0.39	-0.27	0.73	1985	0.26	0.15	0.68	-0.24	2.61	0.80
1939	0.49	1.20	0.14	0.73	-0.30	0.45	1986	0.71	-0.95	0.02	0.61	2.09	0.44
1940	-0.82	-1.89	-1.27	0.20	-0.94	-0.98	1987	0.06	0.25	0.11	0.67	-1.18	-0.04
1941	0.10	0.05	-1.08	0.70	0.90	0.14	1988	-0.99	-0.77	-0.78	-0.29	-1.17	-0.75
1942	0.12	-0.36	0.23	0.85	0.60	0.33	1989	0.02	0.68	-0.28	0.80	0.24	0.36
1943	-0.35	0.28	-0.67	1.08	-2.08	-0.35	1990	1.09	0.45	0.56	0.22	0.55	0.45
1944	0.00	0.61	-0.02	-0.19	0.09	0.12	1991	1.13	1.90	2.44	0.91	-0.46	1.20
1945	0.38	-0.30	1.45	-0.25	0.64	0.39	1992		1.61	-0.57	-0.33		
1946	0.69	0.01	1.63	-0.59	0.67	0.43							

^aCalendar year mean (January–December).^bSeasonal year mean, calculated from four seasons in the following sequence: Win (December–February), Spr (March–May), Sum (June–August), and Fall (September–November).

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Temperature

U.S. national and regional temperature anomalies

T.R. Karl, D.R. Easterling, R.W. Knight, and P.Y. Hughes (continued)

NORTHERN PIEDMONT

Annual mean temperature anomalies.

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U.S. national and regional temperature anomalies

T.R. Karl, D.R. Easterling, R.W. Knight, and P.Y. Hughes (continued)

NORTHERN PIEDMONT

Annual and Seasonal Mean Temperature Anomalies (°C)

Year	cy ^a mean	Win	Spr	Sum	Fall	sy ^b mean	Year	cy ^a mean	Win	Spr	Sum	Fall	sy ^b mean
1900	0.47		-1.41	1.11	2.19		1947	0.01	0.75	-0.65	0.37	0.30	0.19
1901	0.04	-0.91	0.53	1.71	-0.98	0.09	1948	-0.34	-2.71	-0.10	0.00	0.58	-0.56
1902	-0.10	-0.92	1.00	-0.85	0.84	0.02	1949	1.24	2.83	0.45	1.45	0.19	1.23
1903	-0.17	-0.29	1.64	-1.13	-0.63	-0.10	1950	-0.06	2.23	-1.54	-0.69	0.31	0.08
1904	-1.73	-4.14	-0.28	-0.40	-1.71	-1.63	1951	0.42	1.33	0.79	-0.21	-0.54	0.34
1905	-0.87	-3.77	-0.45	-0.05	-0.94	-1.31	1952	0.79	1.89	0.44	0.77	-0.56	0.63
1906	0.11	1.08	-1.14	1.00	0.38	0.33	1953	1.20	3.32	1.71	-0.52	0.03	1.14
1907	-1.15	-2.43	-1.56	-1.09	-0.63	-1.43	1954	0.45	2.10	0.26	-0.65	0.86	0.64
1908	-0.21	-0.32	0.49	-0.07	-0.22	-0.03	1955	0.46	0.58	1.18	1.27	0.06	0.77
1909	-0.34	0.92	-0.54	-0.96	-0.51	-0.27	1956	-0.10	0.57	-1.90	-0.42	-0.65	-0.60
1910	-0.24	-0.82	1.23	-0.51	0.04	-0.01	1957	0.38	1.00	0.74	-0.56	0.26	0.36
1911	0.12	-1.01	-0.69	0.28	-0.60	-0.50	1958	-0.44	0.83	0.55	-0.60	0.02	0.20
1912	-0.63	-1.29	-0.41	-1.00	0.63	-0.52	1959	0.66	-2.16	0.41	1.08	1.05	0.10
1913	0.80	1.99	0.90	-0.81	1.17	0.81	1960	-0.14	2.44	-0.53	-0.45	0.16	0.41
1914	-1.01	-1.04	-0.60	-0.39	-0.78	-0.70	1961	0.12	-2.77	-0.53	0.20	1.88	-0.30
1915	0.24	0.87	-0.66	-0.69	0.80	0.08	1962	-0.79	-0.37	0.25	-0.77	-1.09	-0.50
1916	-0.47	0.22	-1.31	0.25	-1.03	-0.47	1963	-1.10	-2.89	-0.52	-0.77	-0.08	-1.06
1917	-1.48	-0.80	-1.21	0.71	-2.57	-0.97	1964	-0.43	-1.20	0.16	-0.87	-1.15	-0.77
1918	-0.64	-4.86	0.46	-0.62	-0.29	-1.33	1965	-0.49	-0.48	-0.41	-1.23	-0.29	-0.60
1919	0.37	2.25	0.39	0.11	0.63	0.85	1966	-0.37	0.73	-0.77	-0.37	-0.59	-0.25
1920	-0.49	-3.35	-1.23	-0.10	0.81	-0.97	1967	-0.43	0.42	-1.91	0.55	-1.01	-0.49
1921	0.88	1.69	2.22	0.27	0.42	1.15	1968	-0.24	-1.35	0.24	0.09	0.84	-0.04
1922	0.09	-0.84	0.50	0.37	0.32	0.09	1969	0.09	0.11	-0.19	0.32	-0.01	0.06
1923	-0.80	-1.80	-1.93	-0.98	-0.30	-1.25	1970	0.01	-1.97	0.07	0.20	1.71	0.00
1924	-1.15	0.89	-0.95	-1.15	-1.50	-0.68	1971	0.05	-0.93	-1.18	-0.53	1.90	-0.18
1925	-0.37	-0.39	-0.44	-0.28	-1.09	-0.55	1972	-0.27	0.64	-0.90	0.09	-0.93	-0.28
1926	-1.34	-0.01	-2.64	-0.81	-0.52	-0.99	1973	1.18	1.19	1.62	1.53	0.51	1.21
1927	0.06	-0.10	-0.35	-1.64	0.88	-0.30	1974	0.11	1.08	0.28	-0.16	-0.95	0.06
1928	0.17	0.93	-1.21	0.65	-0.11	0.06	1975	0.78	2.34	-0.27	0.79	1.09	0.99
1929	-0.18	0.58	0.69	-1.20	-0.09	-0.00	1976	-0.54	-0.10	0.56	0.30	-1.67	-0.23
1930	0.20	0.76	-0.24	-0.09	0.25	0.17	1977	0.20	-2.77	1.37	-0.06	1.13	-0.08
1931	1.14	0.46	0.46	0.84	2.13	0.97	1978	-0.73	-1.88	-0.65	0.15	-0.88	-0.81
1932	0.45	3.96	-1.02	-0.47	-0.13	0.59	1979	0.49	-0.98	1.43	0.04	0.91	0.35
1933	0.44	2.53	0.79	0.28	-0.85	0.69	1980	-0.32	0.68	0.43	0.19	-0.62	0.17
1934	-0.51	-2.93	-0.81	0.15	1.15	-0.61	1981	0.24	-1.37	0.75	0.38	-0.28	-0.13
1935	-0.32	-1.23	-0.58	0.69	0.15	-0.24	1982	-0.23	-1.00	-0.43	-0.92	0.51	-0.46
1936	-0.14	-2.28	1.05	-0.01	-0.37	-0.40	1983	0.64	2.27	1.03	0.43	0.30	1.01
1937	0.63	3.04	-0.61	1.20	-0.55	0.77	1984	0.46	0.71	-0.88	0.65	-0.09	0.10
1938	0.67	0.74	0.74	0.94	-0.22	0.55	1985	0.31	1.11	1.03	-0.46	1.19	0.72
1939	0.07	1.07	-0.58	0.64	-0.70	0.11	1986	0.38	-0.17	1.22	-0.22	-0.50	0.08
1940	-0.83	-0.79	-1.13	-0.47	-1.07	-0.87	1987	0.42	0.35	1.19	0.62	-0.61	0.39
1941	0.13	0.37	-0.53	-0.14	0.63	0.08	1988	-0.06	0.25	0.53	0.89	-0.75	0.23
1942	0.41	0.39	2.02	0.33	0.11	0.71	1989	-0.17	0.88	-0.17	0.80	-0.01	0.38
1943	-0.46	-0.65	-1.03	1.08	-0.86	-0.37	1990	1.53	0.29	0.67	0.82	0.89	0.67
1944	0.04	-0.35	-0.35	0.38	0.22	-0.02	1991	1.22	2.21	2.32	0.81	0.08	1.35
1945	0.07	-1.80	1.76	-0.05	0.56	0.12	1992		1.69	-0.66	-0.79		
1946	0.13	-0.97	0.73	-1.30	0.98	-0.14							

^aCalendar year mean (January–December).^bSeasonal year mean, calculated from four seasons in the following sequence: Win (December–February), Spr (March–May), Sum (June–August), and Fall (September–November).

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Temperature

U.S. national and regional temperature anomalies

T.R. Karl, D.R. Easterling, R.W. Knight, and P.Y. Hughes (continued)

SOUTHERN PIEDMONT

Annual mean temperature anomalies.

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U.S. national and regional temperature anomalies

T.R. Karl, D.R. Easterling, R.W. Knight, and P.Y. Hughes (continued)

SOUTHERN PIEDMONT

Annual and Seasonal Mean Temperature Anomalies (°C)

Year	CY ^a					SY ^b mean	Year	CY ^a					SY ^b mean
	mean	Win	Spr	Sum	Fall			mean	Win	Spr	Sum	Fall	
1900	0.43		-0.41	0.73	2.32		1947	-0.03	0.17	-0.63	-0.42	1.48	0.15
1901	-0.86	-0.86	-0.84	0.69	-1.97	-0.75	1948	0.46	-0.97	1.54	0.10	0.18	0.21
1902	-0.26	-2.24	0.20	-0.35	0.77	-0.41	1949	1.18	3.78	0.02	0.97	0.30	1.27
1903	-0.31	0.12	1.50	-0.41	-1.27	-0.01	1950	0.23	3.05	-0.56	-0.26	-0.19	0.51
1904	-1.24	-2.89	-0.51	-0.79	-1.47	-1.41	1951	0.06	-0.74	-0.30	0.16	-0.03	-0.23
1905	-0.32	-2.79	1.08	0.09	-0.03	-0.41	1952	0.32	2.01	0.10	0.89	-1.23	0.44
1906	0.29	0.12	-0.65	0.75	0.59	0.20	1953	0.58	1.43	1.12	0.05	-0.54	0.52
1907	-0.45	0.66	-0.50	-0.89	-0.84	-0.39	1954	0.05	0.95	0.12	-0.18	-0.07	0.20
1908	0.01	-1.05	1.86	-0.40	-0.80	-0.10	1955	0.12	-0.60	1.57	0.02	-0.24	0.19
1909	-0.06	1.98	-0.07	-0.27	-0.63	0.25	1956	0.39	-0.36	-0.44	-0.09	0.27	-0.16
1910	-0.37	-1.41	0.72	-0.34	-0.20	-0.31	1957	0.82	3.14	0.98	-0.36	0.69	1.11
1911	0.63	0.21	-0.66	0.22	1.06	0.21	1958	-0.69	-1.75	-0.03	0.48	-0.11	-0.35
1912	-0.12	-1.41	0.88	-0.32	0.62	-0.06	1959	0.43	-1.07	0.50	0.34	0.84	0.15
1913	0.56	2.14	0.64	-0.17	-0.48	0.53	1960	-0.77	0.05	-2.17	0.08	0.45	-0.40
1914	-0.34	0.11	-0.90	0.45	-0.44	-0.20	1961	-0.40	-2.09	-0.85	-0.55	0.54	-0.74
1915	-0.09	0.39	-1.02	-0.40	1.02	-0.00	1962	-0.27	0.13	-0.06	-0.33	-0.13	-0.10
1916	-0.03	0.66	-0.27	0.06	-0.76	-0.08	1963	-1.08	-2.75	0.57	-0.79	-0.82	-0.95
1917	-1.10	0.25	-0.67	-0.29	-2.34	-0.76	1964	-0.18	-2.01	0.31	-0.05	-0.77	-0.63
1918	-0.04	-2.63	1.28	-0.74	-0.60	-0.67	1965	0.01	0.40	0.57	-0.35	0.05	0.17
1919	0.50	1.12	0.40	0.05	1.79	0.84	1966	-0.87	-0.73	-0.70	-0.80	-1.13	-0.84
1920	-0.50	-1.07	-1.08	-0.50	0.03	-0.66	1967	-0.94	-0.44	-0.29	-1.10	-2.70	-1.13
1921	1.04	0.93	1.58	0.22	1.14	0.97	1968	-0.92	-1.62	-0.62	-0.03	-0.16	-0.61
1922	0.77	1.46	1.16	0.02	0.11	0.69	1969	-0.65	-1.32	-0.92	0.29	-0.81	-0.69
1923	0.23	1.16	-0.36	0.00	-0.35	0.11	1970	-0.11	-2.33	0.16	0.03	0.95	-0.30
1924	-0.82	0.29	-1.19	-0.09	-1.11	-0.53	1971	0.25	-0.19	-1.92	-0.06	1.78	-0.10
1925	0.33	0.86	-0.34	0.25	0.68	0.36	1972	-0.06	2.31	-0.46	-1.12	-0.36	0.09
1926	-0.26	0.33	-2.11	0.16	0.26	-0.34	1973	0.31	0.39	0.56	0.47	0.85	0.57
1927	0.58	1.96	0.64	-1.11	1.07	0.64	1974	0.12	1.99	0.75	-0.80	-1.66	0.07
1928	-0.21	-0.27	-0.95	0.35	0.17	-0.18	1975	0.35	1.44	-0.18	-0.19	0.76	0.46
1929	0.19	-0.11	1.33	-0.92	0.40	0.17	1976	-1.12	-0.17	-0.02	-1.16	-2.58	-0.98
1930	-0.05	0.93	-0.11	-0.60	0.16	0.09	1977	-0.21	-3.53	1.34	0.10	0.74	-0.34
1931	0.43	-0.64	-1.40	0.33	1.46	-0.06	1978	-0.66	-2.81	-0.64	0.08	0.50	-0.72
1932	0.77	4.62	-1.03	0.35	-0.12	0.96	1979	-0.47	-1.76	0.45	-0.84	0.36	-0.45
1933	0.80	2.23	0.55	-0.07	0.15	0.72	1980	-0.42	-0.81	-0.41	-0.05	-0.20	-0.37
1934	0.07	0.06	-0.55	1.32	0.53	0.34	1981	-0.95	-1.76	-0.95	0.44	-1.40	-0.92
1935	0.12	-0.16	0.80	0.35	0.59	0.39	1982	0.23	-1.02	0.17	0.02	0.16	-0.17
1936	0.19	-2.68	0.31	0.54	0.84	-0.25	1983	-0.52	0.73	-0.69	-0.19	-0.33	-0.12
1937	0.16	2.92	-0.83	0.59	-1.38	0.32	1984	-0.10	-0.76	-0.94	-0.16	-0.08	-0.48
1938	0.77	1.13	1.46	0.15	0.19	0.73	1985	0.27	0.15	0.46	-0.35	2.62	0.72
1939	0.64	1.37	0.37	0.81	-0.06	0.62	1986	0.64	-0.78	-0.10	0.74	1.88	0.43
1940	-0.76	-2.02	-1.22	0.28	-0.72	-0.92	1987	0.01	-0.35	-0.15	1.10	-0.99	-0.10
1941	0.24	-0.24	-0.62	0.78	1.25	0.29	1988	-1.05	-0.93	-0.96	-0.18	-1.18	-0.81
1942	0.25	-0.43	0.63	0.79	0.70	0.42	1989	0.00	0.53	-0.40	0.62	0.30	0.26
1943	-0.23	0.29	-0.21	1.21	-2.10	-0.20	1990	1.10	0.65	0.60	0.32	0.38	0.49
1944	-0.06	0.36	0.04	-0.18	0.01	0.06	1991	1.13	2.11	2.45	1.06	-0.66	1.24
1945	0.60	-0.43	1.96	0.12	0.72	0.59	1992		1.53	-0.89	-0.16		
1946	0.76	-0.12	1.43	-0.57	1.11	0.46							

^aCalendar year mean (January–December).^bSeasonal year mean, calculated from four seasons in the following sequence: Win (December–February), Spr (March–May), Sum (June–August), and Fall (September–November).

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Temperature

U.S. national and regional temperature anomalies

T.R. Karl, D.R. Easterling, R.W. Knight, and P.Y. Hughes (continued)

COASTAL NORTHEAST

Annual mean temperature anomalies.

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U.S. national and regional temperature anomalies

T.R. Karl, D.R. Easterling, R.W. Knight, and P.Y. Hughes (continued)

COASTAL NORTHEAST

Annual and Seasonal Mean Temperature Anomalies (°C)

Year	CY ^a mean	Win	Spr	Sum	Fall	SY ^b mean	Year	CY ^a mean	Win	Spr	Sum	Fall	SY ^b mean
1900	0.34		-1.15	0.88	2.11		1947	0.00	0.57	-0.64	0.04	0.68	0.16
1901	-0.45	-1.24	-0.24	1.11	-1.32	-0.42	1948	-0.08	-1.94	0.28	0.00	0.47	-0.30
1902	-0.29	-1.28	0.63	-1.11	0.80	-0.24	1949	1.27	2.88	0.51	1.28	0.34	1.25
1903	-0.51	-0.28	1.23	-1.37	-1.15	-0.39	1950	0.01	2.34	-1.34	-0.58	0.24	0.17
1904	-1.91	-3.75	-0.75	-0.68	-2.06	-1.81	1951	0.40	1.00	0.38	-0.01	-0.18	0.30
1905	-1.03	-3.77	-0.34	-0.39	-1.14	-1.41	1952	0.75	1.92	0.49	1.04	-0.66	0.70
1906	0.17	0.90	-1.03	0.85	0.39	0.28	1953	1.10	2.65	1.57	-0.20	0.07	1.03
1907	-1.27	-1.78	-1.67	-1.41	-0.95	-1.45	1954	0.33	1.70	0.25	-0.60	0.63	0.50
1908	-0.20	-0.26	0.49	-0.15	-0.40	-0.08	1955	0.27	0.27	1.02	1.00	-0.03	0.57
1909	-0.44	1.19	-0.50	-0.93	-0.85	-0.27	1956	0.13	0.07	-1.42	-0.27	0.01	-0.40
1910	-0.32	-0.72	0.87	-0.53	-0.35	-0.18	1957	0.61	1.38	0.86	-0.23	0.62	0.66
1911	-0.03	-0.84	-1.06	0.13	-0.38	-0.54	1958	-0.34	0.45	0.48	-0.05	-0.02	0.22
1912	-0.75	-1.59	-0.23	-1.00	0.14	-0.67	1959	0.67	-1.91	0.73	0.78	1.15	0.19
1913	0.57	1.56	0.76	-0.69	0.61	0.56	1960	-0.08	1.91	-0.78	0.10	0.28	0.38
1914	-0.90	-0.44	-0.98	-0.54	-0.81	-0.70	1961	0.23	-2.09	-0.35	0.25	1.80	-0.10
1915	-0.14	0.88	-0.86	-0.87	0.20	-0.16	1962	-0.55	-0.30	0.23	-0.64	-0.74	-0.36
1916	-0.76	-0.24	-1.37	-0.45	-0.99	-0.76	1963	-0.64	-2.01	0.09	-0.48	0.18	-0.56
1917	-1.61	-1.04	-1.44	0.18	-2.81	-1.28	1964	-0.11	-0.91	0.24	-0.53	-0.74	-0.49
1918	-0.79	-4.05	0.34	-0.92	-0.69	-1.33	1965	-0.38	-0.19	-0.22	-0.59	-0.39	-0.35
1919	0.08	1.31	0.42	-0.39	0.61	0.49	1966	-0.23	0.29	-0.55	-0.02	-0.46	-0.18
1920	-0.67	-2.73	-1.28	-0.56	0.28	-1.07	1967	-0.60	0.35	-1.70	0.08	-1.32	-0.65
1921	0.68	1.32	2.01	-0.15	0.41	0.90	1968	-0.17	-1.29	0.07	0.31	0.78	-0.03
1922	0.10	-0.49	0.58	0.24	-0.10	0.06	1969	0.28	0.20	0.03	0.74	-0.09	0.22
1923	-0.55	-1.13	-1.43	-0.69	-0.35	-0.90	1970	0.11	-1.29	-0.05	0.45	1.36	0.12
1924	-0.94	0.73	-0.83	-0.78	-1.29	-0.54	1971	0.38	-0.49	-0.86	0.04	1.88	0.14
1925	-0.18	0.23	-0.33	-0.15	-0.86	-0.28	1972	-0.07	1.17	-0.63	-0.25	-0.58	-0.07
1926	-1.19	-0.29	-2.21	-0.74	-0.68	-0.98	1973	1.12	1.24	1.40	1.47	0.59	1.18
1927	-0.04	-0.04	-0.36	-1.66	0.79	-0.32	1974	0.29	1.48	0.63	-0.11	-0.83	0.29
1928	-0.17	0.30	-1.01	0.31	-0.27	-0.17	1975	0.82	2.11	-0.10	0.70	1.16	0.97
1929	-0.14	-0.00	0.89	-1.04	-0.17	-0.08	1976	-0.35	0.44	0.80	0.13	-1.69	-0.08
1930	0.07	0.73	-0.47	-0.06	0.17	0.09	1977	0.29	-2.74	1.42	0.23	1.29	0.05
1931	0.95	0.24	0.02	0.65	1.92	0.71	1978	-0.56	-1.76	-0.56	0.33	-0.50	-0.62
1932	0.38	3.52	-1.05	-0.35	-0.13	0.50	1979	0.42	-0.98	1.36	-0.08	0.99	0.32
1933	0.39	2.19	0.56	0.11	-0.47	0.60	1980	0.02	0.47	0.73	0.47	-0.24	0.36
1934	-0.43	-2.51	-0.63	0.53	0.70	-0.47	1981	0.01	-1.18	0.47	0.46	-0.58	-0.21
1935	-0.22	-1.15	-0.09	0.44	0.36	-0.11	1982	0.03	-0.68	-0.21	-0.47	0.43	-0.23
1936	-0.13	-2.46	0.73	0.05	-0.05	-0.43	1983	0.64	2.13	0.84	0.40	0.59	0.99
1937	0.50	2.89	-0.40	0.99	-0.88	0.65	1984	0.62	0.51	-0.52	0.88	0.22	0.27
1938	0.60	0.67	0.63	0.64	0.06	0.50	1985	0.52	0.91	1.09	-0.08	1.79	0.93
1939	0.28	1.16	-0.20	0.70	-0.51	0.29	1986	0.47	-0.06	0.74	0.08	0.14	0.22
1940	-0.96	-1.25	-1.21	-0.52	-1.13	-1.03	1987	0.30	0.31	0.67	0.66	-0.50	0.29
1941	0.02	0.18	-0.58	-0.20	0.67	0.02	1988	-0.18	0.11	0.20	0.88	-1.12	0.02
1942	0.27	-0.08	1.34	0.45	0.49	0.55	1989	-0.02	0.79	-0.07	0.85	0.19	0.44
1943	-0.30	-0.45	-0.69	0.90	-0.76	-0.25	1990	1.33	0.36	0.57	0.70	0.67	0.58
1944	0.07	-0.35	-0.02	0.21	0.17	0.00	1991	1.19	2.11	2.12	0.90	0.11	1.31
1945	0.18	-1.16	1.63	-0.20	0.65	0.23	1992		1.46	-0.87	-0.79		
1946	0.31	-0.57	0.94	-1.08	1.04	0.08							

^aCalendar year mean (January–December).^bSeasonal year mean, calculated from four seasons in the following sequence: Win (December–February), Spr (March–May), Sum (June–August), and Fall (September–November).

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Temperature

U.S. national and regional temperature anomalies

T.R. Karl, D.R. Easterling, R.W. Knight, and P.Y. Hughes (continued)

COASTAL SOUTHEAST

Annual mean temperature anomalies.

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U.S. national and regional temperature anomalies

T.R. Karl, D.R. Easterling, R.W. Knight, and P.Y. Hughes (continued)

COASTAL SOUTHEAST

Annual and Seasonal Mean Temperature Anomalies (°C)

Year	CY ^a mean	Win	Spr	Sum	Fall	SY ^b mean	Year	CY ^a mean	Win	Spr	Sum	Fall	SY ^b mean
1900	0.29		-0.25	0.61	1.49		1947	0.37	0.68	0.02	-0.26	1.43	0.47
1901	-1.00	-1.08	-1.41	0.43	-1.43	-0.87	1948	0.89	-0.06	1.86	0.08	0.80	0.67
1902	-0.08	-2.39	0.03	0.14	1.25	-0.24	1949	1.10	3.94	0.23	0.49	0.22	1.22
1903	-0.30	0.64	0.95	-0.05	-1.17	0.09	1950	0.08	3.02	-0.65	-0.20	-0.40	0.44
1904	-0.97	-2.80	-0.53	-0.71	-0.93	-1.24	1951	-0.01	-1.37	-0.42	0.06	0.13	-0.40
1905	0.07	-2.18	1.32	0.29	0.53	-0.01	1952	0.14	1.63	0.06	0.63	-0.71	0.40
1906	0.30	0.18	-0.35	0.87	0.53	0.31	1953	0.54	0.57	1.08	0.06	-0.29	0.35
1907	0.11	0.65	0.16	-0.15	-0.28	0.10	1954	-0.12	0.87	0.11	0.17	-0.54	0.15
1908	0.33	-0.74	1.91	-0.04	-0.42	0.18	1955	-0.18	-1.19	0.89	-0.37	-0.47	-0.28
1909	-0.05	1.58	0.25	0.21	-0.80	0.31	1956	-0.06	-0.40	-0.50	-0.30	-0.36	-0.39
1910	-0.67	-1.64	-0.03	-0.18	-0.52	-0.59	1957	0.64	2.50	0.76	0.00	0.39	0.91
1911	0.79	-0.11	-0.12	0.11	1.37	0.31	1958	-0.51	-2.54	0.05	0.44	0.34	-0.42
1912	0.30	-0.78	1.41	0.20	0.42	0.31	1959	0.67	0.07	0.64	0.22	1.30	0.56
1913	0.44	2.84	0.49	-0.27	-0.95	0.53	1960	-0.50	-0.30	-1.41	0.15	0.76	-0.20
1914	-0.32	0.01	-1.02	0.37	-0.58	-0.31	1961	-0.19	-1.57	-0.31	-0.24	0.06	-0.51
1915	-0.07	0.53	-1.24	0.19	1.22	0.17	1962	-0.42	0.41	-0.54	-0.11	-0.63	-0.22
1916	0.01	0.41	-0.85	-0.05	-0.20	-0.17	1963	-0.93	-2.23	0.30	-0.35	-0.91	-0.80
1917	-0.94	0.47	-0.52	-0.24	-2.19	-0.62	1964	0.07	-2.10	0.53	-0.09	-0.03	-0.42
1918	0.03	-2.01	0.90	-0.65	-0.15	-0.48	1965	-0.06	0.66	0.29	-0.47	0.22	0.17
1919	0.50	0.84	0.39	-0.15	1.85	0.73	1966	-0.65	-0.78	-0.50	-0.55	-0.61	-0.61
1920	-0.56	-0.61	-0.82	-0.50	-0.46	-0.60	1967	-0.52	-0.40	0.15	-0.72	-2.13	-0.77
1921	0.70	0.53	0.94	-0.01	0.95	0.60	1968	-1.07	-1.51	-0.71	0.09	-0.75	-0.72
1922	0.84	1.36	1.12	-0.08	0.46	0.72	1969	-0.69	-1.79	-0.89	0.30	-0.42	-0.70
1923	0.22	1.34	0.19	0.03	-0.77	0.20	1970	-0.44	-2.68	0.42	-0.17	-0.12	-0.64
1924	-0.38	0.42	-0.99	0.22	-0.67	-0.25	1971	0.11	-0.29	-1.72	-0.22	1.03	-0.30
1925	0.37	1.65	-0.27	0.15	0.59	0.53	1972	0.27	2.79	-0.20	-0.76	0.00	0.46
1926	-0.29	-0.12	-1.68	0.12	-0.08	-0.44	1973	0.21	0.26	0.72	0.12	0.78	0.47
1927	0.39	1.64	0.27	-0.33	0.46	0.51	1974	0.25	1.82	0.66	-0.59	-1.12	0.19
1928	-0.21	-0.43	-0.75	0.13	0.24	-0.20	1975	0.52	1.64	0.23	-0.10	0.70	0.62
1929	0.57	0.85	1.46	-0.53	0.66	0.61	1976	-1.01	-0.86	0.19	-0.78	-2.46	-0.98
1930	-0.04	0.81	-0.05	-0.42	-0.12	0.05	1977	-0.50	-3.19	0.75	0.14	0.07	-0.56
1931	0.04	-1.19	-1.58	-0.01	0.68	-0.53	1978	-0.43	-2.59	-0.38	0.11	0.60	-0.57
1932	0.90	4.81	-0.95	0.53	-0.00	1.10	1979	-0.32	-1.11	0.26	-0.51	0.48	-0.22
1933	0.75	2.61	0.68	-0.18	0.14	0.81	1980	-0.45	-0.91	0.06	-0.07	-0.28	-0.30
1934	0.12	0.27	-0.16	0.75	0.44	0.33	1981	-1.19	-2.77	-0.94	0.52	-1.68	-1.22
1935	0.12	0.01	0.96	0.16	0.54	0.42	1982	0.47	-0.41	0.39	0.13	0.15	0.07
1936	0.31	-1.91	0.23	0.21	0.75	-0.18	1983	-0.47	0.58	-0.96	-0.15	-0.18	-0.18
1937	0.25	3.37	-0.58	0.26	-1.04	0.50	1984	-0.20	-0.49	-0.50	-0.47	-0.36	-0.46
1938	0.34	0.53	1.09	-0.32	-0.07	0.31	1985	0.24	-0.29	0.33	-0.20	2.64	0.62
1939	0.42	1.16	0.35	0.36	-0.14	0.43	1986	0.62	-0.60	-0.71	0.44	2.03	0.29
1940	-0.92	-2.43	-1.56	0.37	-1.21	-1.21	1987	-0.31	0.20	-0.72	0.51	-0.77	-0.20
1941	0.05	-0.34	-1.21	0.66	1.31	0.10	1988	-0.86	-0.91	-0.95	-0.43	-0.47	-0.69
1942	-0.13	-0.61	-0.18	0.54	0.25	-0.00	1989	-0.09	0.62	-0.23	0.13	0.21	0.18
1943	-0.54	-0.01	-0.23	0.52	-1.87	-0.40	1990	0.82	0.35	0.35	-0.11	0.23	0.20
1944	-0.13	-0.07	0.53	-0.05	-0.47	-0.01	1991	0.97	2.14	2.33	0.54	-0.67	1.08
1945	0.49	-0.72	1.54	0.27	0.56	0.41	1992		0.92	-1.25	-0.02		
1946	0.85	0.05	1.16	-0.44	1.46	0.56							

^aCalendar year mean (January–December).^bSeasonal year mean, calculated from four seasons in the following sequence: Win (December–February), Spr (March–May), Sum (June–August), and Fall (September–November).

CITE AS: Karl, T.R., D.R. Easterling, R.W. Knight, and P.Y. Hughes. 1994. U.S. national and regional temperature anomalies. pp. 686–736. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

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Temperature

Canadian national and regional annual temperature departures

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Canada • Atlantic Canada • Great Lakes Basin/St. Lawrence Lowlands •
Northeastern Forest • Northwestern Forest • Prairies • South British Columbia
Mountains • Pacific Coast • Yukon/North British Columbia Mountains •
Mackenzie District • Arctic Tundra • Arctic Mountains and Fiords

Period of Record

1895–1992 (varies by region)

Methods

The Canadian national and regional average temperature departures series were prepared from data contained in the Historical Canadian Climate Database (HCCD). The HCCD contains homogeneous maximum, minimum, and mean temperature data sets for 131 locations across Canada. These monthly and annual data sets were subjected to rigorous quality assessment procedures pertaining to length of record, data completeness, data consistency and homogeneity. Partial data sets from a number of sites were sometimes pieced together to form single series in an effort to increase record lengths as much as possible. Outliers exceeding 2.5 standard deviations from the composite area averages were deleted and replaced by estimated values. Small amounts of missing data, in general periods not exceeding four consecutive years, were also estimated using a variation of a long-standing data adjustment procedure endorsed by the World Meteorological Organization (Thom 1966). Abrupt discontinuities in the series resulting from nonclimatic factors such as site relocations, instrument changes, environment changes and observing procedure changes were identified using multiple-phase regression models as described by Vincent (1990) and Gullett et al. (1991). Individual series were adjusted relative to composite area average series using the method described by Jones et al. (1986). Adjustments were made such that the most recent homogeneous period of the record was always retained, and older inhomogeneous segments were adjusted to this. Nonclimatic trends were further sub-divided where possible into distinct inhomogeneous segments that were also adjusted. Time series of monthly, seasonal, and annual departures from the 1951–80 reference period averages were prepared for 131 individual locations.

The individual departures series were combined into regional series representing the 11 Canadian climate regions, outlined in The State of the Environment Report, SOE 92-2 (Gullett and Skinner 1992). Regions were defined through integration of areas exhibiting similarities in vegetation types (Environment Canada 1989), major relief features, and temperature and precipitation characteristics (Hare and Thomas 1979). The 11 regional departures series were subsequently temporally and spatially weighted, taking into account

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Canadian national and regional annual temperature departures

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and R. Whitewood (continued)

the varying length of record for individual reporting locations, the uneven spatial distribution of sites within some regions, and the areal representativeness of each region relative to the area of the nation as a whole. The weighted regional departures series were combined into a single, national, annual, average temperature departures series, for the period 1895–1992. These national and regional series are presented here.

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Canadian national and regional annual temperature departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent, and R. Whitewood (continued)

CANADA

Trends

The trend, calculated for the Canada national annual mean temperature departures series, indicates a warming of 1.0°C over the 98-year period of analysis. This trend is significant at the 5% level. The Canadian national time series shows similar patterns to that of Jones (Folland et al. 1992) for the Northern Hemisphere, with warming evident from the early 1900s to the 1940s, followed by cooling to the 1970s, and followed again by warming through the 1980s. For Canada as a whole, 1981 was the warmest year in the period, followed by 1987 and then by 1931. Eight of the 13 years since 1980 were above the reference average; however, 1982, 1985, 1989, 1990 and 1992, were all below. The national warming trend does not result from a uniform rise in mean temperatures across the nation. Each region contributes differently to the national trend. Ten of the 11 regions show warming trends over their respective period of analysis with 5 of these (Great Lakes Basin/St. Lawrence Lowlands, Northwestern Forest, Prairies, South British Columbia Mountains, and Mackenzie District) significant at the 5% level. Only the Arctic Mountains and Fiords region bordering on the periphery of the northwest Atlantic Ocean (including the Labrador Sea and Baffin Bay) exhibits a cooling trend. However, this trend is not significant. The period of record for this region is only 1946–92, and the results are therefore not strictly comparable with those of the other regions.

Annual temperature departure relative to the 1951–80 reference period.

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Canadian national and regional annual temperature departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent,
and R. Whitewood (continued)

CANADA

Annual Temperature Departures^a

Year	Temperature departure	Year	Temperature departure	Year	Temperature departure
1895	-0.45	1928	0.17	1961	-0.09
1896	-1.33	1929	-0.95	1962	0.10
1897	-1.19	1930	0.46	1963	0.26
1898	0.00	1931	1.38	1964	-0.53
1899	-1.42	1932	-0.37	1965	-0.59
1900	-0.26	1933	-1.42	1966	-0.18
1901	-0.03	1934	-0.35	1967	-0.32
1902	-0.67	1935	-0.66	1968	0.16
1903	-0.40	1936	-1.34	1969	0.41
1904	-0.75	1937	0.54	1970	-0.20
1905	0.47	1938	1.05	1971	-0.02
1906	0.05	1939	-0.23	1972	-1.80
1907	-2.11	1940	0.76	1973	0.65
1908	-0.67	1941	0.43	1974	-0.78
1909	-1.66	1942	0.71	1975	-0.10
1910	-0.11	1943	0.36	1976	0.03
1911	-0.55	1944	1.17	1977	0.92
1912	-0.25	1945	-0.03	1978	-0.36
1913	-0.69	1946	-0.14	1979	-0.07
1914	-0.61	1947	0.50	1980	0.41
1915	0.84	1948	0.02	1981	1.98
1916	-0.84	1949	0.03	1982	-0.93
1917	-1.87	1950	-1.04	1983	0.16
1918	-1.05	1951	-0.36	1984	0.25
1919	-0.84	1952	0.96	1985	-0.04
1920	-0.07	1953	1.02	1986	0.06
1921	0.21	1954	0.17	1987	1.43
1922	-0.83	1955	0.05	1988	0.82
1923	-0.68	1956	-0.58	1989	-0.17
1924	0.09	1957	-0.04	1990	-0.07
1925	-0.72	1958	0.73	1991	0.47
1926	-0.93	1959	-0.25	1992	-0.19
1927	-0.51	1960	0.62		

^aAnnual temperature departure expressed in degrees Celsius and relative to a 1951–80 reference period.

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Canadian national and regional annual temperature departures

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ATLANTIC CANADA

Trends

The Atlantic region includes the provinces of New Brunswick, Nova Scotia, Prince Edward Island and Newfoundland. An overall warming trend of 0.3°C is shown for the region over the period 1895–1992. However, the trend is not significant at the 5% level. A number of trend segments appear in the series with cooling from about 1900 to the late 1920s, warming to the 1950s, cooling to the early 1970s, warming to the early 1980s, and cooling to the 1990s.

Annual temperature departure relative to the 1951–80 reference period.

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Canadian national and regional annual temperature departures

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and R. Whitewood (continued)

ATLANTIC CANADA

Annual Temperature Departures^a

Year	Temperature departure	Year	Temperature departure	Year	Temperature departure
1895	0.15	1928	-0.34	1961	0.04
1896	-0.56	1929	-0.57	1962	-0.56
1897	-0.49	1930	0.33	1963	-0.48
1898	0.20	1931	1.00	1964	-0.59
1899	-0.43	1932	0.30	1965	-0.77
1900	0.08	1933	-0.44	1966	0.61
1901	0.61	1934	-0.84	1967	-0.19
1902	0.39	1935	-0.57	1968	-0.24
1903	-0.50	1936	-0.02	1969	0.76
1904	-1.34	1937	0.85	1970	-0.07
1905	-1.01	1938	0.20	1971	0.05
1906	0.00	1939	-0.65	1972	-1.35
1907	-1.17	1940	-0.35	1973	0.33
1908	0.01	1941	-0.49	1974	-0.91
1909	0.19	1942	0.36	1975	-0.36
1910	0.60	1943	-0.53	1976	-0.28
1911	-0.44	1944	0.26	1977	0.08
1912	-0.78	1945	0.25	1978	-0.63
1913	0.18	1946	0.13	1979	0.83
1914	-1.18	1947	0.29	1980	-0.61
1915	0.32	1948	-0.45	1981	0.97
1916	-0.26	1949	0.60	1982	-0.50
1917	-0.94	1950	-0.09	1983	0.81
1918	-1.02	1951	1.13	1984	0.32
1919	-0.32	1952	0.92	1985	-0.73
1920	-0.41	1953	1.14	1986	-0.69
1921	-0.29	1954	0.41	1987	0.02
1922	-0.87	1955	0.06	1988	-0.02
1923	-1.37	1956	-0.15	1989	-0.61
1924	-0.58	1957	-0.13	1990	0.15
1925	-0.78	1958	0.40	1991	-0.26
1926	-1.28	1959	-0.29	1992	-0.92
1927	-0.03	1960	0.83		

^aAnnual temperature departure expressed in degrees Celsius and relative to a 1951-80 reference period.

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GREAT LAKES BASIN/ST. LAWRENCE LOWLANDS

Trends

The Great Lakes Basin/St. Lawrence Lowlands region includes southern Ontario and the extreme southern portion of Quebec, from Lake Huron in the southwest to Quebec City in the northeast. An overall warming trend of 0.6°C is shown for the region over the period 1895–1992. The trend is significant at the 5% level. Three distinct trend segments appear in the series with gradual warming from the early 1900s to the 1950s, cooling to the early 1970s, and warming to about 1990.

Annual temperature departure relative to the 1951–80 reference period.

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Canadian national and regional annual temperature departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent,
and R. Whitewood (continued) GREAT LAKES BASIN/
ST. LAWRENCE LOWLANDSAnnual Temperature Departures^a

Year	Temperature departure	Year	Temperature departure	Year	Temperature departure
1895	-0.78	1928	-0.22	1961	0.39
1896	-0.38	1929	-0.58	1962	-0.31
1897	-0.21	1930	0.38	1963	-0.61
1898	0.69	1931	1.47	1964	0.38
1899	-0.20	1932	0.46	1965	-0.39
1900	0.32	1933	0.32	1966	0.16
1901	-0.24	1934	-0.73	1967	-0.34
1902	-0.33	1935	-0.66	1968	-0.10
1903	-0.27	1936	-0.65	1969	0.13
1904	-2.00	1937	0.50	1970	-0.21
1905	-0.93	1938	0.72	1971	0.09
1906	-0.06	1939	-0.18	1972	-0.93
1907	-1.31	1940	-0.89	1973	1.08
1908	-0.09	1941	0.59	1974	-0.30
1909	-0.34	1942	0.35	1975	0.59
1910	-0.21	1943	-0.91	1976	-0.72
1911	0.17	1944	0.33	1977	0.06
1912	-1.23	1945	-0.11	1978	-1.06
1913	0.46	1946	0.54	1979	-0.12
1914	-0.87	1947	0.11	1980	-0.73
1915	0.28	1948	0.25	1981	0.23
1916	-0.32	1949	1.10	1982	-0.31
1917	-2.02	1950	-0.43	1983	0.65
1918	-0.53	1951	0.16	1984	0.29
1919	0.52	1952	0.87	1985	-0.13
1920	-0.39	1953	1.48	1986	0.23
1921	1.56	1954	0.09	1987	1.16
1922	0.45	1955	0.68	1988	0.41
1923	-0.56	1956	-0.39	1989	-0.54
1924	-0.99	1957	0.30	1990	1.18
1925	-0.47	1958	-0.40	1991	1.25
1926	-1.49	1959	0.20	1992	-0.61
1927	0.22	1960	0.07		

^aAnnual temperature departure expressed in degrees Celsius and relative to a 1951–80 reference period.

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Canadian national and regional annual temperature departures

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NORTHEASTERN FOREST

Trends

The Northeastern Forest region lies between about 46° N and the tree line at about 57° N and stretches from the Manitoba/Ontario border to the Atlantic coast of Labrador including the Lower St. Lawrence and the Gaspé Peninsula. The region includes much of the Canadian Shield as well as the Hudson Bay Lowlands. An overall warming trend of 0.5°C is shown for the Northeastern Forest over the period 1895–1992. However, the trend is not significant at the 5% level. A number of trend segments appear in the series with cooling from the 1890s to the late 1920s, warming to the 1950s, cooling to the 1970s, warming to the late 1980s, and cooling thereafter.

Annual temperature departure relative to the 1951–80 reference period.

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Canadian national and regional annual temperature departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent,
and R. Whitewood (continued)

NORTHEASTERN FOREST

Annual Temperature Departures^a

Year	Temperature departure	Year	Temperature departure	Year	Temperature departure
1895	0.04	1928	-0.29	1961	0.54
1896	-0.79	1929	-1.17	1962	-0.33
1897	-0.76	1930	0.49	1963	-0.23
1898	0.27	1931	1.92	1964	-0.19
1899	-0.23	1932	0.12	1965	-0.89
1900	0.03	1933	-0.87	1966	0.37
1901	0.25	1934	-0.89	1967	-0.48
1902	0.18	1935	-0.63	1968	0.24
1903	-0.42	1936	-0.96	1969	0.46
1904	-1.05	1937	0.65	1970	-0.23
1905	-0.45	1938	0.59	1971	0.12
1906	0.13	1939	-0.54	1972	-1.89
1907	-1.35	1940	-0.06	1973	0.91
1908	-0.12	1941	0.51	1974	-0.93
1909	-0.29	1942	0.37	1975	0.24
1910	0.31	1943	-0.72	1976	-0.68
1911	-0.15	1944	0.67	1977	0.80
1912	-1.43	1945	-0.09	1978	-0.81
1913	0.13	1946	-0.18	1979	0.08
1914	-0.75	1947	0.10	1980	-0.31
1915	0.81	1948	0.29	1981	1.47
1916	-0.78	1949	0.05	1982	-0.77
1917	-1.80	1950	-1.12	1983	0.53
1918	-0.74	1951	0.17	1984	0.39
1919	0.14	1952	1.16	1985	-0.49
1920	0.24	1953	1.10	1986	-0.06
1921	0.70	1954	0.08	1987	1.72
1922	-0.22	1955	0.83	1988	0.19
1923	-0.85	1956	-0.58	1989	-0.74
1924	-0.87	1957	-0.02	1990	0.13
1925	-0.69	1958	0.34	1991	0.21
1926	-1.57	1959	-0.19	1992	-0.84
1927	-0.31	1960	0.53		

^aAnnual temperature departure expressed in degrees Celsius and relative to a 1951-80 reference period.

CITE AS: Findlay, B.F., D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent, and R. Whitewood. 1994. Canadian national and regional annual temperature departures. pp. 738-764. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Canadian national and regional annual temperature departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent, and R. Whitewood (continued)

NORTHWESTERN FOREST

Trends

The Northwestern Forest region stretches from the northern boundary of the Prairies north to the Mackenzie District at about 60° N and from the foothills of the Rocky Mountains east to the Manitoba/Ontario border. The landscape is low and without major relief features. An overall warming trend of 1.4°C is shown for the Northwestern Forest over the period 1895–1992. The trend is significant at the 5% level. Three distinct trend segments appear in the series with warming from the 1890s to the 1940s, cooling from the 1950s to about 1970, and warming to the 1990s.

Annual temperature departure relative to the 1951–80 reference period.

CITE AS: Findlay, B.F., D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent, and R. Whitewood. 1994. Canadian national and regional annual temperature departures. pp. 738–764. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Canadian national and regional annual temperature departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent,
and R. Whitewood (continued)

NORTHWESTERN FOREST

Annual Temperature Departures^a

Year	Temperature departure	Year	Temperature departure	Year	Temperature departure
1895	-0.69	1928	1.23	1961	0.20
1896	-1.39	1929	-0.64	1962	0.07
1897	-0.89	1930	0.97	1963	0.73
1898	-0.24	1931	2.24	1964	-0.06
1899	-1.74	1932	-0.57	1965	-0.93
1900	0.11	1933	-1.80	1966	-1.24
1901	0.36	1934	0.59	1967	-0.38
1902	-0.37	1935	-0.63	1968	-0.05
1903	-0.60	1936	-1.20	1969	-0.37
1904	-1.00	1937	0.01	1970	-0.38
1905	0.77	1938	1.28	1971	-0.15
1906	0.20	1939	0.46	1972	-1.65
1907	-2.60	1940	0.91	1973	0.55
1908	-0.58	1941	1.14	1974	-0.30
1909	-2.28	1942	0.89	1975	-0.12
1910	0.02	1943	1.20	1976	1.19
1911	-1.55	1944	2.00	1977	1.30
1912	-0.19	1945	-0.33	1978	0.07
1913	-0.65	1946	-0.02	1979	-0.45
1914	-0.31	1947	-0.15	1980	0.90
1915	1.15	1948	-0.05	1981	2.48
1916	-1.41	1949	0.08	1982	-1.44
1917	-1.66	1950	-2.10	1983	0.59
1918	-0.58	1951	-1.74	1984	0.82
1919	-0.98	1952	1.15	1985	-0.13
1920	-0.11	1953	1.22	1986	1.17
1921	0.16	1954	0.19	1987	3.04
1922	-0.44	1955	-1.08	1988	1.20
1923	0.06	1956	-0.30	1989	0.07
1924	-0.62	1957	0.01	1990	0.08
1925	-0.45	1958	1.02	1991	1.34
1926	0.46	1959	0.02	1992	1.03
1927	-1.11	1960	0.46		

^aAnnual temperature departure expressed in degrees Celsius and relative to a 1951–80 reference period.

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Canadian national and regional annual temperature departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent, and R. Whitewood (continued)

PRAIRIES

Trends

The Prairies region stretches eastward from the foothills of the Rocky Mountains across the southern portions of Alberta, Saskatchewan and Manitoba. The region has no major relief features but the gently rolling landscape slopes gradually downward from west to east. An overall warming trend of 0.9°C is shown for the Prairies over the period 1895–1992. The trend is significant at the 5% level. Three distinct trend segments appear in the series with warming from the 1890s to the 1930s, cooling to the 1970s, and warming to the 1990s.

Annual temperature departure relative to the 1951–80 reference period.

CITE AS: Findlay, B.F., D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent, and R. Whitewood. 1994. Canadian national and regional annual temperature departures. pp. 738–764. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Canadian national and regional annual temperature departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent, and R. Whitewood (continued)

PRAIRIES

Annual Temperature Departures^a

Year	Temperature departure	Year	Temperature departure	Year	Temperature departure
1895	-0.79	1928	1.26	1961	1.10
1896	-1.15	1929	-0.53	1962	0.56
1897	-0.64	1930	1.18	1963	1.34
1898	-0.35	1931	2.69	1964	0.05
1899	-1.58	1932	-0.05	1965	-1.13
1900	0.65	1933	-0.07	1966	-0.93
1901	0.43	1934	1.75	1967	-0.24
1902	-0.28	1935	-0.55	1968	0.18
1903	-0.50	1936	-0.71	1969	-0.76
1904	-0.92	1937	-0.31	1970	-0.67
1905	0.46	1938	1.23	1971	-0.28
1906	0.65	1939	1.09	1972	-1.27
1907	-1.55	1940	0.80	1973	0.68
1908	0.64	1941	1.42	1974	0.12
1909	-1.05	1942	0.62	1975	-0.56
1910	0.98	1943	0.59	1976	1.17
1911	-1.09	1944	1.29	1977	0.84
1912	-0.06	1945	-0.46	1978	-0.63
1913	-0.04	1946	0.35	1979	-0.61
1914	0.30	1947	-0.03	1980	0.63
1915	0.94	1948	-0.20	1981	2.49
1916	-1.63	1949	0.03	1982	-1.16
1917	-1.21	1950	-2.18	1983	0.77
1918	0.70	1951	-2.17	1984	0.90
1919	-0.23	1952	0.81	1985	-0.41
1920	0.25	1953	1.32	1986	1.50
1921	0.81	1954	0.15	1987	3.14
1922	0.11	1955	-1.26	1988	1.86
1923	0.77	1956	-0.37	1989	0.14
1924	-0.29	1957	0.32	1990	1.00
1925	0.30	1958	1.08	1991	1.30
1926	0.68	1959	0.04	1992	1.16
1927	-1.26	1960	0.51		

^aAnnual temperature departure expressed in degrees Celsius and relative to a 1951–80 reference period.

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Canadian national and regional annual temperature departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent, and R. Whitewood (continued)

SOUTH BRITISH COLUMBIA MOUNTAINS

Trends

The South British Columbia Mountains region is bounded by the Coast Mountains to the west, the North British Columbia Mountains region to the north, and the Rocky Mountains to the east. The region consists of broad plateaus, valleys, highlands and mountains. An overall warming trend of 0.6°C is shown for the region over the period 1895–1992. The trend is significant at the 5% level. A number of trend segments appear in the series with cooling from about 1900 to the late teens, warming to the 1940s, cooling to the 1970s, and warming to the 1990s.

Annual temperature departure relative to the 1951–80 reference period.

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Canadian national and regional annual temperature departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent,
and R. Whitewood (continued) SOUTH BRITISH
COLUMBIA MOUNTAINSAnnual Temperature Departures^a

Year	Temperature departure	Year	Temperature departure	Year	Temperature departure
1895	-0.01	1928	0.70	1961	0.76
1896	-0.76	1929	-0.43	1962	0.33
1897	-0.06	1930	0.05	1963	0.82
1898	0.55	1931	0.88	1964	-0.55
1899	-0.29	1932	-0.03	1965	0.04
1900	0.78	1933	-0.37	1966	0.10
1901	0.72	1934	1.31	1967	0.85
1902	-0.08	1935	-0.31	1968	-0.16
1903	-0.30	1936	-0.46	1969	0.04
1904	0.38	1937	-0.63	1970	-0.22
1905	0.40	1938	0.95	1971	-0.45
1906	0.87	1939	1.15	1972	-0.97
1907	-0.60	1940	1.31	1973	0.01
1908	0.10	1941	1.64	1974	0.50
1909	-1.25	1942	0.63	1975	-0.66
1910	0.21	1943	-0.25	1976	0.35
1911	-1.30	1944	0.74	1977	0.20
1912	-0.23	1945	0.11	1978	-0.11
1913	-1.06	1946	0.25	1979	0.09
1914	0.04	1947	0.71	1980	0.44
1915	0.91	1948	-0.54	1981	1.31
1916	-2.00	1949	-0.56	1982	-0.55
1917	-0.94	1950	-1.20	1983	0.67
1918	0.17	1951	-1.05	1984	0.05
1919	-0.94	1952	0.27	1985	-0.59
1920	-0.37	1953	1.04	1986	0.85
1921	-0.43	1954	-0.45	1987	1.92
1922	-1.09	1955	-1.82	1988	0.91
1923	0.49	1956	-0.48	1989	0.55
1924	0.00	1957	-0.45	1990	0.67
1925	0.91	1958	1.70	1991	1.03
1926	1.19	1959	-0.35	1992	1.43
1927	-1.02	1960	0.18		

^aAnnual temperature departure expressed in degrees Celsius and relative to a 1951–80 reference period.

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Canadian national and regional annual temperature departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent, and R. Whitewood (continued)

PACIFIC COAST

Trends

The Pacific Coast region comprises a narrow coastal band from Vancouver Island and the lower mainland in the south to the Queen Charlotte Islands in the north. The region consists of islands, west-facing slopes and indented fiords. An overall warming trend of 0.4°C is shown for the Pacific Coast over the period 1895–1992. However, the trend is not significant at the 5% level. Three distinct trend segments appear in the series with very gradual warming from the 1890s to the 1940s, cooling to the 1970s, and warming to the 1990s.

Annual temperature departure relative to the 1951–80 reference period.

CITE AS: Findlay, B.F., D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent, and R. Whitewood. 1994. Canadian national and regional annual temperature departures. pp. 738–764. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Canadian national and regional annual temperature departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent,
and R. Whitewood (continued)

PACIFIC COAST

Annual Temperature Departures^a

Year	Temperature departure	Year	Temperature departure	Year	Temperature departure
1895	-0.07	1928	0.65	1961	0.70
1896	-1.20	1929	-0.04	1962	0.22
1897	-0.39	1930	0.07	1963	0.94
1898	0.29	1931	0.72	1964	-0.48
1899	-0.07	1932	0.03	1965	-0.07
1900	0.51	1933	-0.35	1966	0.04
1901	0.09	1934	1.17	1967	0.62
1902	0.01	1935	0.20	1968	-0.07
1903	-0.35	1936	0.21	1969	-0.12
1904	-0.15	1937	0.13	1970	-0.19
1905	0.45	1938	0.64	1971	-0.73
1906	0.63	1939	0.64	1972	-0.81
1907	-0.15	1940	1.24	1973	-0.48
1908	-0.33	1941	1.22	1974	0.09
1909	-1.37	1942	0.77	1975	-0.70
1910	-0.45	1943	-0.07	1976	-0.15
1911	-0.93	1944	0.62	1977	-0.03
1912	0.33	1945	0.07	1978	0.23
1913	-0.42	1946	-0.15	1979	0.28
1914	0.34	1947	0.29	1980	0.38
1915	1.27	1948	-0.58	1981	0.93
1916	-1.07	1949	-0.58	1982	-0.27
1917	-0.57	1950	-1.12	1983	0.78
1918	0.16	1951	-0.41	1984	0.07
1919	-0.42	1952	-0.05	1985	-0.59
1920	-0.49	1953	0.41	1986	0.68
1921	-0.46	1954	-0.32	1987	1.10
1922	-0.57	1955	-1.23	1988	0.54
1923	0.57	1956	-0.42	1989	0.63
1924	0.12	1957	0.19	1990	0.51
1925	0.61	1958	1.58	1991	0.43
1926	1.29	1959	0.26	1992	1.17
1927	-0.36	1960	0.30		

^aAnnual temperature departure expressed in degrees Celsius and relative to a 1951–80 reference period.

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YUKON/NORTH BRITISH COLUMBIA MOUNTAINS

Trends

The Yukon/North British Columbia Mountains region includes all of Yukon Territory and British Columbia north of about 56° N. The rugged terrain varies from alpine to sub-alpine to lowland boreal. An overall warming trend of 0.8°C is shown for the region over the period 1901–92. However, the trend is not significant at the 5% level. Three distinct trend segments similar to those of the neighboring southern regions appear in the series with warming from the early 1900s to the 1940s, cooling to the 1970s, and warming to the 1990s.

Annual temperature departure relative to the 1951–80 reference period.

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Canadian national and regional annual temperature departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent,
and R. Whitewood (continued) YUKON/NORTH BRITISH
COLUMBIA MOUNTAINSAnnual Temperature Departures^a

Year	Temperature departure	Year	Temperature departure	Year	Temperature departure
1895		1928	1.08	1961	-0.63
1896		1929	0.88	1962	0.68
1897		1930	-0.47	1963	0.97
1898		1931	0.78	1964	-0.53
1899		1932	-1.92	1965	-0.56
1900		1933	-2.62	1966	-1.69
1901	0.29	1934	0.78	1967	0.01
1902	-0.51	1935	-1.07	1968	-0.08
1903	-0.01	1936	-0.82	1969	-0.03
1904	-0.51	1937	1.43	1970	0.27
1905	1.39	1938	1.18	1971	-1.16
1906	-0.11	1939	0.55	1972	-2.12
1907	-0.71	1940	2.08	1973	-1.09
1908	-0.01	1941	0.96	1974	-0.22
1909	-2.31	1942	1.93	1975	-0.85
1910	-0.81	1943	1.68	1976	1.55
1911	-0.41	1944	2.47	1977	1.48
1912	1.39	1945	0.58	1978	1.44
1913	-0.61	1946	0.31	1979	0.22
1914	0.99	1947	1.44	1980	0.88
1915	2.29	1948	-0.72	1981	2.78
1916	0.09	1949	0.40	1982	-1.29
1917	-1.81	1950	-1.30	1983	-0.15
1918	-0.31	1951	-1.05	1984	1.22
1919	-1.21	1952	0.91	1985	0.65
1920	-0.91	1953	1.04	1986	1.24
1921	-0.81	1954	0.02	1987	2.60
1922	-0.71	1955	-1.28	1988	1.65
1923	1.09	1956	-0.93	1989	0.87
1924	-0.21	1957	0.95	1990	-0.13
1925	-0.17	1958	1.04	1991	1.26
1926	2.78	1959	-0.49	1992	0.88
1927	-1.27	1960	1.28		

^aAnnual temperature departure expressed in degrees Celsius and relative to a 1951–80 reference period.

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Canadian national and regional annual temperature departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent, and R. Whitewood (continued)

MACKENZIE DISTRICT

Trends

The Mackenzie district takes in a major portion of the Mackenzie River drainage basin, including Great Bear and Great Slave lakes. The terrain is fairly flat but rugged, rising gently from the east to the Mackenzie Mountains in the west. An overall warming trend of 1.7°C is shown for the Mackenzie District over the period 1895–1992. The trend is significant at the 5% level. Three distinct similar trend segments to those of the Yukon/North British Columbia Mountains region appear in the series with warming from the 1890s to the 1940s, cooling to the 1970s, and warming to the 1990s.

Annual temperature departure relative to the 1951–80 reference period.

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Canadian national and regional annual temperature departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent,
and R. Whitewood (continued)

MACKENZIE DISTRICT

Annual Temperature Departures^a

Year	Temperature departure	Year	Temperature departure	Year	Temperature departure
1895	-0.71	1928	0.84	1961	-1.16
1896	-1.81	1929	-0.20	1962	0.22
1897	-1.81	1930	0.64	1963	0.44
1898	-0.19	1931	0.88	1964	-0.78
1899	-2.29	1932	-1.00	1965	-0.46
1900	-0.79	1933	-2.22	1966	-1.38
1901	-0.54	1934	-0.38	1967	-0.25
1902	-1.54	1935	-1.20	1968	-0.26
1903	-0.39	1936	-2.22	1969	0.35
1904	-0.54	1937	0.78	1970	-0.02
1905	1.06	1938	1.38	1971	-0.04
1906	-0.19	1939	-0.26	1972	-1.31
1907	-3.14	1940	1.22	1973	1.19
1908	-1.49	1941	0.02	1974	-1.09
1909	-2.65	1942	1.00	1975	-0.21
1910	-0.52	1943	1.94	1976	1.16
1911	-0.45	1944	2.37	1977	0.96
1912	0.25	1945	-0.20	1978	0.46
1913	-1.42	1946	-0.38	1979	0.29
1914	-0.98	1947	-0.20	1980	1.22
1915	0.64	1948	-0.20	1981	2.81
1916	-0.73	1949	0.61	1982	-1.54
1917	-2.33	1950	-0.89	1983	-0.29
1918	-1.91	1951	-0.99	1984	0.16
1919	-1.56	1952	1.02	1985	-0.05
1920	-0.03	1953	1.39	1986	0.39
1921	0.09	1954	0.39	1987	2.38
1922	-1.18	1955	-0.79	1988	0.65
1923	-0.51	1956	-0.72	1989	0.36
1924	-0.31	1957	0.14	1990	-0.15
1925	-1.31	1958	0.95	1991	0.85
1926	0.37	1959	-0.82	1992	0.48
1927	-1.18	1960	0.12		

^aAnnual temperature departure expressed in degrees Celsius and relative to a 1951–80 reference period.

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Canadian national and regional annual temperature departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent, and R. Whitewood (continued)

ARCTIC TUNDRA

Trends

The Arctic Tundra region includes all of northern Canada above the tree line except for the Arctic Mountains and Fiords region along its northeastern periphery. The landscape is treeless, open, and covered with ice caps and permafrost. An overall warming trend of 0.6°C is shown for the Arctic Tundra over the period 1922–92. However, the trend is not significant at the 5% level. Trend segments indicate warming from 1922 to the 1940s, followed by cooling to the 1990s.

Annual temperature departure relative to the 1951–80 reference period.

CITE AS: Findlay, B.F., D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent, and R. Whitewood. 1994. Canadian national and regional annual temperature departures. pp. 738–764. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Canadian national and regional annual temperature departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent, and R. Whitewood (continued)

ARCTIC TUNDRA

Annual Temperature Departures^a

Year	Temperature departure	Year	Temperature departure	Year	Temperature departure
1895		1928	-0.34	1961	-0.59
1896		1929	-1.74	1962	0.15
1897		1930	0.39	1963	0.09
1898		1931	0.93	1964	-1.11
1899		1932	-0.51	1965	-0.63
1900		1933	-2.01	1966	0.33
1901		1934	-1.04	1967	-0.70
1902		1935	-0.61	1968	0.67
1903		1936	-2.11	1969	1.00
1904		1937	0.69	1970	-0.22
1905		1938	1.36	1971	0.34
1906		1939	-0.76	1972	-2.40
1907		1940	1.14	1973	1.13
1908		1941	-0.09	1974	-1.39
1909		1942	0.69	1975	0.13
1910		1943	0.54	1976	-0.50
1911		1944	0.99	1977	1.34
1912		1945	0.04	1978	-0.75
1913		1946	-0.58	1979	-0.16
1914		1947	0.86	1980	0.61
1915		1948	0.37	1981	2.23
1916		1949	-0.26	1982	-0.93
1917		1950	-0.81	1983	-0.30
1918		1951	0.21	1984	-0.02
1919		1952	1.02	1985	0.45
1920		1953	0.84	1986	-0.83
1921		1954	0.34	1987	0.51
1922	-1.56	1955	0.83	1988	0.96
1923	-1.56	1956	-0.75	1989	-0.12
1924	1.44	1957	-0.28	1990	-0.70
1925	-1.26	1958	0.63	1991	-0.09
1926	-2.59	1959	-0.30	1992	-0.67
1927	-0.09	1960	0.84		

^aAnnual temperature departure expressed in degrees Celsius and relative to a 1951–80 reference period.

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Canadian national and regional annual temperature departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent,
and R. Whitewood (continued)

ARCTIC MOUNTAINS AND FIORDS

Trends

The Arctic Mountains and Fiords region consists of a long, slender band of rugged, mountainous and icy terrain along the eastern flanks of Ellesmere and Baffin islands and along the western shores of Baffin Bay and Davis Strait. An overall cooling trend of -0.8°C is shown for the region over the period 1946–92. However, the trend is not significant at the 5% level. The cooling evidenced in this region is part of a large, persistent area of cooling air temperatures over the northwest Atlantic Ocean.

Annual temperature departure relative to the 1951–80 reference period.

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Canadian national and regional annual temperature departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent,
and R. Whitewood (continued) ARCTIC MOUNTAINS
AND FIORDSAnnual Temperature Departures^a

Year	Temperature departure	Year	Temperature departure	Year	Temperature departure
1895		1928		1961	-0.92
1896		1929		1962	0.68
1897		1930		1963	0.43
1898		1931		1964	-0.70
1899		1932		1965	0.53
1900		1933		1966	0.08
1901		1934		1967	-0.07
1902		1935		1968	-0.05
1903		1936		1969	0.88
1904		1937		1970	-0.20
1905		1938		1971	0.01
1906		1939		1972	-1.90
1907		1940		1973	0.01
1908		1941		1974	-0.82
1909		1942		1975	-0.32
1910		1943		1976	-0.57
1911		1944		1977	0.63
1912		1945		1978	-0.45
1913		1946	0.07	1979	-0.82
1914		1947	2.02	1980	0.93
1915		1948	-0.05	1981	2.21
1916		1949	-0.32	1982	-0.52
1917		1950	-0.12	1983	-0.72
1918		1951	-0.20	1984	-1.05
1919		1952	0.73	1985	0.53
1920		1953	0.38	1986	-0.72
1921		1954	0.21	1987	-0.90
1922		1955	0.88	1988	1.28
1923		1956	-0.57	1989	-0.85
1924		1957	-0.47	1990	-0.70
1925		1958	0.86	1991	0.03
1926		1959	-0.20	1992	-1.53
1927		1960	1.01		

^aAnnual temperature departure expressed in degrees Celsius and relative to a 1951–80 reference period.

CITE AS: Findlay, B.F., D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent, and R. Whitewood. 1994. Canadian national and regional annual temperature departures. pp. 738–764. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Canadian national and regional annual temperature departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent,
and R. Whitewood (continued)

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Introduction

PRECIPITATION

Global climate models suggest that significant changes in global precipitation will accompany the increase in global mean temperature that is predicted to result from continuing increases in the concentrations of atmospheric greenhouse gases (IPCC 1990). As with temperature change, the various parts of the globe are expected to differ with respect to the type of change (i.e., increased vs. decreased precipitation) and the relative magnitude of change. The resultant geographical and seasonal distribution of the changes will determine the nature of environmental, societal, and economic impacts. Although the many models in use differ greatly in their predicted magnitude of temperature and precipitation changes, all the models predict enhanced precipitation in the high latitudes as well as the tropics throughout the year and in the midlatitudes in winter (IPCC 1990). In assessing the relative validity of these model forecasts, researchers must examine past precipitation records for clues to determine which factors may be associated with observed regional fluctuations or trends. Such efforts have become a major component of climate analysis and research.

Obtaining an accurate record of precipitation (i.e., rain and the liquid water equivalent of the various forms of frozen or freezing water) over a region or nation is inherently more difficult than obtaining an accurate record of temperature. Much of the difficulty arises from the instrumentation itself; numerous types of precipitation gauges, which vary considerably in collection efficiency, have been employed at various times and in various places over the years. In addition, other important differences in the accuracy of measurements may arise from differences in the height of the gauges above the ground, the methods of converting snowfall amount to the liquid water equivalent, the placement of the gauges with respect to their physical surroundings, and the frequency of reading and emptying gauges. All of these factors unintentionally introduce biases into data records. Therefore, it is critical to assess carefully the accuracy and homogeneity of precipitation data sets at all scales, especially long-term data sets covering large regions that may contain records from many nations.

The vast majority of existing precipitation records consist of surface-based observations from land areas. The relatively small number of surface-based observations over the oceans (obtained mainly from island stations, fixed-position weather ships, and buoys) are generally of uncertain quality and utility. During approximately the past 20 years, techniques have been developed for indirectly estimating precipitation by using satellite-based observations of upwelling infrared and microwave radiation that are calibrated with "ground truth" precipitation data (cf. Arkin and Ardanuy 1989). These techniques would seem to offer future promise for significantly improving the monitoring of global precipitation (Rasmusson and Arkin 1993).

As yet, researchers have no firm evidence of global-scale, multidecadal trends in precipitation (IPCC 1990). However, regional trends have been observed, and as noted by Rasmusson and Arkin (1993), the most profound societal impacts of climate change may be associated with changes in local and regional precipitation regimes. With these considerations in mind, we present summaries of ten analyses of surface-based precipitation observations for regions representing much of the world's land area (see figure on next page). The regions range in size from England and Wales to the main portion of the former

Regions of the world (darkened) for which precipitation records are presented in this chapter.

Soviet Union. Data from several of the larger areas (e.g., Canada and the United States) have also been examined on subscales that correspond with variations in land surface type, elevation, and overall climate. For some regions, time series data are expressed as precipitation totals; for others, they are expressed as departures from a specific reference period average. Time series of *annual* precipitation are available for all regions; in addition, series for some regions give *seasonal* or *monthly* values. The length of most of the series is approximately a century, with the exception of the England and Wales series (whose record extends 226 years), and several series for parts of North America (whose records extend 41–45 years).

The data presented in this chapter have been provided to CDIAC by the principal investigator(s) listed at the beginning of each summary. We urge readers to credit the principal investigators and their organizations (rather than CDIAC) when using these data; the appropriate citation for each summary is included at the bottom of each page. Readers are also advised to examine closely any table footnotes for specific details about data sets, and are encouraged to contact CDIAC before applying the data in specific model exercises or research exercises. The editors hope that this chapter will prove to be a convenient and useful source of information on precipitation trends. We anticipate that future issues of *Trends* will expand global coverage by including additional surface-based precipitation records and possibly satellite-based observations.

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Precipitation

Century-scale series of annual precipitation over the contiguous United States and Southern Canada

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United States and Southern Canada (South of 55° N) • Northwestern United States/Southwestern Canada • Northcentral United States/Southcentral Canada • Northeastern United States/Southeastern Canada • Southwestern United States • Southcentral U.S.

Period of Record

1891–1990

Methods

The century-long time series of Groisman and Easterling represent unbiased estimates of annual precipitation amount over the United States and Southern Canada (south of 55° N). The following summary of the methods used in obtaining these estimates draws from Groisman and Easterling (1994). For more specific details on the rather complex methods by which these data were assembled and adjusted, the reader is referred to this source.

*United States and
Southern Canada*

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Century-scale series of annual precipitation over the contiguous United States and Southern Canada

P.Ya. Groisman and D.R. Easterling (continued)

The data used in the construction of these series are records from a 593-station subset of the United States Historical Climatology Network (HCN) (Karl et al. 1990) along with those from 1380 Canadian stations. The stations selected from the HCN were those with records predating 1900 that experienced few station moves or other sources of inhomogeneities. The Canadian stations were a special collection of stations designed to maximize geographical coverage early in the analysis period. Most of the stations with the earliest records did not operate later in the period, so their records were combined (using appropriate adjustment schemes) with those from more modern stations to construct unbiased Canadian series. Area averaging of annual precipitation over the U.S. and Canadian regions was performed separately for each country because of significant differences in methods of precipitation measurements. Each area-average time series was then adjusted to remove biases using methods described in Groisman et al. (1991). The U.S. and Canadian series were then combined to form a series for the entire region under study.

Groisman and Easterling (1994) also examined the spatial correlation of the precipitation field over North America in deciding how to perform regional analyses. They divided the U.S. and Southern Canada region into five homogeneous regions by using the results of a principal component analysis of runoff data for the United States (Lins 1985). The names assigned these five regions were Southwestern United States, Southcentral United States, Northwestern United States, Northcentral United States, and Northeastern United States. The last three regions, however, extend northward into Canada to 55° N, so for further clarity the last three regions will be referred to here as *Northwestern United States/Southwestern Canada*, *Northcentral United States/Southcentral Canada*, and *Northeastern United States/Southeastern Canada*.

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Precipitation

Century-scale series of annual precipitation over the contiguous United States and Southern Canada

P.Ya. Groisman and D.R. Easterling (continued)

UNITED STATES AND SOUTHERN CANADA (South of 55° N)

Trends

Groisman and Easterling (1994) performed simple linear regression analyses on the time series from the entire U.S./Southern Canada study region and the regional North American time series. They found that the area-average precipitation time series for the entire study region showed a significant (at the 5% level) upward trend in precipitation amount of +7.6% per 100 years. They characterize this trend as indicating that during the last century a large-scale increase in North American precipitation has occurred, owing mainly to increases in eastern Canada and adjacent regions of the United States (see following sections detailing regional trends).

Annual precipitation amount for the United States and Southern Canada.

CITE AS: Groisman, P.Ya., and D.R. Easterling. 1994. Century-scale series of annual precipitation over the contiguous United States and Southern Canada. pp. 770–784. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Century-scale series of annual precipitation over the contiguous United States and Southern Canada

P.Ya. Groisman and D.R. Easterling (continued)

UNITED STATES AND SOUTHERN CANADA (South of 55° N)

Annual Precipitation Amount (mm), 1891–1990

Year	Precipitation amount	Year	Precipitation amount	Year	Precipitation amount
1891	938.0	1925	857.4	1959	936.5
1892	902.6	1926	910.0	1960	866.6
1893	907.3	1927	996.2	1961	943.0
1894	859.4	1928	895.0	1962	896.5
1895	880.7	1929	889.0	1963	843.4
1896	910.4	1930	804.0	1964	980.2
1897	883.1	1931	857.6	1965	955.2
1898	914.8	1932	954.2	1966	912.9
1899	888.7	1933	895.2	1967	935.0
1900	954.3	1934	825.9	1968	981.0
1901	885.1	1935	878.7	1969	961.8
1902	957.5	1936	850.0	1970	944.9
1903	917.8	1937	947.9	1971	975.8
1904	864.9	1938	913.5	1972	964.1
1905	949.4	1939	851.0	1973	1055.6
1906	967.0	1940	924.6	1974	964.6
1907	941.4	1941	997.8	1975	1011.9
1908	922.5	1942	961.2	1976	851.8
1909	969.7	1943	854.5	1977	970.0
1910	795.5	1944	932.9	1978	934.9
1911	901.1	1945	1010.1	1979	1012.7
1912	940.9	1946	945.4	1980	940.5
1913	910.6	1947	925.4	1981	922.0
1914	838.9	1948	928.9	1982	1055.6
1915	972.7	1949	907.9	1983	1084.1
1916	923.1	1950	961.2	1984	980.0
1917	827.0	1951	969.8	1985	937.9
1918	908.8	1952	856.6	1986	976.3
1919	931.9	1953	932.8	1987	904.3
1920	915.7	1954	905.9	1988	875.6
1921	895.2	1955	912.1	1989	919.2
1922	890.7	1956	846.0	1990	1014.5
1923	924.1	1957	983.1		
1924	842.8	1958	927.5		

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Precipitation

Century-scale series of annual precipitation over the contiguous United States and Southern Canada

P.Ya. Groisman and D.R. Easterling (continued)

NORTHWESTERN UNITED STATES/ SOUTHWESTERN CANADA

Trends

Groisman and Easterling (1994) performed simple linear regression analyses on their regional North American time series and found that the area-average precipitation time series for the Northwestern U.S./Southwestern Canada region showed a nonsignificant (at the 5% level) upward trend in precipitation amount of +5.5% per 100 years. Groisman and Easterling (1994) also checked for correlations between their regional series and two well-known indices of climatic change: the global surface air temperature series of Vinnikov et al. (1990) and the Southern Oscillation Index (SOI) (Ropelewski 1992, personal communication). They found a statistically significant (at the 5% level) correlation between Northwestern U.S./Southwestern Canada annual precipitation variations and annual variations of hemispheric surface air temperature.

Annual precipitation amount for the Northwestern U.S./Southwestern Canada region.

CITE AS: Groisman, P.Ya., and D.R. Easterling. 1994. Century-scale series of annual precipitation over the contiguous United States and Southern Canada. pp. 770-784. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Century-scale series of annual precipitation over the contiguous United States and Southern Canada

P.Ya. Groisman and D.R. Easterling (continued)

NORTHWESTERN UNITED STATES/ SOUTHWESTERN CANADA

Annual Precipitation Amount (mm), 1891–1990

Year	Precipitation amount	Year	Precipitation amount	Year	Precipitation amount
1891	856.3	1925	773.9	1959	842.2
1892	778.3	1926	773.8	1960	743.4
1893	871.4	1927	935.4	1961	803.0
1894	826.0	1928	695.1	1962	860.5
1895	740.1	1929	635.3	1963	852.3
1896	863.3	1930	671.5	1964	926.3
1897	806.6	1931	746.0	1965	870.4
1898	765.8	1932	874.4	1966	830.3
1899	917.3	1933	874.5	1967	861.5
1900	880.4	1934	743.4	1968	959.4
1901	855.6	1935	736.4	1969	812.3
1902	897.6	1936	686.4	1970	855.9
1903	844.8	1937	828.9	1971	946.7
1904	780.0	1938	752.3	1972	874.2
1905	804.7	1939	750.5	1973	879.4
1906	906.5	1940	803.9	1974	863.4
1907	828.0	1941	855.4	1975	974.2
1908	839.1	1942	842.7	1976	753.0
1909	887.1	1943	725.2	1977	828.4
1910	757.6	1944	760.7	1978	842.5
1911	775.9	1945	827.4	1979	753.9
1912	847.4	1946	845.5	1980	881.2
1913	810.1	1947	849.8	1981	841.0
1914	795.1	1948	883.1	1982	959.0
1915	827.3	1949	735.7	1983	917.7
1916	861.7	1950	900.4	1984	900.8
1917	764.0	1951	840.6	1985	727.8
1918	765.4	1952	667.5	1986	890.5
1919	743.3	1953	940.6	1987	769.8
1920	797.9	1954	892.2	1988	758.3
1921	858.3	1955	896.4	1989	809.2
1922	750.5	1956	820.7	1990	886.1
1923	824.0	1957	814.0		
1924	754.8	1958	825.3		

CITE AS: Groisman, P.Ya., and D.R. Easterling. 1994. Century-scale series of annual precipitation over the contiguous United States and Southern Canada. pp. 770–784. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Precipitation

Century-scale series of annual precipitation over the contiguous United States and Southern Canada

P.Ya. Groisman and D.R. Easterling (continued)

NORTHCENTRAL UNITED STATES/ SOUTHCENTRAL CANADA

Trends

Groisman and Easterling (1994) performed simple linear regression analyses on their regional North American time series and found that the area-average precipitation time series for the Northcentral U.S./Southcentral Canada region showed a significant (at the 0.1% level) upward trend in precipitation amount of +12.1% per 100 years. The linear trend was found to account for 20% of the variance in annual precipitation for this region. Groisman and Easterling (1994) also checked for correlations between their regional series and two well-known indices of climatic change: the global surface air temperature series of Vinnikov et al. (1990) and the Southern Oscillation Index (SOI) (Ropelewski 1992, personal communication). They found a statistically significant (at the 5% level) correlation between the Northcentral U.S./Southcentral Canada annual precipitation variations and both the annual variations of hemispheric surface air temperature and the SOI.

Annual precipitation amount for the Northcentral U.S./Southcentral Canada region.

CITE AS: Groisman, P.Ya., and D.R. Easterling. 1994. Century-scale series of annual precipitation over the contiguous United States and Southern Canada. pp. 770-784. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Century-scale series of annual precipitation over the contiguous
United States and Southern Canada

P.Ya. Groisman and D.R. Easterling (continued)

NORTHCENTRAL UNITED STATES/ SOUTHCENTRAL CANADA

Annual Precipitation Amount (mm), 1891–1990

Year	Precipitation amount	Year	Precipitation amount	Year	Precipitation amount
1891	873.2	1925	772.8	1959	905.2
1892	802.0	1926	800.3	1960	837.0
1893	791.1	1927	869.9	1961	816.8
1894	742.1	1928	870.0	1962	846.0
1895	741.0	1929	792.4	1963	739.6
1896	854.8	1930	772.1	1964	940.1
1897	783.3	1931	788.7	1965	978.5
1898	824.5	1932	860.5	1966	919.0
1899	803.5	1933	783.1	1967	819.9
1900	885.5	1934	769.6	1968	972.1
1901	797.6	1935	809.6	1969	880.7
1902	875.1	1936	740.7	1970	910.8
1903	889.7	1937	863.0	1971	906.4
1904	809.6	1938	922.4	1972	850.5
1905	836.8	1939	756.7	1973	924.4
1906	834.6	1940	797.4	1974	881.2
1907	826.2	1941	960.4	1975	876.0
1908	809.0	1942	911.4	1976	732.0
1909	882.1	1943	845.9	1977	958.1
1910	682.6	1944	880.0	1978	862.9
1911	837.7	1945	885.9	1979	940.4
1912	820.2	1946	877.1	1980	823.1
1913	802.8	1947	872.8	1981	810.1
1914	749.4	1948	800.5	1982	996.4
1915	891.2	1949	863.9	1983	936.3
1916	862.4	1950	906.9	1984	918.1
1917	752.0	1951	930.7	1985	982.5
1918	858.9	1952	844.6	1986	939.5
1919	859.3	1953	878.5	1987	819.5
1920	737.2	1954	899.0	1988	889.8
1921	874.4	1955	852.7	1989	770.2
1922	764.6	1956	782.8	1990	942.0
1923	735.2	1957	877.7		
1924	800.8	1958	772.5		

CITE AS: Groisman, P.Ya., and D.R. Easterling. 1994. Century-scale series of annual precipitation over the contiguous United States and Southern Canada. pp. 770–784. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Precipitation

Century-scale series of annual precipitation over the contiguous United States and Southern Canada

P.Ya. Groisman and D.R. Easterling (continued)

NORTHEASTERN UNITED STATES/ SOUTHEASTERN CANADA

Trends

Groisman and Easterling (1994) performed simple linear regression analyses on their regional North American time series and found that the area-average precipitation time series for the Northeastern U.S./Southeastern Canada region showed a significant (at the 0.1% level) upward trend in precipitation amount of +11.3% per 100 years. The linear trend was found to account for 20% of the variance in annual precipitation for this region. Groisman and Easterling (1994) also checked for correlations between their regional series and two well-known indices of climatic change: the global surface air temperature series of Vinnikov et al. (1990) and the Southern Oscillation Index (SOI) (Ropelewski 1992, personal communication). They found a statistically significant (at the 5% level) correlation between Northeastern U.S./Southeastern Canada annual precipitation variations and annual variations of hemispheric surface air temperature.

Annual precipitation amount for the Northeastern U.S./Southeastern Canada region.

CITE AS: Groisman, P.Ya., and D.R. Easterling. 1994. Century-scale series of annual precipitation over the contiguous United States and Southern Canada. pp. 770-784. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Century-scale series of annual precipitation over the contiguous
United States and Southern Canada

P.Ya. Groisman and D.R. Easterling (continued)

NORTHEASTERN UNITED STATES/ SOUTHEASTERN CANADA

Annual Precipitation Amount (mm), 1891–1990

Year	Precipitation amount	Year	Precipitation amount	Year	Precipitation amount
1891	1292.2	1925	1268.2	1959	1237.6
1892	1265.1	1926	1192.4	1960	1203.5
1893	1340.1	1927	1307.0	1961	1217.7
1894	1184.6	1928	1193.8	1962	1241.4
1895	1301.0	1929	1262.4	1963	1231.6
1896	1192.8	1930	1071.6	1964	1223.5
1897	1233.9	1931	1174.7	1965	1209.4
1898	1273.7	1932	1326.7	1966	1266.0
1899	1075.1	1933	1299.8	1967	1293.9
1900	1260.8	1934	1142.5	1968	1289.8
1901	1299.4	1935	1111.5	1969	1349.8
1902	1341.9	1936	1379.2	1970	1267.7
1903	1224.1	1937	1343.2	1971	1332.4
1904	1228.7	1938	1236.6	1972	1450.9
1905	1127.4	1939	1268.5	1973	1393.0
1906	1198.9	1940	1242.4	1974	1294.8
1907	1319.5	1941	1175.2	1975	1310.0
1908	1176.0	1942	1296.6	1976	1407.1
1909	1272.2	1943	1264.4	1977	1401.5
1910	1191.8	1944	1258.3	1978	1251.5
1911	1188.3	1945	1353.5	1979	1505.2
1912	1294.4	1946	1165.8	1980	1358.1
1913	1183.2	1947	1183.9	1981	1409.1
1914	1074.6	1948	1186.8	1982	1323.6
1915	1221.9	1949	1168.3	1983	1563.1
1916	1215.7	1950	1292.2	1984	1337.7
1917	1245.7	1951	1378.3	1985	1223.6
1918	1253.1	1952	1300.7	1986	1296.8
1919	1184.8	1953	1299.1	1987	1236.2
1920	1248.1	1954	1420.1	1988	1295.1
1921	1076.2	1955	1218.7	1989	1327.1
1922	1153.3	1956	1267.4	1990	1459.7
1923	1161.7	1957	1172.3		
1924	1193.2	1958	1380.0		

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Precipitation

Century-scale series of annual precipitation over the contiguous United States and Southern Canada

P.Ya. Groisman and D.R. Easterling (continued)

SOUTHWESTERN UNITED STATES

Trends

Groisman and Easterling (1994) performed simple linear regression analyses on their regional North American time series and found no century-scale trends or systematic changes in the area-average precipitation time series for the Southwestern United States. However, in checking for correlations between their regional series and two well-known indices of climatic change, the global surface air temperature series of Vinnikov et al. (1990) and the Southern Oscillation Index (SOI) (Ropelewski 1992, personal communication), they found a strong relationship (accounting for 15% of the variance) between Southwestern U.S. precipitation variations and the SOI. This agrees with findings from other studies (e.g., Ropelewski and Halpert 1986).

Annual precipitation amount for the Southwestern U.S. region.

CITE AS: Groisman, P.Ya., and D.R. Easterling. 1994. Century-scale series of annual precipitation over the contiguous United States and Southern Canada. pp. 770-784. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Century-scale series of annual precipitation over the contiguous United States and Southern Canada

P.Ya. Groisman and D.R. Easterling (continued)

SOUTHWESTERN UNITED STATES

Annual Precipitation Amount (mm), 1891–1990

Year	Precipitation amount	Year	Precipitation amount	Year	Precipitation amount
1891	542.1	1925	490.3	1959	427.9
1892	462.3	1926	540.0	1960	431.8
1893	522.6	1927	597.4	1961	460.8
1894	527.6	1928	425.5	1962	470.7
1895	559.7	1929	399.5	1963	552.5
1896	556.5	1930	519.5	1964	509.5
1897	507.1	1931	516.3	1965	599.5
1898	381.0	1932	446.8	1966	440.3
1899	529.1	1933	430.4	1967	573.4
1900	416.0	1934	384.3	1968	486.0
1901	478.0	1935	498.3	1969	673.3
1902	467.7	1936	571.7	1970	562.5
1903	439.7	1937	578.2	1971	468.9
1904	525.8	1938	578.3	1972	449.5
1905	620.0	1939	398.5	1973	570.5
1906	705.6	1940	642.3	1974	448.9
1907	611.0	1941	807.9	1975	462.9
1908	486.9	1942	462.4	1976	378.2
1909	681.0	1943	509.2	1977	444.1
1910	365.1	1944	525.8	1978	666.7
1911	561.0	1945	587.5	1979	503.1
1912	513.1	1946	492.3	1980	594.1
1913	509.4	1947	440.2	1981	537.9
1914	572.9	1948	439.6	1982	697.4
1915	594.8	1949	421.7	1983	851.5
1916	648.7	1950	464.1	1984	567.8
1917	406.3	1951	547.7	1985	489.7
1918	554.0	1952	585.4	1986	571.5
1919	478.3	1953	393.9	1987	501.0
1920	555.5	1954	481.0	1988	434.5
1921	527.7	1955	494.8	1989	346.4
1922	549.5	1956	380.7	1990	486.3
1923	501.4	1957	601.6		
1924	400.9	1958	515.9		

CITE AS: Groisman, P.Ya., and D.R. Easterling. 1994. Century-scale series of annual precipitation over the contiguous United States and Southern Canada. pp. 770–784. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Precipitation

Century-scale series of annual precipitation over the contiguous United States and Southern Canada

P.Ya. Groisman and D.R. Easterling (continued)

SOUTHCENTRAL UNITED STATES

Trends

Groisman and Easterling (1994) performed simple linear regression analyses on their regional North American time series and found that the area-average precipitation time series for the Southcentral U.S. region showed a nonsignificant (at the 5% level) upward trend in precipitation amount of +5.4% per 100 years. Groisman and Easterling (1994) also checked for correlations between their regional series and two well-known indices of climatic change: the global surface air temperature series of Vinnikov et al. (1990) and the Southern Oscillation Index (SOI) (Ropelewski 1992, personal communication). They found a statistically significant (at the 5% level) correlation between Southcentral U.S. annual precipitation variations and the SOI.

Annual precipitation amount for the Southcentral U.S. region.

CITE AS: Groisman, P.Ya., and D.R. Easterling. 1994. Century-scale series of annual precipitation over the contiguous United States and Southern Canada. pp. 770-784. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Century-scale series of annual precipitation over the contiguous United States and Southern Canada

P.Ya. Groisman and D.R. Easterling (continued)

SOUTHCENTRAL UNITED STATES

Annual Precipitation Amount (mm), 1891–1990

Year	Precipitation amount	Year	Precipitation amount	Year	Precipitation amount
1891	1086.7	1925	977.2	1959	1159.9
1892	1143.7	1926	1178.2	1960	1055.6
1893	1006.3	1927	1206.0	1961	1295.2
1894	989.7	1928	1194.3	1962	1010.5
1895	1073.3	1929	1271.4	1963	862.6
1896	1036.3	1930	961.4	1964	1185.0
1897	1048.9	1931	1030.1	1965	1064.6
1898	1223.4	1932	1177.3	1966	1042.3
1899	1026.2	1933	1036.1	1967	1099.0
1900	1204.4	1934	1014.6	1968	1102.9
1901	975.3	1935	1150.9	1969	1111.9
1902	1135.2	1936	951.8	1970	1084.0
1903	1098.5	1937	1112.3	1971	1137.5
1904	971.6	1938	1058.2	1972	1152.7
1905	1266.1	1939	1038.4	1973	1412.3
1906	1151.8	1940	1124.8	1974	1227.8
1907	1115.3	1941	1169.4	1975	1297.7
1908	1195.9	1942	1199.5	1976	992.3
1909	1110.5	1943	939.5	1977	1156.1
1910	939.5	1944	1180.9	1978	1051.9
1911	1098.4	1945	1329.4	1979	1320.9
1912	1168.3	1946	1223.1	1980	1050.8
1913	1165.4	1947	1161.7	1981	1029.0
1914	970.2	1948	1205.9	1982	1242.8
1915	1247.9	1949	1228.5	1983	1226.3
1916	1017.6	1950	1149.5	1984	1130.9
1917	943.3	1951	1124.8	1985	1181.2
1918	1086.9	1952	941.8	1986	1128.4
1919	1280.2	1953	1057.5	1987	1138.5
1920	1192.7	1954	862.1	1988	975.7
1921	1046.1	1955	1031.8	1989	1235.8
1922	1172.8	1956	938.4	1990	1235.0
1923	1282.0	1957	1338.7		
1924	1005.0	1958	1128.0		

CITE AS: Groisman, P.Ya., and D.R. Easterling. 1994. Century-scale series of annual precipitation over the contiguous United States and Southern Canada. pp. 770–784. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Century-scale series of annual precipitation over the contiguous United States and Southern Canada

P.Ya. Groisman and D.R. Easterling (continued)

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Precipitation

Area-average precipitation over the contiguous United States, Alaska, and Canada

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Alaska (West of 141° W) • Northern Canada (55°–70° N) • United States and Canada (45°–55° N) • United States and Canada (35°–45° N) • Southern United States (28°–35° N; East of 105° W)

Period of Record

1950–90

Methods

These time series constructed by Groisman and Easterling represent unbiased estimates of annual precipitation amount over the contiguous United States, Alaska (west of 141° W), and Canada. The following summary of the methods used in obtaining these estimates draws from Groisman and Easterling (1994). For more specific details on the methods by which these data were assembled and adjusted, the reader is referred to this source.

*Contiguous
United States,
Alaska, and
Canada*

CITE AS: Groisman, P.Ya., and D.R. Easterling. 1994. Area-average precipitation over the contiguous United States, Alaska, and Canada. pp. 786–798. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Area-average precipitation over the contiguous
United States, Alaska, and Canada

P.Ya. Groisman and D.R. Easterling (continued)

In constructing these precipitation series, Groisman and Easterling only used U.S. and Canadian records from 1950 onward because of two main factors: (1) station networks for northern Canada (generally north of 55° N) and Alaska only became dense enough to ensure adequate spatial coverage after World War II and (2) all U.S. first-order stations had been relocated to airports, allowing for the uniform positioning of raingauges in relatively open areas. The records used in this analysis consist of those from 593 United States Historical Climatology Network (HCN) stations (Karl et al. 1990), 45 cooperative Alaskan stations, and 1107 Canadian stations. Time series were constructed for five regions: Alaska (west of 141° W), Northern Canada (55°–70° N), the regions bounded by 45°–55° N and 35°–45° N, and the region of the United States south of 35° N and east of 105° W. Each area-average time series was adjusted to remove various regional measurement biases using methods described in Groisman et al. (1991).

CITE AS: Groisman, P.Ya., and D.R. Easterling. 1994. Area-average precipitation over the contiguous United States, Alaska, and Canada. pp. 786–798. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Precipitation

Area-average precipitation over the contiguous United States, Alaska, and Canada

P.Ya. Groisman and D.R. Easterling (continued)

ALASKA

(West of 141° W)

Trends

Although the significance of any precipitation trends in North America over only the last four decades may be limited (and possibly misleading when compared with longer-scale trends), they have been examined because Northern Canada and Alaska lack observations before ca. 1950. Groisman and Easterling (1994) performed simple linear regression analyses on their 1950–90 regional North American time series and found that the area-average precipitation time series for Alaska (west of 141° W) showed a +2.7% per decade (~11% over the 41-year period) trend in precipitation amount (significant at the 10% level; nonsignificant at the 5% level). The series may be characterized, however, by two distinct periods: one showing fairly consistent amounts from 1950–67, the other showing a large upward trend over the period 1968–90.

Annual precipitation amount for Alaska.

CITE AS: Groisman, P.Ya., and D.R. Easterling. 1994. Area-average precipitation over the contiguous United States, Alaska, and Canada. pp. 786–798. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Area-average precipitation over the contiguous United States, Alaska, and Canada

P.Ya. Groisman and D.R. Easterling (continued)

ALASKA

(West of 141° W)

Annual Precipitation Amount (mm), 1950–90

Year	Precipitation amount	Year	Precipitation amount
1950	448.0	1971	526.2
1951	581.3	1972	440.4
1952	567.9	1973	454.0
1953	476.0	1974	450.8
1954	516.7	1975	477.1
1955	549.7	1976	498.9
1956	459.7	1977	510.7
1957	470.5	1978	509.8
1958	485.3	1979	569.6
1959	447.8	1980	539.7
1960	534.5	1981	595.6
1961	558.2	1982	574.9
1962	445.7	1983	460.3
1963	570.6	1984	461.0
1964	459.0	1985	596.9
1965	556.2	1986	547.4
1966	457.0	1987	531.2
1967	546.9	1988	520.7
1968	375.7	1989	633.8
1969	400.7	1990	606.7
1970	496.8		

CITE AS: Groisman, P.Ya., and D.R. Easterling. 1994. Area-average precipitation over the contiguous United States, Alaska, and Canada. pp. 786–798. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Precipitation

Area-average precipitation over the contiguous United States, Alaska, and Canada

P.Ya. Groisman and D.R. Easterling (continued)

NORTHERN CANADA (55°–70° N)

Trends

Although the significance of any precipitation trends in North America over only the last four decades may be limited (and possibly misleading when compared with longer-scale trends), they have been examined because Northern Canada and Alaska lack observations before ca. 1950. Groisman and Easterling (1994) performed simple linear regression analyses on their 1950–90 regional North American time series and found that the area-average precipitation time series for Northern Canada shows a striking and significant (at the 0.1% level) upward trend in precipitation amount of +4.2% per decade (~17% over the 41-year period).

Annual precipitation amount for Northern Canada.

CITE AS: Groisman, P.Ya., and D.R. Easterling. 1994. Area-average precipitation over the contiguous United States, Alaska, and Canada. pp. 786–798. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Area-average precipitation over the contiguous
United States, Alaska, and Canada

P.Ya. Groisman and D.R. Easterling (continued)

NORTHERN CANADA
(55°–70° N)**Annual Precipitation Amount (mm), 1950–90**

Year	Precipitation amount	Year	Precipitation amount
1950	439.6	1971	521.5
1951	436.1	1972	473.1
1952	508.8	1973	511.0
1953	434.2	1974	512.4
1954	428.2	1975	499.2
1955	463.7	1976	497.8
1956	459.9	1977	527.7
1957	454.3	1978	476.9
1958	444.8	1979	509.8
1959	505.0	1980	545.0
1960	528.1	1981	516.5
1961	476.5	1982	507.4
1962	490.9	1983	503.3
1963	475.5	1984	513.6
1964	490.5	1985	513.3
1965	475.2	1986	529.3
1966	471.0	1987	548.6
1967	486.9	1988	565.4
1968	499.8	1989	501.1
1969	452.3	1990	540.1
1970	504.0		

CITE AS: Groisman, P.Ya., and D.R. Easterling. 1994. Area-average precipitation over the contiguous United States, Alaska, and Canada. pp. 786–798. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Precipitation

Area-average precipitation over the contiguous United States, Alaska, and Canada

P.Ya. Groisman and D.R. Easterling (continued)

UNITED STATES AND CANADA (45°–55° N)

Trends

Although the significance of any precipitation trends in North America over only the last four decades may be limited (and possibly misleading when compared with longer-scale trends), they have been examined because Northern Canada and Alaska lack observations before ca. 1950. Groisman and Easterling (1994) performed simple linear regression analyses on their 1950–90 regional North American time series and found that the area-average precipitation time series for the region from 45° N to 55° N showed essentially no trend in precipitation amount.

Annual precipitation amount for the United States and Canada (45°–55°N).

CITE AS: Groisman, P.Ya., and D.R. Easterling. 1994. Area-average precipitation over the contiguous United States, Alaska, and Canada. pp. 786–798. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Area-average precipitation over the contiguous
United States, Alaska, and Canada

P.Ya. Groisman and D.R. Easterling (continued)

UNITED STATES AND
CANADA (45°–55° N)

Annual Precipitation Amount (mm), 1950–90

Year	Precipitation amount	Year	Precipitation amount
1950	947.3	1971	996.5
1951	929.7	1972	938.3
1952	885.3	1973	964.7
1953	960.6	1974	962.4
1954	993.7	1975	950.8
1955	936.0	1976	911.5
1956	897.3	1977	947.4
1957	879.1	1978	899.4
1958	915.2	1979	958.1
1959	947.1	1980	965.8
1960	867.9	1981	941.7
1961	869.8	1982	995.5
1962	927.0	1983	1021.1
1963	893.1	1984	971.2
1964	995.1	1985	884.8
1965	949.2	1986	956.3
1966	984.7	1987	873.1
1967	916.0	1988	949.7
1968	1011.7	1989	885.5
1969	943.1	1990	999.6
1970	919.3		

CITE AS: Groisman, P.Ya., and D.R. Easterling. 1994. Area-average precipitation over the contiguous United States, Alaska, and Canada. pp. 786–798. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Precipitation

Area-average precipitation over the contiguous United States, Alaska, and Canada

P.Ya. Groisman and D.R. Easterling (continued)

UNITED STATES AND CANADA (35°–45° N)

Trends

Although the significance of any precipitation trends in North America over only the last four decades may be limited (and possibly misleading when compared with longer-scale trends), they have been examined because Northern Canada and Alaska lack observations before ca. 1950. Groisman and Easterling (1994) performed simple linear regression analyses on their 1950–90 regional North American time series and found that the area-average precipitation time series for the region from 35° N to 45° N showed a statistically significant (at the 5% level) +1.9% per decade (~8% over the 41-year period) upward trend in precipitation amount.

Annual precipitation amount for the United States and Canada (35°–45°N).

CITE AS: Groisman, P.Ya., and D.R. Easterling. 1994. Area-average precipitation over the contiguous United States, Alaska, and Canada. pp. 786–798. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Area-average precipitation over the contiguous
United States, Alaska, and Canada

P.Ya. Groisman and D.R. Easterling (continued)

**UNITED STATES
AND CANADA (35°–45° N)**

Annual Precipitation Amount (mm), 1950–90

Year	Precipitation amount	Year	Precipitation amount
1950	925.1	1971	878.3
1951	960.7	1972	1002.6
1952	838.9	1973	1034.5
1953	848.8	1974	883.4
1954	863.1	1975	974.2
1955	829.7	1976	802.2
1956	835.5	1977	955.9
1957	944.8	1978	897.6
1958	929.2	1979	990.0
1959	944.7	1980	830.9
1960	844.4	1981	913.7
1961	920.5	1982	989.2
1962	895.5	1983	1045.7
1963	787.1	1984	952.0
1964	863.6	1985	915.6
1965	850.9	1986	966.1
1966	774.6	1987	888.4
1967	931.3	1988	808.3
1968	874.8	1989	905.5
1969	935.2	1990	1004.3
1970	890.3		

CITE AS: Groisman, P.Ya., and D.R. Easterling. 1994. Area-average precipitation over the contiguous United States, Alaska, and Canada. pp. 786–798. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Precipitation

Area-average precipitation over the contiguous United States, Alaska, and Canada

P.Ya. Groisman and D.R. Easterling (continued)

SOUTHERN UNITED STATES

(28°–35° N; East of 105° W)

Trends

Although the significance of any precipitation trends in North America over only the last four decades may be limited (and possibly misleading when compared with longer-scale trends), they have been examined because Northern Canada and Alaska lack observations before ca. 1950. Groisman and Easterling (1994) performed simple linear regression analyses on their 1950–90 regional North American time series and found that the area-average precipitation time series for the region located between 28° N and 35° N and east of 105° W showed a statistically significant (at the 5% level) +3.4% per decade (~14% over the 41-year period) upward trend in precipitation amount. However, Groisman and Easterling (1994) found no significant century-scale trend for an area of the southern United States extending about 5° further north; this discrepancy illustrates the risk of interpreting a recent trend as a continuance of a longer one.

Annual precipitation amount for the Southern United States (28°–35°N; East of 105° W).

CITE AS: Groisman, P.Ya., and D.R. Easterling. 1994. Area-average precipitation over the contiguous United States, Alaska, and Canada. pp. 786–798. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Area-average precipitation over the contiguous
United States, Alaska, and Canada

P.Ya. Groisman and D.R. Easterling (continued)

SOUTHERN UNITED STATES

(28°–35° N; East of 105° W)

Annual Precipitation Amount (mm), 1950–90

Year	Precipitation amount	Year	Precipitation amount
1950	1143.0	1971	1209.8
1951	1022.5	1972	1172.5
1952	1012.4	1973	1469.2
1953	1207.8	1974	1311.1
1954	790.2	1975	1355.6
1955	1029.2	1976	1199.5
1956	953.9	1977	1108.1
1957	1409.1	1978	1057.3
1958	1157.7	1979	1441.6
1959	1291.2	1980	1133.6
1960	1165.7	1981	1086.5
1961	1351.8	1982	1278.9
1962	1049.6	1983	1337.0
1963	968.1	1984	1159.1
1964	1301.9	1985	1203.2
1965	1090.3	1986	1191.9
1966	1179.1	1987	1209.5
1967	1100.0	1988	1075.0
1968	1157.8	1989	1304.4
1969	1185.0	1990	1246.1
1970	1111.8		

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Precipitation

Area-average precipitation over the contiguous United States, Alaska, and Canada

P.Ya. Groisman and D.R. Easterling (continued)

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- Groisman, P.Ya., and D.R. Easterling. 1994. Variability and trends of total precipitation and snowfall over the United States and Canada. *Journal of Climate* 7:184–205.
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Precipitation

Canadian national and regional standardized annual precipitation departures

*B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent,
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Canada • Atlantic Canada • Great Lakes Basin/St. Lawrence Lowlands •
Northeastern Forest • Northwestern Forest • Prairies • South British Columbia
Mountains • Pacific Coast • Yukon/North British Columbia Mountains •
Mackenzie District • Arctic Tundra • Arctic Mountains and Fiords

Period of Record

National: 1948–92; Regional: Varies by region; as long as 1895–1992

Methods

The Canadian precipitation departures series were prepared from data contained in the Historical Canadian Climate Database (HCCD). The HCCD contains a collection of total precipitation data sets (combined rainfall and water equivalent snowfall) for 131 reporting stations across Canada. These monthly and annual data have been subjected to preliminary quality assessment procedures, which take into consideration factors related to length of record, data completeness, data consistency, and homogeneity. Stations included in the present analysis were selected to coincide as much as possible with the reporting locations that were used for the corresponding temperature analyses on pp. 738–764 of this report and in the *State of the Environment Report*, SOE 92-2 (Gullett and Skinner 1992). Inconsistent record lengths, missing data problems, and inhomogeneities necessitated the selection of a small number of alternative stations for inclusion in the present analysis. Partial data sets from several neighboring stations were sometimes pieced together to form single series in an effort to increase record lengths as much as possible. Missing data were extensive in the annual precipitation data sets since missing individual monthly totals (even a single missing monthly total) resulted in corresponding missing annual totals. No attempt was made to estimate missing data; rather, stations were selected to minimize the amount of missing data in individual series. Preliminary homogeneity assessments were performed through visual inspections of the series and through reconciliations with known metadata. No data adjustments were performed.

Inhomogeneities are known to exist in the historical precipitation data sets. Many of these are a result of systematic changes to precipitation networks, measurement methods, and gauges. These include the change from standard ruler snowfall measurements to Nipher-shielded snowgauge measurements over part of the network in the 1960s (Metcalf and Goodison 1993), and the change from the copper Type A to the plastic Type B standard raingauge in the 1970s (Goodison and Louie 1986). Errors associated with overestimation of winter precipitation amounts (snow ruler measurements relative to Nipher-shielded gauge

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Canadian national and regional standardized annual precipitation departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent, and R. Whitewood (continued)

measurements) and undermeasurement of precipitation throughout the year [because of gauge wetting, wind scattering, and exclusion of trace amounts (Metcalf and Goodison 1993)] exist throughout the precipitation database. These kinds of errors and inconsistencies are complicated by the fact that the various gauge and procedural changes took place at different times at different stations throughout the history of the precipitation networks. Other inconsistencies are locally induced, such as those resulting from site relocations and environment changes; and these too have yet to be resolved. Much research and development work is required before detailed studies of trends and variability are feasible.

Extensive missing data in the precipitation database are partly responsible for the fact that monthly and annual precipitation data sets with different starting dates for individual stations have been included in the HCCD. The earliest possible starting dates that were common to the majority of stations within the climate regions were used to define the beginning date for each region. For Canada as a whole, 1948 was considered to be the first year of adequate data coverage (data for 90% of stations were available) for the 131 precipitation reporting stations used. Before 1915, fewer than 40% of the stations had

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Precipitation

Canadian national and regional standardized annual precipitation departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent,
and R. Whitewood (continued)

precipitation data, and before 1948 most of the Canadian north was not represented. Certain southern regions, in particular the more populated areas—including Atlantic Canada, the Great Lakes Basin/St. Lawrence Lowlands, the Prairies, and the South British Columbia Mountains—have suitable precipitation data coverage from 1895 onward. Time series of standardized annual precipitation departures from the 1951–80 reference period averages were prepared for the 131 individual stations in the HCCD.

Calculation of standardized departures series was carried out for individual stations by dividing each station's monthly and annual departures from normal by their standard deviations, where normal values and standard deviations were calculated for the 1951–80 period. The individual standardized departures series were then averaged to produce regional series representing the 11 Canadian climate regions outlined in the *State of the Environment Report*, SOE 92-2 (Gullett and Skinner 1992). These regions were defined through integration of areas exhibiting similar ecological attributes (Environment Canada 1989), major relief features, and temperature and precipitation characteristics (Hare and Thomas 1979). The 11 regional standardized departures series were subsequently areally weighted to account for (1) the uneven spatial distribution of stations within some regions and (2) the areal representativeness of each region relative to the area of the nation as a whole. The analysis periods were cut where necessary to provide the longest complete regional series possible. The regional series were then combined into a single national standardized annual precipitation departures series for the period 1948–92.

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Precipitation

Canadian national and regional
standardized annual precipitation departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent,
and R. Whitewood (continued)

CANADA

Trends

The national precipitation database is considered provisional; rigorous trend analysis is therefore not feasible at this time. In light of this, only general statements about historical precipitation in Canada are made. Nationally, there appears to be an overall increasing trend over the period 1948–92. Amounts prior to the 1960s are generally below the average for the long-term reference period, whereas after about 1970 they are generally above the average. The apparent increase in annual precipitation during and after the 1960s is not readily explained. Known systematic errors exist in the data including those resulting from the change from snow ruler measurements to Nipher-shielded snowgauge measurements in the 1960s, and from the Type A to Type B standard raingauges in the 1970s. Although not of the same magnitude, these two changes could partially offset one another, with the first tending to decrease recorded precipitation after the 1960s and the second tending to increase it somewhat after ca. 1975 (Groisman and Easterling 1994). If precipitation data sets were adjusted accordingly to reduce snowfall amounts before 1960 and to increase rainfall amounts before 1975, a partial canceling of these effects would result. It is difficult to

*Standardized departures of annual precipitation amount for the period 1948–92
for Canada. The departures are relative to the 1951–80 reference period.*

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Canadian national and regional
standardized annual precipitation departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent,
and R. Whitewood (continued)

CANADA

predict, however, the full impact of such adjustments on regional and national precipitation trends because more than half the precipitation recorded in Canada is of the liquid variety, and because not all stations use Nipher-shielded gauges for snowfall measurement. Further assessment of the data is necessary before more definitive statements are possible.

Of the 11 Canadian climate regions, 7 exhibit apparent increasing trends in annual precipitation during various time periods before 1992. Because the period of analysis varies from region to region, comparability of even these preliminary results is difficult. Increasing precipitation trends over the period 1895–1992 are apparent across large areas of southern Canada, including Atlantic Canada, the Great Lakes Basin/St. Lawrence Lowlands, the South British Columbia Mountains, and (from 1911) along the Pacific Coast. However, such is not the case for the Prairies region of central western Canada, where an apparent slight decreasing trend is evident over the period 1895–1992. Apparent increasing trends are evident from the 1930s in the boreal forest regions of eastern and western Canada, and from 1948 in the Arctic Tundra region of central northern Canada. The remaining northern regions—the Yukon/North British Columbia Mountains and the Mackenzie District in the northwest, and the Arctic Mountains and Fiords in the northeast—all show little evidence of any overall trend in annual precipitation for the periods beginning in 1939, 1928, and 1948, respectively.

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Canadian national and regional standardized annual precipitation departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent,
and R. Whitewood (continued)

CANADA

Standardized Departures of Annual Precipitation Amount^a

Year	Standardized departure	Year	Standardized departure	Year	Standardized departure
1948	-0.3	1963	0.1	1978	-0.1
1949	-0.1	1964	0.1	1979	0.3
1950	-0.2	1965	0.0	1980	0.3
1951	-0.1	1966	0.0	1981	0.3
1952	-0.2	1967	-0.2	1982	0.3
1953	0.0	1968	0.2	1983	0.1
1954	-0.1	1969	-0.1	1984	0.2
1955	-0.1	1970	0.0	1985	-0.1
1956	-0.3	1971	0.1	1986	0.1
1957	-0.4	1972	0.0	1987	-0.1
1958	-0.2	1973	0.3	1988	0.3
1959	0.1	1974	0.2	1989	0.0
1960	0.0	1975	0.2	1990	0.3
1961	-0.2	1976	0.1	1991	0.2
1962	-0.1	1977	0.1	1992	-0.1

^aThe standardized departure equals the annual departure from the 1951–80 average precipitation amount, divided by the standard deviation of the 1951–80 annual precipitation amounts.

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Precipitation

Canadian national and regional standardized annual precipitation departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent,
and R. Whitewood (continued)

ATLANTIC CANADA

Trends

The Atlantic region includes the provinces of New Brunswick, Nova Scotia, Prince Edward Island, and Newfoundland. For the region as a whole, there appears to be an overall increasing trend in precipitation amount over the period 1895–1992. Amounts before the 1960s are generally below the long-term reference average, whereas after about 1970 they are mainly above. The associated apparent increase in annual precipitation seems to have levelled off in the 1980s. These data are provisional; further analysis is needed before more definitive statements can be made.

*Standardized departures of annual precipitation amount for the period
1895–1992 for the Atlantic Canada region. The departures are relative to the 1951–80
reference period.*

CITE AS: Findlay, B.F., D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent, and R. Whitewood. 1994. Canadian national and regional standardized annual precipitation departures. pp. 800–828. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Canadian national and regional standardized annual precipitation departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent,
and R. Whitewood (continued)

ATLANTIC CANADA

Standardized Departures of Annual Precipitation Amount^a

Year	Standardized departure	Year	Standardized departure	Year	Standardized departure
1895	-0.5	1928	-0.8	1961	-0.4
1896	-0.4	1929	-0.8	1962	0.6
1897	-0.9	1930	-1.1	1963	0.3
1898	-0.2	1931	-0.5	1964	0.3
1899	-0.8	1932	-0.7	1965	-1.0
1900	0.3	1933	0.5	1966	-1.1
1901	-0.9	1934	-0.7	1967	0.4
1902	-0.4	1935	-0.6	1968	-0.2
1903	-0.2	1936	0.4	1969	0.1
1904	-0.4	1937	-0.5	1970	0.1
1905	-1.1	1938	-0.5	1971	-0.2
1906	0.8	1939	-1.0	1972	0.7
1907	0.1	1940	-0.6	1973	0.2
1908	-0.5	1941	-0.5	1974	-0.1
1909	0.1	1942	-1.0	1975	0.0
1910	0.2	1943	-0.4	1976	0.7
1911	-1.1	1944	-0.4	1977	0.7
1912	-0.1	1945	-0.2	1978	-0.5
1913	-0.9	1946	-1.0	1979	1.1
1914	-1.4	1947	-1.4	1980	0.6
1915	-0.6	1948	-0.5	1981	1.3
1916	-1.1	1949	-0.5	1982	0.7
1917	-0.1	1950	-0.7	1983	1.0
1918	-0.5	1951	0.3	1984	0.4
1919	-0.3	1952	-0.7	1985	-0.8
1920	-0.6	1953	-0.1	1986	-0.1
1921	-1.8	1954	0.3	1987	-0.4
1922	-0.8	1955	-0.4	1988	0.6
1923	-1.1	1956	-0.2	1989	-0.5
1924	-1.2	1957	-0.6	1990	1.4
1925	-0.5	1958	0.1	1991	-0.1
1926	0.0	1959	-0.3	1992	-0.3
1927	0.5	1960	-1.0		

^aThe standardized departure equals the annual departure from the 1951–80 average precipitation amount, divided by the standard deviation of the 1951–80 annual precipitation amounts.

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Precipitation

Canadian national and regional standardized annual precipitation departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent,
and R. Whitewood (continued)

GREAT LAKES BASIN/ST. LAWRENCE LOWLANDS

Trends

The Great Lakes Basin/St. Lawrence Lowlands region includes southern Ontario and the extreme southern portion of Quebec, from Lake Huron in the southwest to Quebec City in the northeast. For the region as a whole, there appears to be an overall slight increasing trend in precipitation amount over the period 1895–1992. Amounts before the early 1960s show no clear trend, often varying greatly from year to year, whereas an increase is apparent from about the mid-1960s onward. These data are provisional; further analysis is needed before more definitive statements can be made.

Standardized departures of annual precipitation amount for the period 1895–1992 for the Great Lakes Basin/St. Lawrence Lowlands region. The departures are relative to the 1951–80 reference period.

CITE AS: Findlay, B.F., D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent, and R. Whitewood. 1994. Canadian national and regional standardized annual precipitation departures. pp. 800–828. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Canadian national and regional standardized annual precipitation departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent,
and R. Whitewood (continued)

GREAT LAKES BASIN/ ST. LAWRENCE LOWLANDS

Standardized Departures of Annual Precipitation Amount^a

Year	Standardized departure	Year	Standardized departure	Year	Standardized departure
1895	-0.6	1928	0.2	1961	-0.4
1896	-0.7	1929	0.2	1962	-0.5
1897	0.5	1930	-1.1	1963	-1.1
1898	0.9	1931	-1.2	1964	-0.9
1899	0.5	1932	0.1	1965	0.4
1900	0.5	1933	-0.8	1966	-0.5
1901	-0.1	1934	-1.2	1967	0.6
1902	0.1	1935	-1.1	1968	0.3
1903	-0.1	1936	0.2	1969	0.1
1904	0.2	1937	1.0	1970	0.1
1905	-0.6	1938	0.5	1971	-0.2
1906	-0.3	1939	-0.3	1972	1.2
1907	0.0	1940	0.6	1973	0.9
1908	-0.5	1941	-0.9	1974	0.0
1909	0.5	1942	0.9	1975	-0.1
1910	-0.3	1943	0.4	1976	0.5
1911	-0.7	1944	-0.7	1977	0.7
1912	1.1	1945	1.2	1978	-0.3
1913	-0.5	1946	-0.9	1979	0.7
1914	-1.2	1947	0.1	1980	0.3
1915	-0.6	1948	-0.6	1981	0.5
1916	0.3	1949	-0.5	1982	0.1
1917	-0.1	1950	0.0	1983	1.1
1918	-0.3	1951	0.3	1984	0.3
1919	-0.4	1952	-0.6	1985	0.2
1920	-0.4	1953	-1.0	1986	0.8
1921	-0.5	1954	0.9	1987	-0.3
1922	-1.1	1955	-0.7	1988	-0.2
1923	-0.5	1956	-0.5	1989	-0.3
1924	-0.4	1957	0.0	1990	1.3
1925	-0.4	1958	-0.9	1991	-0.2
1926	0.4	1959	0.4	1992	0.9
1927	0.5	1960	-0.4		

^aThe standardized departure equals the annual departure from the 1951–80 average precipitation amount, divided by the standard deviation of the 1951–80 annual precipitation amounts.

CITE AS: Findlay, B.F., D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent, and R. Whitewood. 1994. Canadian national and regional standardized annual precipitation departures. pp. 800–828. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Precipitation

Canadian national and regional standardized annual precipitation departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent,
and R. Whitewood (continued)

NORTHEASTERN FOREST

Trends

The Northeastern Forest region lies between about 46° N and the tree line at about 57° N, stretching from the Manitoba/Ontario border to the Atlantic coast of Labrador and including the Lower St. Lawrence and the Gaspé Peninsula. The region includes much of the Canadian Shield as well as the Hudson Bay Lowlands. For the region as a whole, there appears to be an overall slight increasing trend in precipitation amount over the period 1938–92. Amounts before the early 1960s are generally below the long-term reference average, whereas thereafter they are mainly above the average. There is also a noticeable drop to below-average amounts in the mid-1980s. These data are provisional; further analysis is needed before more definitive statements can be made.

Standardized departures of annual precipitation amount for the period 1938–92 for the Northeastern Forest region. The departures are relative to the 1951–80 reference period.

CITE AS: Findlay, B.F., D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent, and R. Whitewood. 1994. Canadian national and regional standardized annual precipitation departures. pp. 800–828. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Canadian national and regional standardized annual precipitation departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent,
and R. Whitewood (continued)

NORTHEASTERN FOREST

Standardized Departures of Annual Precipitation Amount^a

Year	Standardized departure	Year	Standardized departure	Year	Standardized departure
1938	0.1	1957	-0.6	1976	0.0
1939	-0.1	1958	0.0	1977	0.1
1940	-0.6	1959	0.0	1978	0.0
1941	0.5	1960	-0.3	1979	0.9
1942	-0.4	1961	-0.4	1980	0.2
1943	-0.3	1962	-0.7	1981	0.2
1944	-0.2	1963	-0.4	1982	0.4
1945	-0.2	1964	0.3	1983	0.6
1946	-0.4	1965	0.5	1984	0.0
1947	-0.4	1966	0.5	1985	-0.1
1948	-0.7	1967	-0.3	1986	-0.1
1949	-0.2	1968	0.3	1987	-0.7
1950	0.0	1969	0.3	1988	0.2
1951	0.0	1970	0.0	1989	-0.5
1952	0.1	1971	0.3	1990	0.1
1953	-0.4	1972	-0.1	1991	-0.2
1954	0.1	1973	0.3	1992	-0.1
1955	0.1	1974	0.0		
1956	-0.5	1975	-0.2		

^aThe standardized departure equals the annual departure from the 1951-80 average precipitation amount, divided by the standard deviation of the 1951-80 annual precipitation amounts.

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Precipitation

Canadian national and regional standardized annual precipitation departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent,
and R. Whitewood (continued)

NORTHWESTERN FOREST

Trends

The Northwestern Forest region stretches from the northern boundary of the Prairies north to the Mackenzie District at about 60° N and from the foothills of the Rocky Mountains east to the Manitoba/Ontario border. The landscape is low and without major relief features. For the region as a whole, there appears to be an overall slight increasing trend in precipitation amount over the period 1932–92. The trend is so slight as to be almost indiscernible.

Precipitation generally increased over the period from the late 1930s, when most amounts were well below the long-term reference average, to the early 1970s; there is a noticeable drop to mainly below average amounts thereafter. These data are provisional; further analysis is needed before more definitive statements can be made.

Standardized departures of annual precipitation amount for the period 1932–92 for the Northwestern Forest region. The departures are relative to the 1951–80 reference period.

CITE AS: Findlay, B.F., D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent, and R. Whitewood. 1994. Canadian national and regional standardized annual precipitation departures. pp. 800–828. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Canadian national and regional standardized annual precipitation departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent,
and R. Whitewood (continued)

NORTHWESTERN FOREST

Standardized Departures of Annual Precipitation Amount^a

Year	Standardized departure	Year	Standardized departure	Year	Standardized departure
1932	-0.1	1953	-0.1	1974	0.3
1933	1.0	1954	0.4	1975	0.2
1934	-0.1	1955	0.6	1976	0.4
1935	0.4	1956	-0.2	1977	0.4
1936	-0.1	1957	0.1	1978	-0.2
1937	-1.2	1958	-0.8	1979	-0.4
1938	-1.4	1959	0.0	1980	-0.1
1939	0.3	1960	0.0	1981	-1.4
1940	-1.3	1961	-0.6	1982	-0.2
1941	-0.5	1962	0.6	1983	0.1
1942	-0.3	1963	-0.1	1984	0.4
1943	-0.9	1964	0.3	1985	-0.6
1944	-0.5	1965	-0.2	1986	0.0
1945	-1.0	1966	-0.2	1987	-0.4
1946	-0.3	1967	-1.1	1988	0.6
1947	0.0	1968	-0.3	1989	0.0
1948	-0.3	1969	-0.4	1990	-0.4
1949	0.5	1970	0.2	1991	-0.1
1950	-0.3	1971	0.4	1992	-1.4
1951	-0.3	1972	0.1		
1952	-0.5	1973	0.9		

^aThe standardized departure equals the annual departure from the 1951–80 average precipitation amount, divided by the standard deviation of the 1951–80 annual precipitation amounts.

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Precipitation

Canadian national and regional standardized annual precipitation departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent,
and R. Whitewood (continued)

PRAIRIES

Trends

The Prairies region stretches eastward from the foothills of the Rocky Mountains across the southern portions of Alberta, Saskatchewan, and Manitoba. The region has no major relief features, but the gently rolling landscape slopes gradually downward from west to east. For the region as a whole, a slight decreasing trend in precipitation amount is apparent over the period 1895–1992. These data are provisional; further analysis is needed before more definitive statements can be made.

Standardized departures of annual precipitation amount for the period 1895–1992 for the Prairies region. The departures are relative to the 1951–80 reference period.

CITE AS: Findlay, B.F., D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent, and R. Whitewood. 1994. Canadian national and regional standardized annual precipitation departures. pp. 800–828. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Canadian national and regional standardized annual precipitation departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent,
and R. Whitewood (continued)

PRAIRIES

Standardized Departures of Annual Precipitation Amount^a

Year	Standardized departure	Year	Standardized departure	Year	Standardized departure
1895	-0.5	1928	-0.4	1961	-1.3
1896	0.6	1929	-0.8	1962	0.0
1897	-0.1	1930	-0.6	1963	0.2
1898	0.0	1931	-0.8	1964	-0.2
1899	1.1	1932	0.4	1965	0.6
1900	1.1	1933	0.1	1966	-0.3
1901	1.5	1934	-0.6	1967	-0.7
1902	1.2	1935	0.8	1968	-0.2
1903	0.3	1936	-1.0	1969	-0.2
1904	-0.3	1937	-0.4	1970	0.3
1905	-0.2	1938	0.2	1971	-0.3
1906	0.6	1939	-0.4	1972	-0.2
1907	-0.5	1940	0.0	1973	0.1
1908	-0.2	1941	-0.2	1974	0.0
1909	-0.1	1942	1.0	1975	0.9
1910	-0.9	1943	-0.6	1976	-0.6
1911	0.7	1944	0.2	1977	0.0
1912	0.1	1945	0.2	1978	0.6
1913	-0.4	1946	0.5	1979	-0.8
1914	0.2	1947	0.5	1980	0.0
1915	-0.3	1948	-0.3	1981	-0.3
1916	1.2	1949	-0.5	1982	0.4
1917	-1.2	1950	0.2	1983	-0.3
1918	-1.1	1951	1.1	1984	-0.3
1919	-0.7	1952	-0.7	1985	-0.3
1920	-0.4	1953	1.0	1986	0.4
1921	0.2	1954	1.2	1987	-0.6
1922	-0.6	1955	0.6	1988	-0.6
1923	0.4	1956	0.5	1989	-0.1
1924	-0.2	1957	-0.7	1990	-0.3
1925	0.0	1958	-0.7	1991	1.0
1926	0.3	1959	0.2	1992	-0.3
1927	1.7	1960	-0.9		

^aThe standardized departure equals the annual departure from the 1951–80 average precipitation amount, divided by the standard deviation of the 1951–80 annual precipitation amounts.

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Precipitation

Canadian national and regional standardized annual precipitation departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent,
and R. Whitewood (continued)

SOUTH BRITISH COLUMBIA MOUNTAINS

Trends

The South British Columbia Mountains region is bounded by the Coast Mountains to the west, the North British Columbia Mountains region to the north, and the Rocky Mountains to the east. The region consists of broad plateaus, valleys, highlands, and mountains. For the region as a whole, a general increasing trend in precipitation amount is apparent over the period 1895–1992. Amounts were generally below the long-term reference average before the mid-1940s, generally above the average from the mid-1940s until the late 1960s, and widely varying above and below (mostly below) it after the late 1960s. These data are provisional; further analysis is needed before more definitive statements can be made.

Standardized departures of annual precipitation amount for the period 1895–1992 for the South British Columbia Mountains region. The departures are relative to the 1951–80 reference period.

CITE AS: Findlay, B.F., D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent, and R. Whitewood. 1994. Canadian national and regional standardized annual precipitation departures. pp. 800–828. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Canadian national and regional standardized annual precipitation departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent,
and R. Whitewood (continued)

SOUTH BRITISH COLUMBIA MOUNTAINS

Standardized Departures of Annual Precipitation Amount^a

Year	Standardized departure	Year	Standardized departure	Year	Standardized departure
1895	-0.5	1928	-1.8	1961	0.6
1896	-1.4	1929	-1.7	1962	0.1
1897	-0.2	1930	-1.9	1963	-0.2
1898	-0.3	1931	-1.3	1964	0.8
1899	0.3	1932	-0.2	1965	-0.1
1900	0.0	1933	0.2	1966	0.6
1901	-1.3	1934	-0.8	1967	-0.5
1902	0.3	1935	-0.7	1968	0.3
1903	0.1	1936	-0.2	1969	-0.3
1904	-0.8	1937	-0.2	1970	-1.2
1905	-0.9	1938	-1.2	1971	0.4
1906	-0.4	1939	-0.2	1972	0.6
1907	0.1	1940	-0.9	1973	-0.8
1908	-0.2	1941	0.1	1974	0.1
1909	-0.2	1942	-0.4	1975	0.0
1910	-0.5	1943	-1.0	1976	-0.1
1911	-0.8	1944	-1.0	1977	-0.4
1912	-0.3	1945	0.1	1978	-0.7
1913	-0.1	1946	0.3	1979	-1.0
1914	-0.4	1947	0.6	1980	0.6
1915	0.1	1948	0.6	1981	-0.3
1916	-0.2	1949	0.0	1982	0.5
1917	-0.1	1950	0.0	1983	-0.1
1918	-0.2	1951	0.4	1984	0.3
1919	-0.5	1952	-1.3	1985	-1.0
1920	-0.2	1953	0.6	1986	0.0
1921	-0.4	1954	0.4	1987	-1.1
1922	-1.6	1955	0.4	1988	0.1
1923	-0.6	1956	-0.2	1989	-0.2
1924	-0.5	1957	-0.1	1990	1.4
1925	-0.8	1958	-0.3	1991	-0.4
1926	-1.2	1959	1.5	1992	-0.1
1927	0.4	1960	-0.5		

^aThe standardized departure equals the annual departure from the 1951–80 average precipitation amount, divided by the standard deviation of the 1951–80 annual precipitation amounts.

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Precipitation

Canadian national and regional standardized annual precipitation departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent,
and R. Whitewood (continued)

PACIFIC COAST

Trends

The Pacific Coast region comprises a narrow coastal band from Vancouver Island and the lower mainland in the south to the Queen Charlotte Islands in the north. The region consists of islands, west-facing slopes, and indented fiords. For the region as a whole, a general increase in precipitation amount is apparent over the period 1911–92. Amounts were generally below the long-term reference average before the late 1950s and generally above it thereafter. These data are provisional; further analysis is needed before more definitive statements can be made.

*Standardized departures of annual precipitation amount for the period 1911–92
for the Pacific Coast region. The departures are relative to the 1951–80 reference period.*

CITE AS: Findlay, B.F., D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent, and R. Whitewood. 1994. Canadian national and regional standardized annual precipitation departures. pp. 800–828. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Canadian national and regional standardized annual precipitation departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent,
and R. Whitewood (continued)

PACIFIC COAST

Standardized Departures of Annual Precipitation Amount^a

Year	Standardized departure	Year	Standardized departure	Year	Standardized departure
1911	-1.1	1939	1.2	1967	0.5
1912	-1.7	1940	-0.6	1968	0.6
1913	0.8	1941	-0.2	1969	-0.7
1914	-0.6	1942	-1.1	1970	-1.3
1915	-0.1	1943	-1.4	1971	1.0
1916	-0.6	1944	-1.3	1972	0.1
1917	0.6	1945	-0.5	1973	-0.1
1918	0.3	1946	-0.2	1974	0.9
1919	-0.8	1947	0.2	1975	0.6
1920	-0.3	1948	0.4	1976	0.4
1921	-0.3	1949	-0.2	1977	-0.1
1922	-1.7	1950	0.1	1978	-0.3
1923	-0.3	1951	-1.0	1979	-0.7
1924	-0.3	1952	-0.9	1980	1.3
1925	-1.1	1953	1.1	1981	1.0
1926	-0.8	1954	0.3	1982	-0.1
1927	-0.6	1955	-0.7	1983	0.9
1928	-1.0	1956	-0.1	1984	0.7
1929	-2.6	1957	-1.6	1985	-1.7
1930	-1.4	1958	-0.1	1986	0.3
1931	-0.2	1959	0.3	1987	0.3
1932	0.9	1960	0.0	1988	0.1
1933	0.4	1961	0.5	1989	-0.7
1934	0.0	1962	0.3	1990	0.5
1935	-1.1	1963	-0.1	1991	0.6
1936	-0.4	1964	0.1	1992	0.2
1937	-0.7	1965	-0.7		
1938	-1.1	1966	0.4		

^aThe standardized departure equals the annual departure from the 1951–80 average precipitation amount, divided by the standard deviation of the 1951–80 annual precipitation amounts.

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Precipitation

Canadian national and regional standardized annual precipitation departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent,
and R. Whitewood (continued)

YUKON/NORTH BRITISH COLUMBIA MOUNTAINS

Trends

The Yukon/North British Columbia Mountains region includes all of Yukon Territory and British Columbia north of about 56° N. The rugged terrain varies from alpine to subalpine to lowland boreal. For the region as a whole, there is no apparent trend in precipitation amount over the period 1939–92. These data are provisional; further analysis is needed before more definitive statements can be made.

Standardized departures of annual precipitation amount for the period 1939–92 for the Yukon/North British Columbia Mountains region. The departures are relative to the 1951–80 reference period.

CITE AS: Findlay, B.F., D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent, and R. Whitewood. 1994. Canadian national and regional standardized annual precipitation departures. pp. 800–828. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Canadian national and regional standardized annual precipitation departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent,
and R. Whitewood (continued)

YUKON/NORTH BRITISH COLUMBIA MOUNTAINS

Standardized Departures of Annual Precipitation Amount^a

Year	Standardized departure	Year	Standardized departure	Year	Standardized departure
1939	1.2	1957	-1.1	1975	0.5
1940	-1.1	1958	-0.5	1976	0.4
1941	-0.6	1959	0.2	1977	-0.2
1942	-0.1	1960	0.1	1978	-0.4
1943	0.1	1961	0.6	1979	0.3
1944	0.7	1962	1.1	1980	0.2
1945	0.2	1963	0.3	1981	0.2
1946	0.0	1964	0.0	1982	-0.4
1947	-0.1	1965	-0.2	1983	0.1
1948	0.2	1966	-0.2	1984	-0.3
1949	0.5	1967	0.3	1985	0.3
1950	-1.0	1968	0.2	1986	0.4
1951	-1.3	1969	-0.7	1987	0.3
1952	0.4	1970	-0.2	1988	0.9
1953	0.3	1971	-0.5	1989	-0.4
1954	0.0	1972	0.2	1990	0.5
1955	-1.1	1973	-0.3	1991	1.1
1956	0.3	1974	1.2	1992	-0.7

^aThe standardized departure equals the annual departure from the 1951-80 average precipitation amount, divided by the standard deviation of the 1951-80 annual precipitation amounts.

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Precipitation

Canadian national and regional standardized annual precipitation departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent,
and R. Whitewood (continued)

MACKENZIE DISTRICT

Trends

The Mackenzie District takes in a major portion of the Mackenzie River drainage basin, including Great Bear and Great Slave lakes. The terrain is fairly flat but rugged, rising gently from the east to the Mackenzie Mountains in the west. For the region as a whole, there is no apparent trend in precipitation amount over the period 1928–92. These data are provisional; further analysis is needed before more definitive statements can be made.

Standardized departures of annual precipitation amount for the period 1928–92 for the Mackenzie District. The departures are relative to the 1951–80 reference period.

CITE AS: Findlay, B.F., D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent, and R. Whitewood. 1994. Canadian national and regional standardized annual precipitation departures. pp. 800–828. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Canadian national and regional standardized annual precipitation departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent,
and R. Whitewood (continued)

MACKENZIE DISTRICT

Standardized Departures of Annual Precipitation Amount^a

Year	Standardized departure	Year	Standardized departure	Year	Standardized departure
1928	-0.4	1950	-0.4	1972	0.1
1929	0.2	1951	-0.8	1973	0.6
1930	1.0	1952	0.3	1974	1.3
1931	-0.3	1953	-0.7	1975	-0.1
1932	0.0	1954	-0.4	1976	-0.2
1933	1.2	1955	-0.8	1977	-0.4
1934	-0.2	1956	0.1	1978	-0.6
1935	0.7	1957	0.1	1979	-0.8
1936	-0.6	1958	0.5	1980	-0.4
1937	-0.3	1959	0.1	1981	0.8
1938	0.1	1960	1.0	1982	-0.1
1939	1.4	1961	0.7	1983	-0.6
1940	-0.7	1962	1.2	1984	0.8
1941	-0.4	1963	0.7	1985	-0.1
1942	-1.1	1964	-0.4	1986	-0.3
1943	-0.6	1965	0.0	1987	0.1
1944	0.2	1966	0.1	1988	1.3
1945	-0.7	1967	-0.3	1989	0.4
1946	-1.4	1968	-0.3	1990	0.5
1947	-0.9	1969	-0.4	1991	0.9
1948	0.7	1970	0.3	1992	-0.1
1949	-0.4	1971	-0.5		

^aThe standardized departure equals the annual departure from the 1951–80 average precipitation amount, divided by the standard deviation of the 1951–80 annual precipitation amounts.

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Precipitation

Canadian national and regional standardized annual precipitation departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent,
and R. Whitewood (continued)

ARCTIC TUNDRA

Trends

The Arctic Tundra region includes all of northern Canada north of the tree line except for the Arctic Mountains and Fiords region along its northeastern periphery. The landscape is treeless, open, and covered with ice caps and permafrost. For the region as a whole, there appears to be strong evidence of increasing precipitation over the period 1948–92. Amounts appear to be generally below the long-term reference average in the 1950s and generally above it since ca. 1970. This finding is consistent with the results of Groisman and Easterling (1994) for this same general area. These data are provisional; further analysis is needed before more definitive statements can be made.

Standardized departures of annual precipitation amount for the period 1948–92 for the Arctic Tundra region. The departures are relative to the 1951–80 reference period.

CITE AS: Findlay, B.F., D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent, and R. Whitewood. 1994. Canadian national and regional standardized annual precipitation departures. pp. 800–828. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Canadian national and regional standardized annual precipitation departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent,
and R. Whitewood (continued)

ARCTIC TUNDRA

Standardized Departures of Annual Precipitation Amount^a

Year	Standardized departure	Year	Standardized departure	Year	Standardized departure
1948	-0.1	1963	0.6	1978	0.0
1949	-0.3	1964	0.2	1979	0.5
1950	-0.1	1965	-0.3	1980	0.6
1951	-0.5	1966	-0.2	1981	0.8
1952	-0.4	1967	0.2	1982	0.5
1953	-0.1	1968	0.1	1983	-0.1
1954	-0.9	1969	0.0	1984	0.1
1955	-0.1	1970	-0.1	1985	0.6
1956	-0.4	1971	0.4	1986	0.3
1957	-0.3	1972	-0.5	1987	0.9
1958	-0.3	1973	0.5	1988	0.3
1959	-0.1	1974	-0.1	1989	0.3
1960	0.6	1975	0.6	1990	0.3
1961	-0.4	1976	0.0	1991	0.1
1962	-0.6	1977	0.3	1992	0.3

^aThe standardized departure equals the annual departure from the 1951–80 average precipitation amount, divided by the standard deviation of the 1951–80 annual precipitation amounts.

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Precipitation

Canadian national and regional standardized annual precipitation departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent,
and R. Whitewood (continued)

ARCTIC MOUNTAINS AND FIORDS

Trends

The Arctic Mountains and Fiords region consists of a long, slender band of rugged, mountainous, and icy terrain along the eastern flanks of Ellesmere and Baffin islands and along the western shores of Baffin Bay and Davis Strait. For the region as a whole, there appears to be little evidence of any long-term trend in precipitation over the period 1948–92. Amounts appear to be generally below the long-term reference average before the mid-1970s and generally above it thereafter. These data are provisional; further analysis is needed before more definitive statements can be made.

Standardized departures of annual precipitation amount for the period 1948–92 for the Arctic Mountains and Fiords region. The departures are relative to the 1951–80 reference period.

CITE AS: Findlay, B.F., D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent, and R. Whitewood. 1994. Canadian national and regional standardized annual precipitation departures. pp. 800–828. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Canadian national and regional standardized annual precipitation departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent,
and R. Whitewood (continued)

ARCTIC MOUNTAINS AND FIORDS

Standardized Departures of Annual Precipitation Amount^a

Year	Standardized departure	Year	Standardized departure	Year	Standardized departure
1948	-1.3	1963	-0.3	1978	0.7
1949	0.2	1964	-0.5	1979	1.1
1950	0.0	1965	-0.1	1980	0.2
1951	1.2	1966	-0.3	1981	0.7
1952	0.5	1967	-0.5	1982	0.5
1953	1.1	1968	1.1	1983	-0.2
1954	0.1	1969	-0.2	1984	0.6
1955	-0.7	1970	0.2	1985	0.1
1956	-1.2	1971	-0.3	1986	-0.1
1957	-0.1	1972	-0.3	1987	-0.3
1958	-0.2	1973	0.3	1988	-0.3
1959	-0.2	1974	-0.4	1989	0.8
1960	-0.1	1975	-0.3	1990	-0.2
1961	-0.1	1976	-0.1	1991	0.4
1962	-0.1	1977	0.2	1992	0.3

^aThe standardized departure equals the annual departure from the 1951–80 average precipitation amount, divided by the standard deviation of the 1951–80 annual precipitation amounts.

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Precipitation

Canadian national and regional standardized annual precipitation departures

B.F. Findlay, D.W. Gullett, L. Malone, J. Reycraft, W.R. Skinner, L. Vincent,
and R. Whitewood (continued)

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Precipitation

United States historical climatology network—National and regional estimates of monthly and annual precipitation

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Contiguous United States • North Pacific Coast • South Pacific Coast • North Cascades • California Interior Valleys • East Slope North Cascades • Great Basin • Southern Desert • Northern Rockies • Southern Rockies • Northern Steppes • Southern Steppes • Northern Plains • Southern Plains • South Coastal Plain • Gulf Coast • Great Lakes • Eastern Prairies • Northern Appalachians • Southern Appalachians • Northern Piedmont • Southern Piedmont • Coastal Northeast • Coastal Southeast

Period of Record

1900–92

Methods

National and regional estimates of precipitation amount over the contiguous United States were derived from records of select stations in the National Climatic Data Center's (NCDC's) United States Historical Climatology Network (HCN) (Karl et al. 1990). The HCN data described in Karl et al. (1990) extend through 1987 and include 1219 stations; the updated records used here extend through September 1992 and include 1221 stations.

The contiguous United States. Regions outlined are the 23 climatic regions specified for the contiguous United States in Karl et al. (1988).

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United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

Precipitation totals from all stations have been quality-controlled by NCDC through use of outlier and areal edits; totals were adjusted for instrument changes and station relocations using techniques described in Karl and Williams (1987). In constructing the time series presented here, records from stations with more than 25% of their data estimated from neighboring stations (because of missing data or frequent station moves) or whose statistical confidence interval ranks fell in the lowest 10% of all stations, were not used. Removing stations on the basis of these criteria left a total of 877 stations for use in this analysis. The stations were partitioned into 23 groups corresponding to the U.S. climatic regions specified by Karl et al. (1988) (depicted at left). The resulting number of stations per region ranges from 12, in the South Pacific Coast region, to 88, in the Southern Plains region. Area-average monthly and annual precipitation amounts for all regions were calculated by equally weighting the totals for each station within a region. Composite values for the contiguous United States were produced by taking an areally weighted average of the regional values.

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Precipitation

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

CONTIGUOUS UNITED STATES

Trends

The time series of area-average annual precipitation amount derived from the HCN for the contiguous United States (hereafter referred to as "United States") shows two main periods that are fairly distinct from one another: one extending from 1900 to the mid-1930s, in which a general decrease in precipitation is observed, and another extending from the mid-1930s to near the end of the record, which shows a general increase. The bottoming out of annual precipitation between these two eras is, of course, associated with the "Dust Bowl" period, in which vast areas of the United States experienced extreme drought conditions (Karl and Knight 1985; Karl and Heim 1990). Whereas the mid-1950s stand out as a major dry period, the 1930s mark the main turning point in a long-term decreasing trend for the United States; Bradley et al. (1987) observe that this trend began ca. 1880. Bradley et al. (1987) also found a general upward trend beyond the 1930s, a trend which is consistent with the analyses of Plantico et al. (1990) and Groisman and Easterling (1994). [The area studied by Groisman and Easterling (1994) extended from the United States into southern Canada; results of the study are presented on pp. 770–784 of this document.]

The U.S. regional series presented on the following pages help point out the principal areas that are associated with the general trends and the major dry periods observed in the composite U.S. series. The dryness of the 1930s in the U.S. series is clearly evident in many of the regional series, mainly from the adjoining Great Basin, Northern Rockies, Northern Steppes, Northern Plains, Southern Plains and Great Lakes regions. The dryness of the 1950s was experienced mainly across the southern United States, and is readily observed in the time series of the Southern Desert, Southern Rockies, Southern Steppes, Southern Plains, and South Coastal Plain regions.

The wettest year in the U.S. series (and in 5 of the 23 regional series), 1983, coincides with the extraordinary El Niño/Southern Oscillation (ENSO) episode of 1982–83, which deserves special mention here. Various studies [e.g., Ropelewski and Halpert (1986) and Redmond and Cayan (1994)] have shown that ENSO periods are often associated with discrete precipitation patterns in particular regions of the United States and usually extend over the midautumn to early spring period that coincides with the peak in positive sea surface temperature anomalies in the east equatorial Pacific (EEP). For example, monthly precipitation data (see tables in this section) reveal that the southeastern United States and the desert southwest received well above normal precipitation from October 1982 through March 1983, as would often be expected during an ENSO period. However, all regions in the west—even those in the Pacific Northwest, which are usually drier than normal during an ENSO period—recorded very high totals during these months (the highest of the century for the South Pacific Coast, California Interior Valleys, Great Basin, and Northern Rockies regions). As described by Quiroz (1983), the phenomenal precipitation in the west was associated with an unusual eastward displacement (toward the northeast Pacific Ocean) of the Aleutian low-pressure system, which resulted in record negative 700 mb seasonal mean

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United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

CONTIGUOUS UNITED STATES

height anomalies for the Northern Hemisphere. These anomalies, in combination with ENSO-induced positive temperature and height anomalies over the EEP, intensified the meridional height gradient and created upper-level westerly winds of historic magnitude. This persistent pattern resulted in an unusually high frequency of storms invading the western United States over the September 1982 through March 1983 period (Douglas and Englehart 1984).

Area-average annual precipitation amount for the contiguous United States.

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Precipitation

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

CONTIGUOUS UNITED STATES

Area-Average Annual Precipitation Amount

Year	Precipitation (mm)												Ann
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	
1900	41.1	62.5	55.9	90.4	59.4	78.0	82.6	63.8	70.4	65.0	54.9	42.4	770.4
1901	44.2	48.3	57.4	63.5	66.8	66.3	61.7	75.2	61.7	36.1	33.8	58.9	677.9
1902	32.5	58.7	69.9	42.4	75.9	76.5	82.3	64.3	69.6	49.0	64.5	67.8	756.4
1903	53.3	76.2	73.2	50.0	78.2	75.7	78.7	82.0	52.6	45.0	37.3	32.5	734.3
1904	42.4	49.8	70.6	50.3	63.5	73.7	78.0	74.4	57.7	38.6	23.4	48.3	675.6
1905	48.8	55.6	71.9	74.7	97.5	82.6	88.9	70.1	66.5	54.6	51.8	55.4	821.4
1906	55.9	36.8	76.5	51.3	75.9	76.7	88.4	88.6	73.2	51.6	54.4	64.0	794.3
1907	58.4	39.4	52.6	57.9	85.1	80.0	80.3	68.6	62.0	48.0	51.6	63.0	746.3
1908	41.9	64.5	52.6	65.5	103.6	80.0	81.3	75.4	42.9	49.0	37.6	39.4	735.6
1909	55.1	67.6	55.9	56.9	77.7	84.6	79.5	63.5	57.7	38.1	66.5	61.0	762.8
1910	49.3	47.5	22.6	49.0	63.8	64.5	66.3	61.0	52.3	47.8	36.8	38.4	602.2
1911	51.8	49.3	38.9	68.3	50.8	55.6	73.9	82.6	68.6	60.7	48.3	71.4	720.3
1912	44.2	46.5	83.1	82.3	73.9	72.4	77.2	78.0	61.7	50.8	33.5	50.0	757.7
1913	66.0	46.0	76.7	52.6	64.3	69.3	70.9	48.8	73.9	61.7	53.3	56.4	739.4
1914	52.1	48.5	46.0	66.0	59.4	74.4	63.0	85.1	54.1	57.4	34.5	58.7	699.0
1915	65.5	65.8	38.1	54.6	100.3	82.6	87.1	84.6	69.6	48.8	46.5	60.7	802.6
1916	84.8	40.1	50.3	51.1	72.6	83.3	89.4	63.0	48.8	49.5	33.8	50.5	715.5
1917	51.1	40.6	58.4	66.3	64.0	62.0	64.8	63.8	55.4	33.0	21.6	36.1	618.5
1918	55.4	36.6	40.4	70.6	66.3	58.2	61.2	63.2	61.0	72.4	54.4	66.0	707.4
1919	44.5	62.2	64.8	62.5	83.3	78.7	81.5	66.0	54.6	81.8	65.0	41.1	785.4
1920	50.0	35.8	68.3	82.8	69.6	72.1	71.4	85.6	61.5	51.3	50.5	64.3	765.0
1921	47.8	41.4	60.7	70.6	64.0	71.9	77.7	67.3	64.3	34.0	54.1	49.3	703.8
1922	46.0	56.4	86.4	75.9	79.5	67.6	73.4	56.1	36.8	41.1	48.0	61.7	730.0
1923	54.6	42.2	59.2	67.8	83.3	85.3	69.1	74.4	67.8	61.5	44.4	64.5	776.0
1924	48.5	42.9	54.1	58.2	61.2	73.7	62.0	57.2	76.7	31.2	29.7	63.5	658.1
1925	56.6	41.1	36.1	50.3	47.0	77.0	66.5	51.8	69.9	70.1	50.8	38.9	656.3
1926	56.1	47.8	59.2	53.6	56.6	63.2	70.4	82.3	84.3	59.2	62.7	59.2	756.4
1927	38.4	62.2	64.5	74.7	72.1	81.0	74.2	73.9	59.9	56.4	61.2	64.5	782.6
1928	27.7	47.8	56.6	72.6	61.2	110.5	79.0	83.1	51.8	54.9	50.8	40.4	736.1
1929	56.4	50.8	67.8	73.7	87.6	69.9	68.8	46.7	68.8	64.0	48.5	49.5	753.4
1930	60.7	37.3	46.5	46.0	77.7	60.2	49.3	52.1	60.7	52.8	54.9	31.5	631.2
1931	37.3	42.9	56.1	49.8	60.2	55.6	70.9	68.8	52.1	45.0	61.7	78.2	676.7
1932	76.7	50.5	53.8	50.8	62.5	81.8	66.8	73.4	52.6	63.2	49.0	70.6	751.6
1933	48.8	46.2	61.0	65.0	84.6	37.1	69.6	74.4	59.7	38.1	25.4	58.4	667.8
1934	39.6	39.4	53.8	41.7	46.0	68.6	53.6	58.4	70.4	41.7	70.4	43.4	626.6
1935	54.4	38.9	66.0	64.0	93.7	78.5	67.3	67.6	60.7	38.1	47.8	41.1	719.6
1936	68.1	59.4	49.3	49.8	55.9	49.0	57.7	56.9	73.2	51.8	27.4	64.8	662.4
1937	87.1	50.0	52.6	70.1	60.7	82.3	66.5	67.1	47.8	65.0	48.5	51.8	749.6
1938	46.7	52.6	75.9	68.3	82.3	77.5	82.3	50.8	64.5	29.2	46.0	39.9	718.1
1939	56.9	69.9	50.8	53.8	55.6	87.4	60.7	68.8	41.4	36.1	22.9	41.9	647.2
1940	45.5	68.8	56.1	75.9	53.8	77.0	66.5	79.2	47.0	40.9	69.6	67.3	748.5
1941	47.5	40.4	50.5	71.9	64.5	97.3	78.5	70.4	74.9	92.5	38.6	65.3	791.5
1942	37.3	49.5	64.0	68.8	78.5	90.9	65.3	81.0	70.6	50.3	51.8	70.4	779.3
1943	47.8	28.7	70.6	51.8	89.9	83.3	66.3	54.1	47.5	45.5	30.7	41.9	655.6
1944	44.5	62.2	78.0	85.6	74.7	73.2	62.2	76.2	56.9	32.8	61.7	46.2	757.4
1945	41.9	63.8	74.7	75.9	71.4	88.4	78.5	68.6	91.2	47.0	49.5	64.0	815.8
1946	57.9	49.8	65.8	40.4	92.7	73.2	68.3	67.1	65.3	64.3	71.1	41.7	755.7

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

CONTIGUOUS UNITED STATES

Area-Average Annual Precipitation Amount (continued)

Year	Precipitation (mm)												Ann
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	
1947	58.9	21.6	59.2	81.3	80.5	99.3	51.3	59.9	53.8	54.4	68.1	48.8	739.6
1948	46.0	57.7	79.0	59.7	70.4	82.8	75.2	59.9	47.8	36.6	84.6	61.2	762.0
1949	75.2	55.1	61.0	53.1	75.9	82.3	80.3	65.3	55.9	64.0	25.7	49.0	743.0
1950	74.4	52.6	59.9	50.8	73.2	69.6	101.1	64.3	63.2	44.5	47.8	46.5	747.5
1951	54.1	52.6	67.3	57.4	59.9	90.7	73.4	66.8	64.5	53.3	56.4	71.4	768.9
1952	56.6	47.5	71.6	59.2	68.3	54.9	62.0	67.3	39.4	13.0	49.8	57.9	648.2
1953	58.2	50.3	65.0	73.4	82.3	64.3	71.1	59.9	37.6	33.3	42.7	62.5	701.0
1954	54.4	33.3	50.8	57.4	69.6	59.9	51.3	66.0	47.0	56.9	36.1	47.2	630.4
1955	40.6	52.6	45.5	63.2	76.5	63.2	74.9	68.3	51.1	51.3	43.4	47.2	678.2
1956	48.3	61.7	45.5	50.5	64.0	57.7	71.9	57.7	38.4	45.2	31.8	46.7	619.3
1957	46.5	46.5	60.7	88.1	104.6	93.5	59.7	56.9	73.7	64.0	72.6	55.4	822.5
1958	53.3	55.4	64.8	74.7	62.0	83.8	101.1	61.2	66.5	34.5	49.3	29.5	737.9
1959	51.3	54.9	53.1	51.8	84.6	65.8	77.2	71.1	71.6	87.4	38.9	53.3	762.3
1960	55.1	60.7	52.1	52.3	73.4	66.5	68.6	72.9	54.9	57.9	42.4	42.7	699.5
1961	33.3	69.6	79.8	58.7	73.4	73.7	79.2	69.9	73.7	42.9	63.5	66.0	786.6
1962	52.3	57.2	51.8	51.3	64.5	83.8	75.2	52.1	68.6	57.9	46.7	37.1	699.3
1963	38.6	37.3	59.7	53.6	57.2	73.2	69.9	58.4	55.1	21.6	61.5	35.6	623.3
1964	57.4	38.4	71.1	83.1	56.4	70.9	68.3	74.2	60.2	36.3	57.2	72.9	747.8
1965	52.6	53.3	54.1	61.2	66.5	83.6	70.4	72.4	91.4	36.6	44.2	49.8	738.6
1966	56.1	59.2	38.6	59.7	55.1	55.9	62.7	77.5	59.4	39.6	45.0	58.9	670.3
1967	49.0	33.5	44.2	65.5	74.9	88.1	73.7	65.8	58.7	56.1	36.8	72.6	719.8
1968	49.3	31.8	50.0	59.9	81.3	73.9	70.1	75.7	56.1	51.6	67.1	67.6	738.6
1969	65.5	51.8	47.0	66.0	68.6	83.1	79.5	62.0	58.4	63.8	36.1	68.8	752.9
1970	46.2	36.8	64.3	67.1	65.5	68.1	61.7	62.5	77.5	71.1	49.3	52.3	722.9
1971	45.2	59.2	49.0	42.4	70.9	66.0	78.5	68.3	74.2	66.5	48.3	77.5	744.5
1972	54.6	40.6	50.0	53.6	77.0	76.5	73.9	65.3	66.0	66.3	75.7	73.7	773.7
1973	59.7	47.0	102.6	84.1	74.2	74.7	75.9	49.8	90.2	57.2	73.4	74.7	864.1
1974	71.9	41.4	61.2	62.2	77.7	67.3	54.9	89.2	65.5	46.2	52.3	58.9	750.6
1975	62.5	61.5	80.8	64.8	83.3	84.8	74.9	72.6	65.0	54.9	55.6	49.3	811.8
1976	41.4	42.4	65.5	56.1	74.9	66.8	65.8	50.3	61.5	59.7	27.4	33.5	644.4
1977	38.6	29.2	75.4	57.4	67.3	60.5	65.3	92.5	82.6	54.6	70.4	61.0	755.9
1978	75.4	39.6	53.6	61.7	93.0	64.8	70.4	73.4	56.9	26.7	61.0	57.9	736.6
1979	81.0	63.2	67.1	79.2	78.5	62.0	84.6	75.2	63.5	53.6	58.7	44.2	810.8
1980	61.5	44.7	88.9	62.5	78.2	59.9	50.5	65.8	67.1	48.3	41.4	36.1	704.3
1981	20.6	52.1	52.3	51.3	86.6	84.8	80.8	73.2	52.6	74.2	46.7	57.9	731.5
1982	68.1	54.1	58.9	61.5	86.1	84.6	76.2	67.1	60.2	55.4	70.4	89.2	833.1
1983	50.3	64.5	89.9	85.1	86.6	78.7	49.5	58.9	58.4	66.0	94.0	82.8	865.6
1984	31.5	51.6	67.1	74.7	78.0	73.4	72.1	62.2	45.0	86.9	64.3	58.4	766.3
1985	35.1	52.3	59.4	48.0	65.0	67.3	68.1	76.5	74.9	82.6	84.6	35.1	750.3
1986	32.3	62.2	47.5	54.9	74.2	75.2	69.9	72.9	95.0	73.2	72.6	49.8	782.6
1987	53.8	57.4	68.6	34.8	82.0	72.9	71.4	72.9	56.1	26.7	59.7	64.8	724.4
1988	46.0	38.6	50.5	59.2	50.0	39.9	68.6	66.0	74.4	36.3	73.9	40.1	645.2
1989	47.2	46.0	70.4	43.4	84.3	99.1	76.7	70.1	72.1	46.0	41.7	34.0	734.6
1990	66.5	66.5	66.8	59.7	95.3	65.3	71.6	68.1	50.0	68.1	50.0	65.3	801.6
1991	57.7	39.4	78.7	83.3	96.5	69.6	67.8	66.8	61.5	49.5	59.2	65.5	802.1
1992	51.1	54.6	60.2	49.8	55.9	86.4	96.8	79.5	60.2				

CITE AS: Karl, T.R., D.R. Easterling, and P.Ya. Groisman. 1994. United States historical climatology network—National and regional estimates of monthly and annual precipitation. pp. 830–905. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Precipitation

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

NORTH PACIFIC COAST

Trends

The annual precipitation record for the North Pacific Coast region exhibits generally decreasing precipitation from 1900 to ca. 1930; a gradual increase from ca. 1930 to 1950; relatively uniform precipitation from ca. 1950 to the mid-1970s; and a period of wide, short-term fluctuations thereafter. Within this last period, 1976 and 1985 were much drier than any years since 1929–30. The main cause of the low total in 1976 was the relative lack of precipitation during the normally wet October–December period. The lack of precipitation extended into January and February of 1977 and may be attributed to the El Niño/Southern Oscillation (ENSO) episode of 1976–77. [See Redmond and Cayan (1984) for a discussion of typical ENSO effects on western U.S. climate.] As with much of the extreme western United States in general, this region relies on the “winter” months (actually late fall through early spring) for most of its annual precipitation. The extreme wetness of 1982–83, observed to varying degrees in the time series for other western regions, resulted primarily from the unusual nature of the 1982–83 ENSO, as described by Quiroz (1983). (Also see earlier discussion of trends for the contiguous United States.)

Area-average annual precipitation amount for the North Pacific Coast region of the United States.

CITE AS: Karl, T.R., D.R. Easterling, and P.Ya. Groisman. 1994. United States historical climatology network—National and regional estimates of monthly and annual precipitation. pp. 830–905. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

NORTH PACIFIC COAST

Area-Average Annual Precipitation Amount

Year	Precipitation (mm)												Ann
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	
1900	174.2	143.8	153.3	83.4	79.2	68.2	10.9	30.3	39.1	196.3	166.7	201.5	1355.7
1901	224.8	184.1	110.1	140.3	54.6	32.6	10.7	2.2	77.4	71.7	215.9	123.4	1275.0
1902	104.4	376.0	199.7	116.6	82.2	21.7	26.5	12.5	33.2	79.4	258.8	232.6	1561.2
1903	280.1	75.2	176.0	67.0	56.9	40.1	15.9	17.4	57.0	70.8	305.0	111.5	1250.1
1904	153.4	321.2	366.6	88.8	16.2	22.1	15.8	3.7	39.3	89.8	192.7	198.5	1569.4
1905	162.8	88.9	201.8	41.4	88.5	33.9	6.3	15.2	86.1	108.3	100.3	146.9	1149.0
1906	221.7	153.2	157.9	46.3	108.4	71.4	1.7	6.4	78.6	94.0	201.2	207.7	1369.3
1907	194.2	173.4	241.3	86.8	33.3	34.7	9.8	27.9	38.1	31.4	139.6	246.4	1282.3
1908	153.0	138.5	131.8	65.7	75.8	20.5	8.9	26.4	7.3	101.9	126.4	139.8	1040.8
1909	350.3	236.1	102.3	25.2	42.0	14.7	29.3	12.5	32.0	98.7	355.1	153.5	1473.6
1910	201.5	130.3	112.2	60.6	43.3	28.8	1.3	6.5	36.9	100.3	220.4	139.5	1186.4
1911	246.6	87.9	83.7	80.4	93.2	14.8	6.7	9.3	54.7	46.5	162.9	133.8	1027.7
1912	195.9	122.2	95.5	86.5	69.0	58.7	14.0	53.5	67.9	85.2	204.6	157.9	1265.7
1913	232.8	43.0	100.1	77.0	56.8	62.4	21.2	12.6	53.7	76.8	214.2	191.1	1141.6
1914	358.2	126.4	80.1	91.0	32.9	45.4	2.4	3.9	93.4	136.9	160.6	132.0	1263.0
1915	214.1	211.0	108.3	56.6	103.8	9.7	19.8	1.5	14.2	87.7	196.3	249.1	1272.1
1916	296.0	189.3	220.8	60.7	51.2	26.2	46.7	6.6	22.3	39.7	138.9	170.5	1269.0
1917	138.9	149.5	134.3	126.9	29.9	37.0	3.9	5.9	39.0	17.6	142.5	242.6	1068.0
1918	141.3	197.8	145.4	38.2	27.5	5.8	12.4	27.9	27.1	83.7	160.7	165.9	1033.7
1919	231.6	242.6	149.7	98.4	44.2	14.6	2.0	4.2	47.6	32.2	136.1	157.1	1160.2
1920	107.4	25.3	143.3	107.1	29.1	42.6	13.5	21.9	109.4	175.5	214.3	289.6	1279.0
1921	272.0	175.7	112.2	78.5	52.2	44.9	1.3	16.0	53.1	118.7	226.9	170.6	1322.3
1922	82.8	165.8	174.3	69.4	48.9	6.3	0.2	24.7	49.2	105.0	83.9	272.8	1083.3
1923	200.5	59.5	64.8	96.0	49.6	22.4	14.7	8.0	44.7	65.5	68.7	161.2	898.2
1924	116.4	156.8	57.4	33.9	10.1	13.5	7.1	25.0	55.1	204.7	187.7	213.2	1125.5
1925	183.4	236.9	84.1	113.8	61.5	29.2	4.7	18.8	50.3	30.9	143.7	169.2	1170.3
1926	173.4	207.9	36.1	72.2	91.0	4.9	2.9	32.1	39.1	112.0	322.3	178.8	1320.4
1927	214.3	264.9	116.6	98.9	63.3	21.3	9.0	30.8	61.7	112.5	256.7	126.1	1426.6
1928	165.1	80.9	224.9	128.3	16.0	15.1	9.3	2.9	25.7	93.9	152.5	174.5	1089.2
1929	89.6	51.6	105.1	92.9	21.4	53.0	7.5	8.0	6.2	29.5	29.1	265.1	759.0
1930	151.2	172.2	90.7	83.1	53.2	20.6	1.3	2.9	45.4	76.3	98.0	80.3	875.3
1931	199.8	96.4	176.5	62.4	28.4	83.4	3.4	3.1	68.9	116.9	161.6	294.0	1294.8
1932	165.3	132.1	179.5	112.2	47.4	14.6	34.1	20.0	14.8	78.4	234.8	214.6	1247.9
1933	263.5	111.4	193.8	24.2	104.5	29.7	10.0	8.9	81.0	131.3	67.4	412.3	1438.2
1934	203.5	88.5	112.2	44.5	67.2	19.5	16.2	12.3	36.8	151.8	243.7	197.1	1193.3
1935	283.4	102.1	195.5	98.0	15.5	18.8	13.0	12.0	41.0	83.7	73.5	159.3	1095.8
1936	306.2	215.1	91.0	44.7	81.1	60.0	20.5	12.1	20.9	20.1	17.5	147.8	1037.2
1937	134.3	225.4	148.6	138.1	40.8	80.6	2.2	27.4	38.7	96.5	333.9	235.9	1502.4
1938	175.0	263.1	269.7	105.2	29.8	3.4	7.3	5.9	35.8	104.3	129.1	148.9	1277.4
1939	193.8	148.5	105.6	25.0	51.5	36.7	20.3	7.7	18.4	73.6	64.0	277.6	1022.8
1940	192.5	346.3	203.1	79.6	57.8	6.4	20.5	13.9	48.6	147.2	114.4	266.4	1494.7
1941	234.9	151.0	89.5	95.7	92.5	42.6	7.9	40.5	81.7	75.3	133.2	309.9	1358.2
1942	148.6	165.0	92.5	105.5	92.5	52.6	22.6	6.0	10.5	81.0	272.5	262.8	1312.2
1943	193.3	112.8	139.1	101.5	55.8	29.1	14.6	31.6	12.3	146.5	84.2	117.5	1038.4
1944	145.2	132.8	89.4	109.1	53.5	24.0	9.6	12.6	41.4	81.6	217.9	120.9	1038.0
1945	156.5	187.8	197.6	68.0	88.6	9.5	7.1	7.1	59.3	109.8	271.7	284.0	1447.0
1946	170.2	186.0	129.1	75.5	23.5	57.3	25.0	4.9	32.3	104.3	188.7	143.6	1140.4

Precipitation

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

NORTH PACIFIC COAST

Area-Average Annual Precipitation Amount (continued)

Year	Precipitation (mm)												
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1947	141.0	108.2	143.2	65.2	20.0	79.2	40.1	14.5	26.7	235.8	104.5	144.5	1122.8
1948	177.5	174.2	144.8	173.3	107.4	27.2	17.8	39.0	66.1	74.3	180.6	239.3	1421.5
1949	36.9	207.8	161.1	36.4	46.3	18.0	14.0	14.0	28.1	79.0	164.3	184.7	990.6
1950	309.4	201.3	217.2	88.6	40.2	25.6	17.7	25.6	31.1	268.9	202.5	260.3	1688.4
1951	259.8	208.2	116.9	41.8	51.4	3.3	3.8	7.2	48.0	157.3	198.0	256.9	1352.6
1952	284.7	137.7	151.8	51.5	35.4	50.0	6.5	16.2	12.6	27.3	70.4	344.1	1188.2
1953	410.6	97.0	144.8	106.1	93.5	43.7	8.1	32.2	37.3	95.7	233.3	187.8	1490.1
1954	338.6	170.4	121.7	103.7	20.8	53.3	21.2	51.2	41.1	61.1	193.2	208.5	1384.7
1955	124.9	95.1	113.0	140.6	30.2	25.5	36.0	3.7	37.9	142.4	225.0	421.7	1396.1
1956	346.6	203.4	159.7	31.0	39.1	53.8	10.8	19.0	52.2	206.7	48.6	161.9	1332.9
1957	130.5	171.2	214.1	83.7	68.9	24.9	19.7	20.5	42.0	147.6	103.1	241.6	1267.8
1958	256.7	317.2	128.3	140.6	31.0	44.8	5.3	14.0	39.1	79.4	180.1	156.4	1404.1
1959	275.9	186.7	125.4	78.4	50.0	31.6	12.3	15.0	99.9	71.0	101.7	134.1	1225.3
1960	187.8	216.3	176.5	87.9	120.5	12.1	0.6	30.9	15.3	85.4	246.1	131.3	1334.3
1961	179.8	276.0	225.9	88.1	76.1	14.4	11.1	14.7	27.9	107.8	177.6	177.5	1435.5
1962	94.7	165.7	141.3	82.9	47.7	20.4	5.7	47.3	46.2	200.6	205.7	149.5	1207.8
1963	97.9	151.0	155.1	175.7	56.3	26.7	21.1	13.7	26.9	145.1	284.6	122.8	1276.7
1964	302.7	56.3	143.6	51.8	40.8	45.6	27.7	29.7	40.7	52.2	245.0	374.0	1466.2
1965	252.8	120.3	27.1	115.3	43.1	12.6	6.4	38.8	12.1	65.4	213.0	168.2	1115.2
1966	245.3	108.4	154.0	51.3	28.2	26.8	24.8	18.3	35.6	75.8	220.2	274.9	1323.9
1967	332.9	91.8	175.8	123.0	29.1	23.9	4.1	2.1	34.7	165.0	115.7	201.2	1371.6
1968	233.1	159.6	158.0	53.1	46.5	47.2	10.1	74.6	46.2	117.1	183.0	301.3	1501.9
1969	321.5	162.7	65.7	91.4	38.7	34.6	7.1	8.0	70.0	90.9	84.7	291.6	1267.0
1970	383.1	109.2	84.3	88.2	35.4	16.3	12.3	2.9	50.7	100.5	266.8	309.3	1458.9
1971	254.7	99.7	217.8	76.9	38.5	43.0	12.7	19.5	75.3	72.3	180.4	244.9	1335.6
1972	193.8	193.9	174.7	121.8	21.1	24.0	26.6	10.8	61.8	56.0	152.5	237.9	1274.7
1973	227.5	110.3	124.5	28.8	43.2	42.5	4.6	8.6	59.5	122.4	381.8	275.0	1428.7
1974	268.0	180.6	231.5	104.4	50.2	23.1	42.2	5.3	7.0	39.6	127.9	212.9	1292.8
1975	192.9	222.1	212.5	68.1	43.8	21.1	9.9	46.2	3.0	230.8	178.8	205.0	1434.3
1976	158.7	169.1	107.4	67.8	32.7	19.6	24.4	57.6	25.4	39.6	55.4	59.3	817.0
1977	70.0	89.0	140.0	30.3	79.5	16.8	10.3	43.5	89.7	74.1	238.0	262.1	1143.4
1978	213.7	153.3	119.8	118.5	58.8	26.4	9.0	35.1	120.6	15.3	102.5	67.9	1040.7
1979	129.0	255.3	80.6	84.3	55.9	15.7	19.5	19.1	45.9	160.3	153.5	267.1	1320.6
1980	162.1	214.5	119.6	99.1	32.6	37.7	13.9	13.0	34.7	42.4	156.4	225.9	1195.6
1981	116.6	162.6	129.4	95.3	53.6	58.1	14.4	5.8	66.1	157.5	252.3	327.6	1478.0
1982	247.6	232.3	187.1	151.4	8.0	36.2	20.8	11.7	41.5	147.2	198.9	285.1	1595.4
1983	253.4	262.4	296.0	91.8	44.8	37.5	56.0	55.6	42.4	47.2	353.7	271.0	1852.0
1984	120.0	169.0	130.3	90.3	87.0	46.8	3.3	12.4	42.0	126.5	369.0	113.0	1309.7
1985	23.9	108.3	139.3	50.2	32.3	43.0	5.0	13.5	49.9	152.1	128.8	81.4	827.9
1986	230.0	329.9	153.2	64.7	74.4	16.6	21.6	1.1	84.3	67.7	156.8	114.7	1314.9
1987	189.0	141.5	176.7	47.0	50.2	9.3	17.7	5.7	8.2	16.0	111.6	269.7	1042.6
1988	190.8	43.6	94.4	79.6	82.1	48.9	13.5	8.3	27.7	44.3	278.6	157.7	1097.1
1989	142.8	78.2	238.3	61.6	55.3	21.3	20.9	26.6	32.8	108.3	142.5	70.9	1022.4
1990	253.6	180.9	92.4	63.7	110.0	45.1	13.3	33.0	7.2	121.5	227.5	122.2	1366.4
1991	110.8	144.4	206.5	104.5	51.2	26.7	18.9	52.8	5.9	53.0	166.7	113.4	1091.9
1992	167.4	144.4	68.0	119.4	8.5	35.1	18.7	13.9	29.9				

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United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

SOUTH PACIFIC COAST

Trends

The annual precipitation time series for the South Pacific Coast region is marked by large short-term variations, but it shows evidence of a general downward trend from the early 1900s to ca. 1950 (interrupted by some very wet years ca. 1940), followed by a generally increasing trend through the unusual El Niño/Southern Oscillation (ENSO) episode of 1982–83 [see Quiroz (1983) for a detailed explanation of this event].

Area-average annual precipitation amount for the South Pacific Coast region of the United States.

CITE AS: Karl, T.R., D.R. Easterling, and P.Ya. Groisman. 1994. United States historical climatology network—National and regional estimates of monthly and annual precipitation. pp. 830–905. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Precipitation

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

SOUTH PACIFIC COAST

Area-Average Annual Precipitation Amount

Year	Precipitation (mm)												
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1900	68.9	8.1	51.3	39.4	35.9	2.7	5.9	0.1	14.4	39.6	319.4	17.5	603.1
1901	151.2	160.0	20.6	37.3	42.3	0.4	0.0	2.4	9.4	58.5	58.2	15.8	556.1
1902	50.5	160.1	102.3	31.7	8.9	5.7	37.4	0.5	0.0	42.1	113.3	50.7	652.4
1903	93.3	49.6	171.4	50.9	1.9	0.0	0.0	6.8	20.6	15.4	77.9	16.8	526.5
1904	24.1	128.7	174.5	50.6	3.9	0.0	4.8	39.4	71.1	58.4	18.9	45.7	619.7
1905	91.2	151.3	147.7	27.6	62.6	0.8	0.4	0.0	13.6	0.8	192.2	29.7	736.6
1906	109.0	100.7	228.1	25.8	62.1	21.6	2.1	63.8	13.7	10.3	78.5	147.5	882.5
1907	184.3	68.4	206.6	12.3	3.2	41.2	0.0	0.0	1.7	86.7	17.2	68.6	708.4
1908	122.0	101.9	29.7	13.5	10.4	0.1	0.0	54.7	40.0	41.2	39.5	41.7	494.6
1909	257.9	152.6	101.5	1.4	1.9	1.9	3.1	24.7	10.7	30.2	106.7	191.7	953.9
1910	76.2	17.5	87.3	8.4	0.0	0.6	25.4	1.5	9.4	39.3	36.7	21.8	330.5
1911	249.3	93.7	171.8	26.7	2.6	3.1	10.8	0.0	8.8	14.6	9.3	42.2	640.6
1912	36.4	3.0	171.3	56.1	24.7	16.7	14.2	10.8	6.4	68.7	46.7	9.4	486.0
1913	78.3	107.6	27.9	13.2	9.2	20.2	13.3	46.4	1.9	5.0	122.2	83.1	548.2
1914	266.1	131.8	24.5	25.5	8.7	16.6	1.5	20.7	2.3	33.2	28.5	124.9	684.4
1915	159.2	173.2	38.6	51.1	72.0	0.0	0.9	6.9	5.4	0.1	48.9	80.5	636.8
1916	356.8	60.6	53.4	5.8	3.2	0.0	38.6	37.1	33.5	85.4	13.0	120.1	800.7
1917	62.8	108.0	19.9	21.2	8.7	0.0	19.9	0.3	5.6	1.4	23.1	10.7	283.4
1918	24.0	134.8	154.5	4.5	4.2	11.2	2.6	27.6	49.5	18.7	105.3	44.2	640.2
1919	23.2	109.4	69.7	6.6	4.9	0.0	19.2	15.7	18.9	30.6	33.1	69.5	420.8
1920	25.7	77.7	112.0	31.4	3.5	5.7	1.1	13.5	2.6	67.6	42.0	64.4	455.5
1921	116.5	35.8	53.5	10.3	57.1	0.1	25.7	1.0	35.2	31.4	18.4	244.6	629.6
1922	110.5	119.0	60.9	11.3	14.9	0.4	8.0	21.6	2.4	25.9	106.3	152.1	633.2
1923	65.2	38.7	9.6	71.0	0.4	9.1	7.1	0.0	19.7	25.9	26.7	32.8	308.7
1924	32.2	11.5	83.1	23.0	0.3	0.0	0.0	0.2	0.0	33.4	46.1	63.3	282.4
1925	22.5	68.5	59.9	61.1	35.4	45.7	0.2	0.5	2.8	79.1	33.0	71.2	479.8
1926	68.5	121.9	9.0	135.1	5.2	0.4	0.0	2.3	0.0	14.1	135.8	70.6	563.1
1927	46.7	246.6	59.8	31.1	4.7	39.8	0.0	0.1	6.0	80.7	63.9	88.6	668.0
1928	17.2	63.2	73.7	12.6	9.5	0.2	0.0	0.0	0.6	15.5	67.9	86.1	342.3
1929	44.9	49.2	43.7	39.0	0.1	29.7	8.6	19.8	39.4	0.5	0.0	19.2	297.8
1930	142.0	46.8	92.5	21.0	40.8	0.7	0.0	23.7	3.0	15.5	89.0	4.1	488.9
1931	100.8	84.1	11.9	41.5	32.7	14.9	10.5	5.9	23.3	22.4	101.3	192.8	642.9
1932	66.3	159.9	10.7	15.6	6.2	0.6	0.4	0.2	3.1	60.2	5.9	67.3	396.3
1933	201.6	7.8	25.6	17.7	21.1	14.9	7.9	4.9	0.6	18.7	16.1	119.0	458.1
1934	31.6	83.4	3.3	2.8	4.5	53.7	15.5	33.5	6.9	48.3	77.5	83.8	454.8
1935	115.4	69.7	74.9	81.9	1.2	0.0	9.2	32.5	4.7	14.9	26.7	38.2	471.0
1936	52.7	226.3	41.7	27.0	7.9	6.6	29.1	2.2	0.3	57.2	15.7	168.5	627.6
1937	111.6	182.1	135.7	13.2	4.2	6.7	4.9	0.0	0.0	5.9	20.8	107.4	592.4
1938	71.2	209.5	186.8	33.2	5.0	0.3	0.3	0.9	2.8	24.5	11.9	107.0	646.1
1939	88.8	55.1	49.7	11.4	7.5	0.0	0.1	4.7	96.3	16.7	17.0	23.2	366.7
1940	186.6	171.5	65.0	34.5	5.5	0.1	0.6	0.0	1.8	52.2	29.8	203.4	765.5
1941	126.8	216.6	169.1	116.9	15.5	1.3	0.5	15.5	4.1	66.7	28.9	165.2	927.0
1942	60.6	60.1	48.2	75.9	13.2	0.0	0.0	6.9	0.9	21.6	40.0	51.0	378.4
1943	253.0	75.8	104.8	31.9	0.4	3.4	0.0	0.2	0.1	18.8	7.7	143.6	639.8
1944	60.0	209.1	44.0	32.5	9.9	3.3	0.0	0.0	0.2	11.7	157.4	42.1	570.1
1945	16.2	124.2	113.6	6.6	6.0	4.3	0.2	48.4	5.8	26.7	30.6	176.7	559.5
1946	20.1	47.2	79.4	10.8	10.2	0.0	20.6	3.1	1.0	28.5	171.8	77.3	469.9

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

SOUTH PACIFIC COAST

Area-Average Annual Precipitation Amount (continued)

Year	Precipitation (mm)												
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1947	14.6	29.2	41.0	7.2	7.9	5.4	0.0	3.9	2.8	27.2	12.8	44.3	196.4
1948	11.5	49.5	89.0	69.6	10.2	7.8	14.5	0.0	0.2	19.0	6.4	82.4	336.0
1949	70.8	59.6	81.2	2.7	15.5	0.4	0.2	0.8	0.1	8.9	48.6	67.2	345.3
1950	109.0	59.8	44.3	25.8	7.7	0.4	13.2	0.1	7.8	24.8	82.6	56.6	374.3
1951	79.1	44.7	29.7	40.2	7.0	0.3	1.5	15.1	2.0	30.1	54.6	182.0	486.2
1952	239.1	23.4	151.8	41.8	1.8	3.0	7.9	0.0	1.9	0.2	97.7	128.4	697.1
1953	46.8	7.3	38.7	46.3	9.1	2.9	0.0	1.0	0.0	2.4	52.8	7.9	215.2
1954	122.5	72.3	119.3	16.9	2.9	4.3	12.2	1.1	9.1	0.5	54.6	55.6	471.3
1955	119.2	45.6	15.0	40.0	36.4	0.6	5.7	9.6	0.1	0.2	43.1	161.4	476.8
1956	151.8	35.6	1.0	65.5	23.7	0.0	0.5	0.1	3.2	18.8	0.2	11.0	311.4
1957	144.3	62.6	39.2	45.1	48.5	9.2	0.2	6.7	4.3	60.4	23.0	92.3	535.6
1958	76.0	199.9	170.3	131.8	8.2	1.9	2.3	3.4	13.7	4.1	10.4	7.1	648.5
1959	71.9	143.4	5.1	13.1	1.4	0.1	1.7	4.9	23.3	2.8	1.9	37.3	306.8
1960	99.6	108.0	27.7	39.2	7.3	0.1	1.1	2.0	3.3	3.9	81.0	18.5	391.8
1961	44.3	10.1	44.7	10.2	7.2	1.0	0.0	3.7	1.7	2.3	66.5	53.7	245.6
1962	74.5	250.0	53.3	3.9	11.1	2.6	0.0	0.2	1.6	35.9	4.8	31.3	469.4
1963	55.2	105.3	68.6	78.5	5.7	4.2	0.0	10.4	37.7	27.5	93.1	4.8	491.2
1964	73.5	7.1	57.2	24.5	14.7	6.1	0.0	2.7	1.9	18.5	64.6	111.4	382.0
1965	46.8	20.7	39.3	111.7	0.4	0.6	8.8	3.3	9.5	0.7	234.1	129.0	604.8
1966	45.4	48.2	10.4	4.9	2.3	1.1	2.1	0.7	6.1	5.5	87.5	178.6	392.8
1967	137.8	6.8	91.9	132.3	3.3	9.6	1.2	1.2	17.5	1.7	91.5	69.7	564.6
1968	52.4	36.7	71.2	19.5	4.9	0.2	6.7	3.1	0.0	20.7	37.0	71.6	323.9
1969	345.2	256.1	31.7	37.6	3.0	2.3	1.9	0.0	0.9	12.9	42.7	47.7	782.0
1970	114.4	51.1	79.9	7.3	0.3	4.8	0.6	2.6	0.0	7.2	144.9	141.4	554.4
1971	34.1	21.2	27.1	26.3	17.9	0.3	0.3	5.7	3.4	14.4	23.1	152.5	326.2
1972	15.6	16.2	1.7	14.9	3.8	6.6	0.3	0.9	8.6	44.2	118.6	57.4	288.8
1973	164.7	196.4	108.2	4.7	2.8	0.4	0.0	3.3	2.7	23.2	94.8	54.3	655.5
1974	153.3	15.5	111.6	39.1	1.6	1.0	16.9	0.1	0.4	34.5	12.0	87.3	466.8
1975	14.4	97.5	131.7	60.9	1.9	1.4	1.6	4.0	5.5	30.0	16.7	9.4	381.6
1976	2.2	110.9	43.1	32.2	1.7	4.4	1.3	17.4	75.1	14.6	24.2	35.1	360.4
1977	75.7	14.0	44.8	3.1	60.5	0.6	0.6	34.5	7.1	6.4	19.0	136.9	405.5
1978	223.5	191.4	199.8	76.2	2.6	0.3	0.0	1.2	23.2	2.6	73.7	55.7	836.3
1979	165.9	115.1	110.9	9.6	6.5	0.3	1.7	1.4	1.7	37.9	27.9	59.1	554.4
1980	215.2	270.6	89.4	29.1	15.2	0.9	5.1	0.0	0.1	5.0	1.5	35.4	694.5
1981	94.8	46.5	127.3	11.4	5.2	0.1	0.0	2.4	6.6	28.5	79.5	44.8	447.0
1982	145.2	50.2	172.3	70.6	2.6	2.7	0.5	3.8	28.1	27.8	135.5	97.0	761.9
1983	166.6	164.0	255.8	111.9	7.8	0.2	0.0	26.8	18.9	37.8	121.0	118.3	1056.7
1984	4.8	17.3	18.3	18.6	0.4	1.8	9.4	11.5	6.6	22.6	96.5	124.0	343.5
1985	22.7	44.7	62.2	6.4	2.2	1.6	2.7	0.2	8.0	17.5	120.3	38.9	327.3
1986	68.3	193.4	142.3	18.3	2.5	0.0	5.6	0.8	29.9	10.9	16.6	30.7	509.1
1987	57.1	69.0	63.2	9.2	3.0	0.5	1.3	1.9	4.2	54.0	57.8	88.2	407.1
1988	72.3	40.1	15.6	64.7	8.4	2.6	0.3	3.2	1.3	1.0	49.8	106.7	357.9
1989	22.6	51.7	58.8	8.9	4.8	0.7	0.0	0.7	25.4	24.9	10.3	2.6	197.2
1990	77.0	71.3	21.3	17.4	35.3	3.5	0.4	4.9	3.7	2.5	14.6	17.6	259.4
1991	28.7	79.6	252.0	6.2	1.6	3.3	1.3	7.1	2.6	22.9	8.9	80.4	513.6
1992	64.0	220.4	124.6	8.7	2.8	1.9	6.7	4.8	0.4				

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Precipitation

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

NORTH CASCADES

Trends

The annual precipitation time series for the North Cascades region shows no obvious long-term trends; however, the first three decades of the series were consistently drier than any period since then. Interannual variability has increased somewhat since the early part of the record, and is particularly evident from about the late 1920s through the early 1950s and since the mid-1970s.

Area-average annual precipitation amount for the North Cascades region of the United States.

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United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

NORTH CASCADES

Area-Average Annual Precipitation Amount

Year	Precipitation (mm)												
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1900	141.0	123.7	122.3	62.2	98.5	83.7	19.5	26.2	51.8	170.3	129.1	177.6	1277.4
1901	191.1	169.4	112.0	94.0	59.1	51.5	9.9	6.1	81.4	57.5	188.8	127.1	1148.0
1902	113.8	218.9	142.2	102.4	82.7	27.3	46.5	21.8	50.1	58.1	253.0	244.8	1361.7
1903	253.3	60.9	107.9	68.3	53.5	62.5	23.7	28.3	88.8	72.8	250.4	110.5	1180.8
1904	163.5	301.8	211.1	71.3	25.9	37.8	21.8	5.7	19.0	72.8	179.7	211.5	1321.9
1905	101.0	64.2	119.1	34.0	94.8	44.9	8.6	14.0	75.1	136.0	87.0	159.1	951.4
1906	163.2	129.0	54.4	42.3	101.0	96.0	2.8	4.8	83.8	98.7	209.9	160.7	1146.6
1907	158.8	153.9	100.2	83.6	31.5	49.9	14.2	39.5	52.8	32.0	174.3	246.3	1137.1
1908	109.3	112.3	135.9	62.5	88.2	45.9	12.2	34.9	8.3	130.9	113.4	134.0	987.8
1909	234.5	195.0	62.3	36.5	50.2	16.0	37.7	9.5	45.6	95.5	325.3	115.4	1223.4
1910	171.4	158.0	90.5	70.3	58.1	37.4	2.4	9.6	33.2	124.7	262.6	140.8	1159.0
1911	171.3	85.8	40.0	57.2	98.9	24.8	8.1	11.7	103.2	40.1	159.1	150.4	950.8
1912	206.0	129.5	69.6	80.3	64.4	74.9	19.2	90.7	42.0	90.8	177.1	183.7	1223.1
1913	198.2	51.9	100.8	60.0	54.0	91.6	31.8	18.6	73.9	104.2	165.9	92.3	1043.3
1914	277.2	98.8	74.9	94.3	40.1	67.2	4.4	2.1	104.7	116.5	142.3	58.7	1081.0
1915	134.9	105.6	69.4	72.2	100.0	29.9	43.3	0.8	28.9	106.9	240.9	234.0	1166.8
1916	138.3	188.2	234.8	85.8	71.2	58.4	80.7	11.9	30.6	41.2	163.0	139.2	1243.2
1917	120.6	100.5	141.5	140.8	48.3	75.0	4.6	2.4	42.5	17.3	134.7	368.7	1196.8
1918	181.9	172.9	105.1	39.1	53.6	8.2	25.8	45.9	16.9	125.4	139.8	153.8	1068.4
1919	246.9	194.2	146.8	119.2	67.9	25.7	5.5	5.3	75.8	75.5	176.5	157.1	1296.3
1920	128.8	16.4	130.9	130.4	33.4	62.1	24.4	39.6	131.8	147.8	158.7	232.5	1236.9
1921	201.7	183.0	119.1	90.7	54.3	56.3	5.0	20.2	74.3	100.8	244.9	123.6	1273.9
1922	93.2	109.1	151.0	87.4	54.8	11.6	0.6	43.5	55.5	117.7	72.6	234.6	1031.6
1923	266.9	61.1	82.3	67.7	70.0	49.4	35.9	27.8	39.2	85.6	101.8	183.8	1071.3
1924	116.4	146.9	62.9	44.0	15.7	30.4	13.4	53.7	64.3	186.2	186.4	161.0	1081.3
1925	209.5	171.3	66.6	90.5	61.9	29.7	1.3	37.8	38.0	24.8	126.1	160.5	1039.7
1926	124.5	191.1	28.2	45.1	89.1	11.6	0.6	61.4	56.6	124.8	217.0	147.0	1120.5
1927	205.4	204.7	92.8	65.0	81.3	31.7	7.3	24.8	110.9	108.0	251.1	112.4	1295.5
1928	159.2	44.6	229.9	131.8	19.1	31.4	14.0	2.1	26.6	100.0	112.2	148.9	1019.9
1929	111.2	43.2	99.8	104.1	49.5	71.0	3.4	11.4	12.9	44.2	25.1	245.3	840.0
1930	88.0	156.8	66.5	77.5	76.6	35.8	1.1	1.4	47.6	81.7	92.3	72.4	797.7
1931	145.4	89.3	183.1	68.0	34.8	115.6	2.4	4.5	72.8	124.5	162.4	198.5	1201.2
1932	170.6	116.6	209.0	105.1	62.5	16.6	38.3	26.1	13.3	119.0	256.0	204.2	1373.4
1933	230.6	120.2	151.7	40.8	107.9	51.1	11.2	31.6	104.6	118.2	81.3	401.1	1450.2
1934	213.9	48.9	126.4	60.1	63.2	20.4	14.7	11.7	46.4	162.4	268.9	210.3	1247.4
1935	186.1	82.3	142.1	78.8	17.8	38.1	22.3	11.9	40.1	94.9	74.7	130.7	919.7
1936	266.2	153.6	98.4	43.7	102.9	83.1	26.4	12.3	51.1	16.4	17.9	196.9	1068.9
1937	123.6	178.1	98.3	183.6	52.7	134.8	6.6	37.9	38.7	98.2	286.8	243.4	1482.8
1938	141.4	151.1	195.1	91.3	35.3	15.3	8.3	7.3	35.6	103.4	141.3	141.0	1066.4
1939	155.6	155.1	91.8	21.7	50.8	60.3	30.6	19.8	27.0	96.1	57.8	236.9	1003.4
1940	92.1	261.0	157.4	86.9	52.9	11.9	23.7	7.8	81.1	129.0	138.9	149.9	1192.6
1941	133.2	62.2	46.6	65.2	121.8	58.8	6.5	50.2	105.4	79.7	147.1	251.6	1128.4
1942	100.4	110.8	68.7	73.1	101.0	83.5	29.0	10.4	7.4	86.8	328.7	274.5	1274.1
1943	153.0	101.3	148.5	99.2	65.3	75.5	14.4	38.5	10.3	153.4	75.6	90.7	1025.8
1944	106.7	104.9	79.1	96.0	60.3	45.9	12.8	9.8	68.4	51.5	138.9	65.3	839.8
1945	146.7	178.0	176.1	111.0	112.1	17.3	7.1	13.3	89.5	87.7	273.2	202.8	1414.7
1946	194.5	154.0	140.7	60.1	34.6	82.9	22.8	8.6	44.1	133.5	196.9	178.5	1251.1

Precipitation

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

NORTH CASCADES

Area-Average Annual Precipitation Amount (continued)

Year	Precipitation (mm)												Ann
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	
1947	151.2	90.1	125.3	85.7	22.9	119.8	47.4	17.5	42.9	235.8	151.4	147.0	1287.6
1948	172.0	193.6	116.3	104.3	116.0	57.3	40.4	44.6	78.7	76.6	203.4	244.4	1501.5
1949	46.5	249.9	92.0	40.9	67.5	29.8	19.4	11.7	46.2	104.9	167.7	189.7	1085.5
1950	260.1	169.7	191.8	85.5	41.3	53.0	17.6	32.4	42.5	265.1	216.5	205.9	1581.4
1951	246.8	179.5	128.3	29.3	63.4	7.5	4.3	16.0	52.1	191.3	169.0	202.9	1290.4
1952	141.9	120.7	116.3	48.2	40.3	79.9	9.3	11.9	21.0	25.8	37.5	196.2	849.0
1953	366.6	141.1	120.0	80.2	103.1	72.4	8.4	47.4	39.2	101.9	213.5	237.1	1531.0
1954	286.8	130.9	79.2	92.5	46.1	91.7	26.6	46.1	47.0	70.8	148.0	161.8	1227.6
1955	94.6	104.0	139.0	137.2	51.0	40.9	44.1	2.8	52.7	186.4	229.2	328.7	1410.6
1956	264.7	142.9	158.1	27.3	59.5	78.0	11.8	27.1	45.1	196.3	60.1	182.3	1253.2
1957	88.5	150.4	200.9	68.0	67.8	47.3	18.9	23.8	33.0	105.5	112.4	245.7	1162.2
1958	212.7	193.7	68.6	115.1	35.6	79.0	11.2	10.6	47.5	88.1	238.3	170.3	1270.6
1959	235.9	118.7	124.7	76.0	74.4	58.2	17.4	19.1	114.8	109.9	133.1	125.3	1207.8
1960	120.9	152.5	172.1	110.8	138.8	24.2	2.8	53.1	29.8	109.6	264.5	98.0	1277.0
1961	143.7	280.7	183.6	89.6	85.2	20.8	15.1	20.2	47.0	132.4	165.2	187.6	1371.1
1962	81.7	83.4	141.8	90.4	80.3	29.5	10.2	55.7	56.5	140.0	224.3	117.8	1111.7
1963	59.4	149.2	128.0	122.0	75.2	62.9	39.0	28.7	44.6	101.6	212.0	118.8	1141.4
1964	300.5	53.4	135.1	71.3	47.6	81.6	30.3	38.9	51.3	46.4	203.6	361.9	1421.7
1965	245.5	105.5	22.6	92.0	47.6	17.1	13.4	57.0	13.6	71.3	155.5	173.9	1015.0
1966	212.7	79.7	149.8	49.8	39.5	43.7	44.7	12.4	45.8	97.1	185.5	210.0	1170.6
1967	252.6	88.8	122.8	76.7	37.2	33.4	3.0	1.6	35.6	176.5	82.9	167.2	1078.3
1968	167.8	168.6	111.1	68.6	73.3	63.2	14.9	112.7	61.0	140.3	189.6	244.3	1415.3
1969	229.8	84.1	64.2	85.8	62.0	74.5	8.7	7.7	97.3	98.4	79.2	226.6	1118.4
1970	301.4	91.7	89.6	113.5	43.2	26.5	11.6	5.6	65.3	100.9	194.4	230.4	1274.0
1971	269.6	137.8	181.0	82.7	61.7	69.4	16.1	18.7	96.3	92.1	199.6	225.0	1449.9
1972	241.2	189.4	192.5	140.0	50.9	48.2	27.1	21.0	87.7	42.6	110.6	234.4	1385.6
1973	126.7	52.4	94.5	56.2	51.9	56.4	2.9	14.4	73.3	103.1	333.6	259.6	1224.9
1974	269.3	163.8	194.3	106.2	70.0	38.4	43.4	6.0	7.3	44.6	159.2	230.0	1332.5
1975	213.6	164.9	151.4	72.3	53.7	37.3	16.0	69.4	4.8	183.2	181.0	238.6	1386.2
1976	188.4	154.4	117.6	75.6	52.5	34.0	29.2	91.0	33.1	51.1	44.3	61.2	932.5
1977	49.3	72.7	138.6	39.3	124.4	27.7	17.4	76.4	102.7	76.1	207.2	266.6	1198.4
1978	139.8	109.3	75.8	112.8	78.1	42.3	29.2	64.9	114.8	22.4	129.3	105.9	1024.6
1979	82.3	210.3	76.3	112.1	59.9	23.6	23.8	35.4	50.0	144.0	100.5	207.8	1125.9
1980	176.5	131.5	123.7	97.3	49.5	65.6	13.1	19.1	51.4	41.7	193.6	244.1	1207.0
1981	61.9	145.2	96.8	101.7	81.3	104.2	21.3	4.8	81.3	140.8	166.1	305.8	1311.0
1982	200.0	206.5	113.9	107.4	22.1	46.9	27.1	26.8	74.3	129.8	143.1	237.2	1335.0
1983	199.5	205.1	190.0	67.6	56.6	73.3	79.4	48.6	46.6	50.5	282.6	195.6	1495.4
1984	125.3	150.2	137.4	110.5	121.3	95.7	3.4	16.6	48.3	130.8	300.0	134.6	1374.3
1985	15.4	98.8	103.1	66.3	47.3	58.4	8.6	23.7	72.0	153.0	144.4	58.2	849.1
1986	187.2	221.1	105.5	79.0	86.3	23.9	36.5	2.7	115.2	74.8	232.7	97.3	1262.1
1987	161.6	111.4	137.3	67.1	63.0	17.5	49.8	9.4	13.1	6.3	101.6	244.7	997.8
1988	164.1	59.5	139.9	117.2	103.6	58.5	17.1	7.8	47.6	48.8	291.8	119.4	1199.6
1989	162.2	76.5	205.9	77.7	69.5	30.4	17.4	38.7	22.0	80.0	153.4	91.3	1056.0
1990	265.8	161.3	86.8	93.8	77.5	77.0	20.9	48.0	10.7	171.1	222.7	119.9	1400.4
1991	115.3	133.0	145.6	140.2	95.5	48.5	14.7	38.2	6.2	64.5	224.9	126.7	1200.8
1992	147.8	98.8	37.4	136.4	17.3	42.5	30.9	14.1	54.1				

CITE AS: Karl, T.R., D.R. Easterling, and P.Ya. Groisman. 1994. United States historical climatology network—National and regional estimates of monthly and annual precipitation. pp. 830–905. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

CALIFORNIA INTERIOR VALLEYS

Trends

The annual precipitation time series for the California Interior Valleys region shows no obvious long-term trends, but the last 10 to 15 years of the record exhibit especially high variability. The driest year in the record, 1976, coincides with the 1976–77 El Niño/Southern Oscillation (ENSO) event. As with much of the extreme western United States in general, this region relies on “winter” (actually late fall through early spring) precipitation for most of its annual precipitation. The monthly precipitation data show that the winter of 1976–77 was easily the driest of the century, whereas the winter of 1982–83 was by far the wettest (helping 1983 set a record for annual precipitation during this century). The wetness of 1982–83 resulted from a very unusual ENSO episode [see Quiroz (1983) for a detailed explanation of the event].

Area-average annual precipitation amount for the California Interior Valleys region of the United States.

CITE AS: Karl, T.R., D.R. Easterling, and P.Ya. Groisman. 1994. United States historical climatology network—National and regional estimates of monthly and annual precipitation. pp. 830–905. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Precipitation

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

CALIFORNIA INTERIOR VALLEYS

Area-Average Annual Precipitation Amount

Year	Precipitation (mm)												
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1900	91.4	24.2	63.1	56.9	35.4	9.8	0.3	0.8	8.2	56.2	118.4	45.7	546.4
1901	127.1	139.1	24.0	66.7	23.9	0.2	0.1	1.2	24.5	31.5	65.4	42.6	607.1
1902	29.8	236.5	77.1	52.3	25.1	2.1	2.9	0.5	0.8	51.2	88.7	79.2	708.6
1903	120.8	40.4	143.3	20.1	7.7	6.5	0.8	1.8	0.9	10.1	140.1	44.5	534.7
1904	41.4	233.2	208.0	59.4	6.4	0.3	3.4	7.2	76.1	76.2	36.7	83.4	849.6
1905	100.8	81.9	126.7	28.4	55.6	4.5	0.5	2.5	5.8	1.0	43.6	39.4	512.8
1906	174.1	115.0	217.7	42.8	86.7	45.3	0.7	4.7	4.5	0.8	36.6	203.4	917.5
1907	153.8	91.0	224.3	29.1	17.9	46.6	0.5	1.4	2.2	29.4	6.6	138.5	744.2
1908	92.3	93.5	24.5	14.8	39.9	6.2	0.8	0.2	13.1	22.3	43.7	54.3	393.4
1909	348.6	179.2	68.2	3.7	7.6	6.6	0.6	4.4	9.9	42.2	119.7	161.1	936.0
1910	101.8	58.7	80.1	15.2	3.8	0.9	0.6	0.0	16.5	21.0	36.3	50.2	385.7
1911	305.6	73.8	146.6	50.3	12.5	7.4	1.0	0.0	8.8	10.4	19.8	43.7	679.9
1912	66.7	10.2	106.7	63.9	43.9	21.7	2.6	0.6	45.9	19.3	66.4	31.1	480.8
1913	109.3	24.4	46.3	36.8	28.5	39.1	26.1	5.5	1.1	3.1	115.4	184.2	621.3
1914	288.0	105.6	19.2	51.1	14.7	39.8	0.9	0.0	2.5	34.0	14.7	107.4	691.9
1915	149.7	194.5	46.1	38.1	94.6	0.3	1.4	0.0	1.5	2.0	36.5	134.3	709.1
1916	279.6	88.9	75.2	11.1	15.5	5.8	9.8	4.7	10.2	45.6	37.9	123.8	725.2
1917	50.4	146.9	42.6	40.8	18.4	0.7	2.9	1.0	5.8	0.2	33.9	36.5	383.6
1918	30.2	149.4	152.0	16.8	11.2	1.1	0.0	0.8	71.7	26.0	65.0	49.1	568.6
1919	57.4	188.5	78.8	16.5	5.7	0.0	0.3	0.0	24.9	9.7	17.4	93.8	475.5
1920	18.8	47.7	135.3	56.8	1.4	19.2	0.3	11.7	4.7	60.5	121.3	131.9	605.6
1921	171.0	43.4	58.5	11.8	35.8	8.7	0.0	0.0	2.6	12.7	37.5	160.3	536.5
1922	71.3	187.0	87.9	15.8	26.2	17.8	2.6	0.5	0.1	45.4	83.6	183.0	721.2
1923	89.7	27.7	6.3	106.6	8.5	34.4	3.2	6.3	33.5	23.7	14.0	40.3	394.1
1924	57.4	57.7	56.0	18.1	2.9	0.1	0.0	1.3	2.3	80.5	53.0	120.5	449.9
1925	41.0	186.1	73.1	65.6	41.3	26.6	3.0	8.0	17.6	21.1	44.3	46.9	574.7
1926	98.8	150.3	6.9	109.4	16.1	1.1	1.5	1.3	1.0	35.1	181.5	47.0	650.1
1927	98.6	198.3	59.5	65.6	19.0	19.8	0.0	0.9	3.3	56.5	99.6	85.6	706.9
1928	51.1	57.7	143.4	33.9	6.6	5.8	0.6	0.0	1.7	6.3	76.0	88.8	471.9
1929	37.4	61.2	62.4	45.5	2.5	78.7	0.9	0.4	2.8	3.2	0.5	134.4	429.7
1930	119.9	81.5	74.7	34.7	25.3	1.0	0.0	1.6	17.3	10.5	66.2	12.4	445.0
1931	110.9	55.3	33.1	24.3	27.2	47.0	0.0	0.4	5.1	29.6	63.7	224.9	621.5
1932	80.8	77.5	29.1	38.8	34.7	7.1	1.5	0.0	2.9	3.2	20.3	69.6	365.4
1933	135.0	22.9	68.6	11.1	38.8	9.8	0.5	0.1	3.3	46.9	0.8	163.0	500.7
1934	48.8	98.5	17.3	17.5	18.1	42.2	0.0	2.7	8.1	1.5	116.8	70.1	481.6
1935	153.8	67.7	96.9	142.6	6.9	0.0	0.7	2.6	1.7	1.2	29.5	65.2	598.7
1936	151.6	243.5	48.0	46.2	13.3	56.6	1.8	1.0	6.5	22.2	1.3	96.5	688.7
1937	89.3	178.8	132.3	35.2	3.1	30.3	2.7	0.0	0.2	38.5	120.1	150.4	781.0
1938	99.9	228.6	200.9	61.4	11.2	7.5	5.9	0.0	10.2	47.4	29.5	34.5	736.9
1939	67.3	42.7	67.9	9.3	32.7	4.1	1.9	0.6	20.0	33.6	7.0	51.1	338.4
1940	258.2	225.1	130.2	28.5	18.6	2.4	0.0	0.3	7.7	44.8	44.5	258.0	1018.4
1941	174.8	186.9	83.5	97.6	37.8	13.4	4.7	2.6	2.5	37.1	54.7	221.8	917.5
1942	135.7	123.5	53.4	110.6	51.4	2.1	0.0	0.6	1.6	10.9	119.2	103.4	712.3
1943	193.9	53.7	115.6	54.6	6.6	21.2	1.8	0.0	0.7	21.3	28.2	51.0	555.2
1944	93.0	146.6	42.2	55.8	24.1	25.8	3.0	0.0	3.5	39.3	132.3	81.8	674.6
1945	33.6	147.6	97.5	15.9	38.6	30.3	0.8	0.6	1.5	90.2	96.4	194.4	768.1
1946	32.1	56.9	75.8	7.8	17.4	0.3	7.9	0.2	5.0	22.7	113.7	82.8	420.0

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

CALIFORNIA INTERIOR VALLEYS

Area-Average Annual Precipitation Amount (continued)

Year	Precipitation (mm)												Ann
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	
1947	21.4	68.6	87.9	18.7	10.5	39.6	0.0	2.2	1.6	91.0	25.9	27.3	384.3
1948	53.5	44.1	104.1	137.5	41.8	17.8	0.0	0.9	5.3	15.3	38.7	103.1	545.6
1949	42.0	75.3	141.4	3.1	27.9	0.5	0.2	8.6	1.6	3.7	48.2	44.5	404.1
1950	173.6	87.1	77.2	42.7	19.6	9.5	1.0	1.0	8.6	89.5	170.1	158.1	848.4
1951	117.7	73.3	41.8	41.4	29.3	1.5	0.0	0.9	1.4	60.4	98.1	199.5	667.6
1952	211.4	80.5	119.3	35.1	8.4	22.8	21.4	0.3	7.9	3.2	59.9	215.8	800.3
1953	126.3	6.6	63.4	71.9	36.6	25.6	2.0	8.5	0.6	20.3	77.5	28.4	469.6
1954	125.3	89.8	110.7	49.9	3.2	12.3	0.0	6.8	1.8	4.7	87.5	118.4	617.1
1955	89.7	43.1	19.0	70.5	16.3	2.6	2.9	0.0	7.8	8.7	71.7	366.8	705.4
1956	194.8	82.4	9.6	46.4	45.7	4.6	9.3	0.1	9.1	72.5	1.9	28.8	493.7
1957	85.6	111.0	80.7	41.6	70.7	3.2	1.6	0.1	24.9	62.8	37.4	103.7	617.3
1958	114.4	209.9	157.8	112.1	24.8	31.0	6.4	2.3	11.1	6.9	20.6	31.4	739.6
1959	132.8	139.0	21.5	24.0	14.4	0.7	0.2	3.5	56.7	0.4	0.4	36.0	436.2
1960	112.7	138.7	86.8	38.3	24.5	0.2	2.7	0.4	1.6	8.9	120.4	58.6	616.7
1961	65.6	59.6	83.0	30.3	25.5	12.0	1.8	11.5	9.6	16.0	78.7	64.6	483.4
1962	43.6	234.3	81.6	15.6	12.2	3.4	2.1	3.7	3.2	188.6	32.8	73.1	735.8
1963	95.7	85.4	104.3	138.2	32.3	19.5	0.5	2.3	11.2	53.0	144.1	17.7	722.3
1964	90.6	6.8	52.9	20.2	32.3	30.3	0.9	6.2	4.9	36.9	120.9	271.4	691.1
1965	132.5	22.4	34.5	84.7	4.5	19.9	3.6	36.8	5.4	4.7	147.2	88.0	584.3
1966	72.1	61.5	23.3	23.4	7.7	2.4	1.2	1.3	4.3	0.3	148.1	137.5	482.9
1967	203.8	14.2	135.9	141.9	19.7	38.8	1.2	3.2	7.4	18.6	58.1	60.9	720.0
1968	120.8	92.6	63.2	12.3	12.6	14.9	0.7	35.0	0.8	47.0	92.9	144.5	658.6
1969	295.5	205.1	39.8	52.6	3.2	24.9	0.9	0.0	2.9	49.4	36.0	171.9	909.6
1970	272.3	51.4	62.1	19.8	4.0	27.5	0.3	0.0	3.7	31.9	188.1	154.8	816.0
1971	53.8	14.3	86.7	26.8	43.5	25.6	0.9	2.9	13.4	9.2	64.6	136.6	478.2
1972	45.8	54.4	18.4	49.4	11.8	12.3	0.0	2.9	24.2	57.7	136.3	89.8	503.2
1973	208.4	160.3	89.1	9.9	11.8	3.5	0.9	6.9	10.1	59.1	217.2	124.3	901.4
1974	130.6	40.0	158.1	56.6	3.7	4.4	48.0	2.1	0.0	41.9	38.8	80.8	605.0
1975	42.6	181.7	151.6	51.5	6.9	6.0	5.3	14.8	4.0	96.2	28.3	24.0	612.9
1976	11.4	70.8	34.6	35.7	2.5	3.7	1.8	42.2	23.8	13.4	22.5	14.2	280.0
1977	47.7	34.5	41.0	5.0	52.6	5.5	1.3	2.7	25.5	7.3	75.7	160.0	475.0
1978	232.6	138.5	156.0	104.8	9.2	3.0	1.0	5.8	42.7	0.2	54.3	36.2	801.7
1979	148.1	144.2	90.4	35.0	20.5	2.1	2.4	9.7	2.9	71.4	81.4	120.2	753.0
1980	185.2	204.0	66.2	39.7	28.4	11.8	8.3	0.6	4.0	13.3	14.2	73.7	649.3
1981	143.5	51.9	118.5	31.4	24.6	0.9	0.8	0.4	13.2	80.7	200.8	147.6	814.3
1982	151.6	85.8	185.6	112.8	4.1	28.3	2.7	2.5	49.1	97.5	151.4	114.3	1022.6
1983	175.2	195.2	252.7	95.2	14.7	10.7	2.7	12.0	29.0	31.8	226.8	225.5	1271.5
1984	11.3	66.2	56.0	34.3	7.4	17.7	3.4	7.2	5.6	52.0	183.9	47.3	492.3
1985	24.8	53.0	98.4	6.9	3.4	6.0	4.1	2.2	35.6	30.3	119.9	63.7	476.6
1986	106.4	315.8	147.8	28.9	15.5	1.8	2.9	0.2	50.1	6.9	9.3	30.9	739.1
1987	80.6	95.5	107.2	9.4	14.1	2.5	2.4	0.1	0.5	25.7	62.9	131.3	532.1
1988	116.1	13.6	12.7	61.3	32.4	13.9	5.0	0.3	1.9	2.2	109.6	87.2	424.9
1989	36.8	47.2	191.0	28.6	12.7	11.1	0.0	8.7	66.3	66.4	37.4	0.5	442.5
1990	112.7	75.0	43.0	25.1	77.7	3.9	5.1	5.6	8.4	11.0	21.8	27.2	371.3
1991	13.6	56.5	276.2	21.6	27.6	15.8	3.6	4.5	2.9	45.7	24.3	65.2	505.2
1992	46.1	166.4	84.5	22.3	2.9	24.7	14.8	0.9	2.0				

CITE AS: Karl, T.R., D.R. Easterling, and P.Ya. Groisman. 1994. United States historical climatology network—National and regional estimates of monthly and annual precipitation. pp. 830–905. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Precipitation

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

EAST SLOPE NORTH CASCADES

Trends

The annual precipitation time series for the East Slope North Cascades region bears some resemblance to that for the North Cascades region in terms of shape. There are no obvious long-term trends, but the second half of the record is generally wetter than the first half. In addition, distinct periods of especially high interannual variability occurred: from about the late 1920s through the early 1950s and from the mid-1970s through the end of the record. Notable features of the series include the three consecutive very dry years 1928–30 and the extremely wet years 1948 and 1983. As in other western time series, the high total for 1983 is related to the El Niño/Southern Oscillation (ENSO) episode of 1982–83, during which an unusually high frequency of Pacific storms affected the western United States (Douglas and Englehart 1984) [see Quiroz (1983) for a detailed description of this ENSO event]. A more typical response to the ENSO in this part of the United States [as cited by Douglas and Englehart (1984)] is seen in the meager monthly precipitation received from late fall 1976 through early spring 1977 as a result of the 1976–77 ENSO. Precipitation from October through March was by far the lowest of the century for this region.

Area-average annual precipitation amount for the East Slope North Cascades region of the United States.

CITE AS: Karl, T.R., D.R. Easterling, and P.Ya. Groisman. 1994. United States historical climatology network—National and regional estimates of monthly and annual precipitation. pp. 830–905. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

EAST SLOPE NORTH CASCADES

Area-Average Annual Precipitation Amount

Year	Precipitation (mm)												Ann
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	
1900	29.3	29.2	30.1	19.6	35.0	13.5	3.4	8.7	22.4	48.7	42.5	41.9	297.6
1901	48.6	54.8	18.7	14.8	23.0	21.6	5.7	0.6	25.7	8.1	50.0	26.3	269.6
1902	31.8	81.9	19.7	31.4	30.4	8.3	18.4	2.0	7.0	10.2	65.8	61.1	355.0
1903	50.2	15.9	23.9	11.8	14.0	22.5	9.7	16.2	20.6	22.7	75.0	24.4	283.0
1904	34.5	66.8	62.0	20.5	7.4	15.7	11.6	3.0	6.4	20.6	30.1	35.7	281.5
1905	38.0	12.8	28.5	11.5	32.9	51.6	4.1	3.4	20.4	48.0	25.5	26.2	286.2
1906	40.2	41.4	21.5	5.7	50.5	26.0	3.0	8.9	14.1	22.6	96.3	76.7	392.8
1907	51.6	47.1	30.7	15.4	25.5	24.6	9.7	17.6	23.4	8.5	42.5	61.2	345.9
1908	33.6	29.5	34.3	15.1	22.9	11.0	16.7	10.5	6.3	44.1	26.9	38.9	288.6
1909	61.3	40.5	14.7	8.8	23.0	9.8	23.7	1.2	17.6	24.8	93.5	41.2	367.3
1910	37.0	39.5	28.6	20.2	24.0	15.8	3.2	3.7	17.7	21.6	78.7	34.8	330.2
1911	33.8	21.9	10.0	8.0	45.6	24.8	2.1	10.8	43.5	13.7	39.6	34.7	290.8
1912	70.3	34.6	21.5	30.4	46.4	29.2	19.3	34.2	11.0	31.5	45.1	53.7	431.0
1913	53.8	14.8	27.2	22.7	31.8	49.6	8.0	12.4	15.9	40.2	53.7	31.4	364.3
1914	74.3	29.7	13.5	32.5	20.0	27.8	9.8	1.1	30.2	36.1	31.5	19.9	326.4
1915	27.7	41.0	30.8	30.2	59.2	15.5	21.9	0.9	8.3	19.6	72.5	68.5	396.1
1916	46.2	65.2	55.7	23.8	29.6	44.4	24.8	8.8	9.1	8.1	35.9	42.7	394.5
1917	28.9	30.0	31.8	49.0	32.1	10.5	1.5	0.4	19.0	2.4	35.7	108.2	349.5
1918	47.7	34.5	20.1	6.7	18.9	7.5	20.9	21.2	14.2	45.8	29.7	34.8	301.9
1919	63.8	56.1	27.0	20.8	12.9	6.1	3.0	6.6	22.1	20.7	48.5	46.1	333.7
1920	33.7	4.9	23.9	41.3	15.4	28.0	16.1	24.7	32.2	34.1	44.1	63.3	361.8
1921	66.1	44.0	28.0	26.4	23.9	15.3	2.9	3.7	17.3	22.8	87.6	42.3	380.4
1922	21.5	26.0	33.6	20.7	8.0	9.7	1.0	25.0	10.9	26.4	20.5	71.1	274.4
1923	63.5	21.7	15.1	28.4	23.5	44.8	20.5	16.1	11.3	40.0	23.9	58.2	367.1
1924	34.1	42.1	11.0	5.2	2.5	15.6	5.3	14.1	14.4	28.5	65.6	42.3	280.7
1925	53.2	38.2	14.1	31.0	35.6	14.3	3.6	5.6	18.2	11.9	29.6	42.4	297.7
1926	34.4	45.0	12.1	16.8	18.4	12.0	3.0	27.1	23.5	28.8	74.7	45.6	341.3
1927	50.8	52.4	27.4	13.0	23.4	28.1	3.7	12.4	66.9	34.6	73.4	28.5	420.1
1928	50.6	8.8	40.9	27.1	8.1	21.8	13.4	3.2	8.7	18.2	25.7	44.8	271.3
1929	39.0	7.7	18.2	20.0	12.4	32.0	0.2	2.9	4.4	9.6	3.2	72.4	222.0
1930	28.0	43.1	18.3	18.3	26.3	20.0	1.6	6.8	20.0	21.4	25.8	16.9	246.4
1931	47.2	19.7	48.3	13.8	9.1	40.9	1.2	0.5	13.9	24.7	44.2	74.6	338.0
1932	41.1	27.2	51.9	22.6	30.9	5.5	3.6	3.2	2.4	22.6	72.0	43.3	326.5
1933	44.6	29.1	33.5	11.5	33.3	18.7	3.9	9.3	30.2	41.8	26.2	116.7	399.0
1934	47.5	11.4	32.9	16.5	9.5	23.9	2.6	5.4	16.9	48.1	65.0	53.0	332.7
1935	46.3	18.6	24.9	27.3	8.7	18.7	12.1	4.5	5.4	22.7	18.2	37.2	244.7
1936	74.4	39.9	21.0	21.9	20.3	54.0	6.8	3.5	13.6	2.6	3.0	46.3	307.4
1937	39.0	39.3	41.2	47.9	6.0	71.2	8.7	6.5	15.6	24.2	82.1	69.0	450.7
1938	33.8	50.6	48.7	20.0	10.6	25.5	10.1	3.9	10.9	33.2	32.6	32.3	312.1
1939	32.1	35.3	24.7	6.4	13.9	15.9	6.2	3.4	9.1	19.2	9.2	71.3	246.7
1940	42.1	83.5	42.8	36.1	12.6	5.8	19.5	0.4	45.8	49.8	50.3	45.1	433.8
1941	43.8	25.6	14.9	28.5	46.1	50.1	12.6	39.1	34.4	26.5	48.2	66.7	436.5
1942	35.1	35.3	10.8	25.4	61.5	34.7	14.1	5.0	2.3	22.0	92.8	76.2	415.3
1943	42.8	28.1	31.4	33.9	18.7	36.6	7.1	12.5	1.3	52.9	19.6	22.5	307.4
1944	21.2	33.2	13.4	34.6	18.2	43.5	6.9	3.0	18.3	11.0	50.8	22.4	276.4
1945	43.3	48.8	37.7	19.6	58.3	14.3	1.6	5.8	26.3	25.1	61.9	68.2	410.9
1946	48.2	37.9	34.1	12.9	29.3	33.1	7.2	7.6	21.0	34.9	54.3	36.2	356.8

Precipitation

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

EAST SLOPE NORTH CASCADES

Area-Average Annual Precipitation Amount (continued)

Year	Precipitation (mm)												Ann
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	
1947	33.1	22.7	24.6	25.4	10.9	49.0	13.8	5.6	22.9	80.2	35.9	35.2	359.3
1948	52.3	47.2	22.2	43.1	91.8	65.3	28.9	15.6	24.8	18.0	56.7	72.0	537.8
1949	10.8	65.8	30.3	8.5	19.1	8.0	3.2	3.0	14.3	21.4	65.7	33.1	283.3
1950	68.9	36.3	46.4	20.5	12.8	50.2	6.6	5.1	4.1	83.6	60.3	57.3	452.1
1951	67.6	44.9	38.1	9.2	27.9	28.8	8.1	17.3	10.8	53.6	47.4	55.9	409.6
1952	42.2	32.4	14.3	14.4	25.6	51.0	2.5	3.2	12.1	2.1	10.6	57.5	267.8
1953	102.9	31.9	24.6	29.5	47.0	31.0	0.7	26.3	5.6	14.5	48.6	55.3	417.9
1954	64.9	26.8	21.5	14.0	21.0	33.9	12.1	23.0	23.0	16.5	40.8	33.7	331.2
1955	22.7	26.1	25.8	35.9	19.2	14.7	26.6	0.1	20.1	44.4	71.1	93.2	400.0
1956	82.7	31.1	25.2	6.5	39.7	32.0	15.2	23.6	8.7	49.9	14.8	39.9	369.3
1957	27.6	38.1	65.8	21.5	45.7	20.8	5.7	8.1	14.6	50.8	22.4	59.0	380.2
1958	60.0	60.3	29.3	41.4	22.9	41.8	13.3	4.7	11.8	16.8	75.8	54.3	432.2
1959	71.8	35.4	28.2	11.7	25.4	15.8	2.6	13.6	51.1	29.9	34.7	25.0	345.2
1960	31.7	40.2	43.2	29.1	48.7	7.1	2.8	15.8	12.4	21.0	70.1	25.0	347.2
1961	28.5	68.9	49.8	21.7	38.8	19.3	7.6	12.7	10.5	23.7	43.6	57.0	382.2
1962	20.4	27.9	31.3	25.0	51.6	8.9	3.4	18.7	17.1	50.4	58.8	42.5	355.8
1963	17.1	41.6	29.5	43.7	23.5	17.2	10.9	14.7	18.2	18.9	51.9	42.5	329.7
1964	58.8	7.7	22.5	14.6	7.7	42.1	15.4	14.3	10.8	15.1	54.8	117.4	381.2
1965	69.0	15.8	8.6	27.9	15.5	24.0	15.8	41.0	5.5	6.4	50.9	32.9	313.4
1966	52.5	15.5	30.8	3.8	9.3	21.6	25.0	9.4	17.6	22.9	66.3	58.2	333.0
1967	50.6	12.5	29.8	35.3	20.3	27.3	1.0	1.7	7.8	49.9	23.0	38.8	297.8
1968	47.4	43.6	15.0	7.4	20.6	18.4	4.4	42.1	13.2	35.3	64.7	71.6	383.9
1969	73.4	27.6	14.2	35.2	24.5	35.2	3.4	0.6	22.1	21.2	13.8	64.6	336.0
1970	101.9	27.9	25.6	18.7	16.1	21.9	5.9	3.0	17.3	29.0	58.1	52.9	378.3
1971	59.1	18.3	47.7	21.9	29.0	36.1	10.4	7.9	31.7	22.9	46.7	66.0	397.8
1972	52.1	37.4	45.9	19.1	39.0	35.0	7.4	19.0	21.1	12.4	35.7	57.5	381.4
1973	32.2	13.7	13.6	5.8	19.0	8.0	2.4	3.2	37.1	34.8	104.0	94.8	368.7
1974	63.3	31.8	37.7	33.0	16.6	10.4	22.2	2.7	1.5	7.5	41.6	58.8	327.1
1975	69.3	46.9	31.6	28.8	17.2	22.7	19.0	31.3	0.9	53.2	41.6	64.3	426.7
1976	46.0	37.8	22.4	26.4	16.0	13.2	9.8	57.4	4.5	8.8	10.0	11.5	263.9
1977	11.4	17.4	25.3	3.2	41.2	17.0	4.6	32.0	32.8	14.6	65.4	91.0	355.8
1978	55.1	35.7	27.3	52.4	22.1	17.6	22.3	31.8	27.9	2.6	34.3	30.6	359.7
1979	30.4	43.5	25.5	27.0	19.2	11.6	7.1	30.9	13.0	44.2	41.5	48.3	342.0
1980	65.3	47.9	27.2	26.3	45.3	34.7	10.4	8.1	27.9	22.5	46.0	75.5	436.9
1981	24.6	45.2	25.8	19.5	51.2	37.5	14.6	3.4	24.2	36.3	50.6	86.6	419.5
1982	53.6	40.6	29.9	25.7	14.0	31.7	26.3	13.7	37.8	45.3	34.5	63.7	416.8
1983	59.3	58.0	72.2	26.7	25.0	30.3	29.3	25.7	17.4	19.7	93.4	69.7	526.7
1984	30.6	31.6	51.9	33.9	30.8	40.6	6.4	18.0	18.4	29.1	86.8	31.6	409.7
1985	8.1	28.9	23.7	12.3	20.6	20.0	6.8	10.0	36.7	35.0	41.3	22.1	267.6
1986	63.1	67.9	29.9	18.3	23.5	7.9	11.4	4.9	44.5	15.3	53.9	25.9	368.4
1987	45.5	29.0	38.8	14.4	26.8	18.0	30.5	6.7	1.3	0.7	26.0	77.7	315.2
1988	37.8	11.9	32.1	43.9	24.7	31.4	2.3	3.4	16.7	7.2	80.2	27.6	319.7
1989	36.6	30.6	54.5	33.2	40.0	10.8	8.4	31.4	7.5	25.0	35.9	17.3	332.5
1990	61.2	37.5	21.4	29.6	53.3	27.7	16.4	27.7	1.8	42.1	40.7	33.4	395.7
1991	29.9	23.7	42.0	23.6	55.2	38.5	11.7	12.7	1.5	18.4	75.6	27.6	359.0
1992	34.5	34.1	14.1	33.8	6.1	41.0	34.7	9.4	12.1				

CITE AS: Karl, T.R., D.R. Easterling, and P.Ya. Groisman. 1994. United States historical climatology network—National and regional estimates of monthly and annual precipitation. pp. 830–905. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

GREAT BASIN

Trends

The annual precipitation time series for the Great Basin region shows no obvious long-term trends, but an important feature is the fairly steady decrease from 1905 to the mid-1930s. The dryness of the mid-1930s (the "Dust Bowl" years) is also evidenced in time series from regions extending generally north and east of the Great Basin. The remainder of the Great Basin series reveals no sustained trends, but the very wet years 1982–83 are noteworthy because they are related to the unusual 1982–83 El Niño/Southern Oscillation (ENSO) event, which brought an especially high number of Pacific storms into the west (Douglas and Englehart 1984) [see Quiroz (1983) for a detailed explanation of the 1982–83 ENSO].

Area-average annual precipitation amount for the Great Basin region of the United States.

CITE AS: Karl, T.R., D.R. Easterling, and P.Ya. Groisman. 1994. United States historical climatology network—National and regional estimates of monthly and annual precipitation. pp. 830–905. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Precipitation

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

GREAT BASIN

Area-Average Annual Precipitation Amount

Year	Precipitation (mm)												Ann
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	
1900	16.4	12.5	13.2	55.0	20.1	8.9	10.1	2.9	18.3	29.4	38.0	11.8	247.2
1901	29.6	51.0	19.0	21.5	31.6	8.4	6.5	33.2	5.1	23.6	13.7	25.0	276.1
1902	12.6	38.4	31.3	16.3	12.2	3.0	9.0	10.7	10.9	9.5	35.6	20.4	212.4
1903	42.1	14.8	29.2	20.7	22.3	11.2	4.4	5.3	13.6	14.4	30.7	8.0	224.6
1904	21.7	51.2	55.8	18.1	28.9	6.1	14.5	32.3	24.2	30.4	3.3	25.8	321.0
1905	18.9	27.7	41.6	17.4	33.1	8.2	5.1	16.5	24.4	4.0	27.3	13.4	247.2
1906	44.0	24.9	58.4	42.0	42.7	19.3	11.7	30.7	19.0	3.7	29.9	41.4	373.6
1907	38.8	29.1	59.3	16.3	24.7	38.1	10.9	15.1	11.4	28.2	12.0	48.0	339.6
1908	20.2	17.7	16.3	13.1	39.9	22.0	14.4	16.6	40.0	33.1	17.5	16.6	277.7
1909	60.5	32.6	21.4	15.8	11.9	10.9	13.2	24.8	21.5	21.5	42.9	42.6	322.5
1910	35.1	21.1	12.2	14.1	11.4	2.4	20.0	6.9	24.7	26.0	28.0	26.7	232.3
1911	47.7	24.9	24.8	14.7	15.0	22.3	10.7	2.6	15.0	16.1	15.9	18.6	228.3
1912	21.7	14.8	37.7	29.3	20.7	16.0	14.7	10.5	13.8	45.7	22.6	12.8	260.4
1913	23.6	14.8	15.9	22.1	24.3	59.7	59.4	18.1	16.7	17.7	38.8	35.6	346.6
1914	60.4	19.9	7.2	43.1	13.0	39.2	22.2	5.3	9.6	23.6	1.4	8.2	253.2
1915	19.4	37.9	14.4	37.1	40.2	7.1	9.8	2.6	21.0	2.1	20.4	28.5	240.7
1916	84.6	26.2	30.8	8.4	11.5	9.1	28.6	10.9	11.5	43.4	15.3	28.8	309.0
1917	21.3	27.8	17.0	30.6	51.9	5.5	11.6	5.8	17.1	0.3	22.9	11.7	223.4
1918	25.6	28.1	30.4	16.6	18.4	31.7	15.7	9.6	31.7	27.2	22.4	17.3	274.7
1919	7.9	36.4	22.8	16.5	19.2	0.9	5.9	6.7	28.6	18.4	31.9	24.2	219.6
1920	8.9	17.3	39.9	29.9	19.8	13.8	13.3	18.8	10.2	49.1	27.6	33.2	281.7
1921	28.8	20.3	13.9	30.3	49.1	21.2	12.9	18.1	8.1	14.1	23.4	40.5	280.6
1922	28.1	34.8	22.1	29.9	19.5	10.5	10.5	28.9	2.7	14.4	23.6	40.0	265.1
1923	29.2	8.9	13.9	36.0	26.5	45.0	18.3	19.4	22.1	31.1	11.5	19.9	281.8
1924	11.1	14.2	31.9	7.5	11.6	2.4	3.7	7.5	9.6	28.1	18.0	40.4	186.0
1925	19.3	22.5	22.4	38.6	18.1	38.6	21.4	24.8	29.0	30.1	23.0	16.2	304.5
1926	14.0	27.5	8.8	20.6	19.4	6.8	12.3	14.1	6.3	4.0	47.6	23.8	203.9
1927	19.2	40.4	28.2	19.9	19.1	14.8	10.3	15.0	21.6	29.2	36.4	16.7	267.5
1928	16.8	11.5	38.0	13.8	15.7	14.8	8.7	6.0	2.3	19.1	22.3	16.4	183.6
1929	23.5	17.7	26.4	32.2	4.7	23.0	18.0	17.7	20.8	7.4	1.3	18.7	209.0
1930	31.9	23.9	16.1	18.7	46.4	10.7	12.8	38.7	27.6	22.5	27.8	3.5	283.0
1931	11.2	20.0	16.1	18.0	9.1	12.4	6.5	11.0	11.2	15.0	33.3	33.5	197.2
1932	27.6	23.5	24.4	26.2	24.7	25.9	19.2	22.5	3.3	13.2	10.1	24.4	244.8
1933	31.4	15.1	15.5	20.7	29.5	2.4	6.7	8.9	5.8	15.3	10.0	28.9	190.0
1934	17.6	27.0	9.6	9.4	9.6	31.8	7.0	8.2	7.7	17.7	37.3	22.8	205.7
1935	18.5	19.5	25.4	42.8	34.1	2.4	6.8	8.2	4.2	6.5	15.0	24.4	207.7
1936	42.4	50.1	18.8	11.4	9.5	35.5	29.1	18.0	7.7	21.1	4.9	30.3	278.8
1937	31.9	32.8	25.0	20.7	18.4	11.3	27.1	7.8	13.3	12.2	33.4	36.8	270.9
1938	20.6	31.5	59.1	26.6	30.2	17.8	17.9	10.5	8.5	34.3	21.1	12.9	291.0
1939	18.9	19.3	20.8	12.6	15.5	11.2	9.7	6.6	28.1	28.1	4.0	13.0	191.6
1940	48.7	44.8	34.7	35.2	3.6	7.6	2.7	3.3	45.0	32.5	27.2	31.5	323.6
1941	23.8	30.3	25.4	40.5	25.9	35.5	16.4	24.2	12.2	49.2	23.6	44.1	351.1
1942	21.3	25.9	18.0	25.6	32.5	7.2	6.9	8.8	4.4	16.7	49.5	36.1	253.0
1943	36.0	19.7	24.9	22.6	13.6	40.6	10.5	13.3	5.0	33.9	13.7	15.5	249.3
1944	24.0	27.0	26.4	48.3	16.9	48.4	4.7	1.2	5.6	9.4	46.2	15.0	273.0
1945	13.6	40.8	45.0	18.4	30.8	49.9	8.1	27.9	12.7	27.7	29.9	33.6	338.3
1946	17.7	13.4	35.7	13.2	30.8	2.6	22.8	13.2	10.3	66.9	45.5	21.5	293.5

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

GREAT BASIN

Area-Average Annual Precipitation Amount (continued)

Year	Precipitation (mm)												Ann
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	
1947	11.7	13.9	15.4	26.8	27.9	34.1	3.8	18.5	12.0	33.9	27.4	19.2	244.7
1948	11.4	20.6	26.8	22.7	15.1	36.0	5.1	8.1	11.9	13.2	17.7	39.4	227.9
1949	24.9	23.6	24.0	7.0	42.3	15.7	7.9	4.3	10.8	17.3	19.5	18.5	215.8
1950	34.2	13.5	26.7	12.2	18.3	15.9	18.9	3.5	19.1	22.9	40.4	29.9	255.3
1951	26.4	23.2	16.3	30.2	22.5	10.2	17.9	18.8	4.6	35.9	30.6	46.3	282.8
1952	44.8	25.7	40.8	25.7	14.5	38.7	20.2	9.2	11.0	0.3	16.8	27.5	275.3
1953	35.3	16.1	12.4	22.0	28.4	17.9	13.9	14.5	1.1	13.7	16.9	17.2	209.4
1954	29.4	16.9	36.3	15.4	14.0	30.0	7.7	8.1	14.0	12.4	20.4	23.4	228.1
1955	21.6	21.9	7.5	17.0	24.6	18.4	14.6	22.4	14.1	9.5	28.6	57.9	258.1
1956	53.0	18.2	4.0	25.3	35.1	13.4	12.9	2.8	6.8	37.7	5.6	14.7	229.5
1957	32.4	20.2	32.6	36.2	57.5	14.9	7.1	10.4	4.9	34.5	28.0	26.5	305.3
1958	25.1	37.9	34.8	22.5	16.8	37.6	8.5	20.9	12.6	3.2	25.1	13.6	258.6
1959	23.5	31.5	13.1	10.4	23.3	10.4	7.9	13.9	34.8	9.7	4.2	20.6	203.3
1960	22.0	31.1	26.2	15.6	15.5	3.8	9.7	8.0	15.1	19.2	48.4	10.8	225.4
1961	8.2	22.9	33.3	13.0	17.1	7.3	13.2	26.9	27.0	24.3	25.0	22.0	240.1
1962	19.4	54.4	27.3	14.0	40.4	10.9	10.3	3.4	10.8	39.8	15.5	13.9	260.1
1963	22.1	23.3	19.9	43.8	26.7	44.9	2.2	19.4	26.5	22.3	45.2	16.0	312.4
1964	26.6	6.1	24.7	32.5	31.7	45.6	7.4	11.6	9.1	8.1	36.2	72.3	312.0
1965	33.1	10.6	11.0	32.6	33.0	30.3	17.0	41.5	22.5	4.5	40.4	26.9	303.4
1966	9.5	14.0	13.9	10.3	9.4	6.1	8.2	8.5	16.0	11.5	26.6	45.3	179.3
1967	41.5	4.4	28.6	37.5	27.5	43.5	19.1	7.8	29.6	14.7	16.8	23.7	294.5
1968	20.5	35.0	20.6	24.5	19.6	18.7	16.2	45.3	5.7	19.1	33.3	36.9	295.4
1969	55.1	39.4	10.5	23.7	11.7	45.1	12.8	7.1	10.7	31.7	13.3	39.5	300.7
1970	56.0	10.4	24.2	24.0	14.1	39.0	19.3	23.7	19.0	17.3	50.7	37.8	335.5
1971	26.8	22.6	22.4	31.9	40.9	21.0	9.8	17.2	15.7	35.5	28.8	42.0	314.8
1972	19.4	15.4	12.8	20.5	9.9	23.8	4.1	12.4	20.5	53.7	31.6	38.2	262.3
1973	31.6	17.3	39.5	25.4	20.2	12.6	13.2	11.2	12.6	16.9	48.3	34.6	283.3
1974	32.5	13.6	30.1	21.1	2.6	2.0	15.0	4.0	1.3	35.2	18.1	24.1	199.7
1975	23.3	30.7	44.1	28.2	33.6	20.6	17.7	13.2	7.6	37.6	18.9	16.4	291.9
1976	17.3	30.8	15.8	26.0	12.9	11.9	18.3	22.2	28.8	13.1	5.1	1.6	203.9
1977	14.2	7.9	15.8	5.3	46.3	19.5	19.0	21.4	13.9	6.9	22.1	38.8	231.1
1978	44.4	38.2	45.8	56.4	14.9	4.8	5.1	8.2	38.4	6.6	35.0	17.2	315.1
1979	35.5	28.3	33.1	15.1	24.1	5.6	8.3	20.8	1.8	25.3	21.3	17.9	237.0
1980	53.5	43.5	36.0	16.3	54.8	12.7	13.9	8.6	37.8	16.5	21.4	19.2	334.3
1981	20.4	15.2	41.9	25.0	48.3	9.9	8.5	8.6	16.9	45.7	41.7	42.9	325.2
1982	29.7	22.3	37.2	19.5	18.1	21.3	20.8	19.3	65.0	37.9	31.8	36.1	359.0
1983	33.7	36.7	59.0	32.8	27.0	15.6	10.2	40.6	23.4	20.8	60.8	68.1	428.6
1984	13.5	23.2	29.7	32.8	17.1	32.5	25.4	25.6	13.9	35.4	36.4	21.6	306.9
1985	13.1	17.8	32.0	14.6	21.6	10.2	23.0	1.4	30.0	25.6	45.3	20.5	255.0
1986	15.3	54.2	29.4	34.7	22.0	9.3	9.8	13.6	33.5	17.1	10.7	5.2	254.7
1987	24.0	22.9	38.1	9.1	52.6	12.6	15.7	11.7	2.5	19.5	32.4	27.5	265.2
1988	33.0	5.8	16.9	39.7	24.8	14.8	5.9	14.0	8.6	4.2	53.2	23.6	242.3
1989	17.6	23.5	38.7	9.5	24.3	12.3	8.0	20.0	18.4	22.2	13.5	2.5	206.0
1990	23.8	26.0	23.9	36.1	25.8	16.5	8.5	10.2	11.1	14.8	17.6	15.5	229.1
1991	14.8	9.6	32.0	24.3	49.1	13.4	4.5	11.2	18.5	25.2	35.9	11.7	252.3
1992	14.1	22.0	27.5	9.5	14.4	18.6	10.5	8.9	6.7				

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Precipitation

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

SOUTHERN DESERT

Trends

The annual precipitation time series for the Southern Desert region shows a generally decreasing trend from ca. 1905 to the mid-1950s, followed by an increasing trend through the end of the record. The driest years in the record, 1953 and 1956, are associated with the severe to extreme drought conditions that covered much of the southwestern United States during the mid-1950s (Karl and Knight 1985). The wettest years of the century, 1905 and 1941, were both El Niño/Southern Oscillation (ENSO) years (Ropelewski and Halpert 1986). Redmond and Cayan (1994) have shown that the southwestern United States is typically wetter than normal during ENSO periods.

Area-average annual precipitation amount for the Southern Desert region of the United States.

CITE AS: Karl, T.R., D.R. Easterling, and P.Ya. Groisman. 1994. United States historical climatology network—National and regional estimates of monthly and annual precipitation. pp. 830–905. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

SOUTHERN DESERT

Area-Average Annual Precipitation Amount

Year	Precipitation (mm)												Ann
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	
1900	21.9	6.7	26.2	22.0	15.5	7.3	47.7	23.3	34.7	12.0	18.5	2.2	230.6
1901	19.9	35.7	11.7	8.4	6.5	5.0	44.4	36.8	13.0	23.8	8.3	1.4	213.3
1902	9.7	9.1	13.9	1.6	4.5	5.5	38.2	62.8	20.5	5.1	21.9	25.4	208.5
1903	28.0	14.1	32.0	16.3	10.5	27.8	22.5	33.8	32.6	4.2	0.1	1.2	222.1
1904	2.4	6.4	12.0	2.2	16.1	13.7	26.4	56.7	29.4	26.2	4.7	15.4	211.6
1905	40.1	68.7	94.8	44.6	12.0	19.5	44.0	34.1	45.7	7.7	67.3	19.8	496.6
1906	19.1	21.4	39.7	24.0	12.1	5.1	59.0	63.3	14.3	2.9	27.5	48.1	326.9
1907	33.4	8.1	18.9	7.6	14.4	11.0	45.8	43.7	20.1	38.4	13.8	5.2	256.6
1908	24.7	21.7	15.4	16.5	6.6	2.6	68.3	46.4	24.1	6.3	7.0	22.9	262.2
1909	12.9	13.7	36.9	1.1	2.0	15.2	49.4	68.0	21.6	2.6	18.3	27.0	272.4
1910	14.6	1.2	9.9	5.7	2.0	13.6	35.1	31.1	9.4	6.4	25.0	3.9	157.3
1911	27.6	32.4	20.4	14.2	16.0	14.7	50.8	21.3	35.5	21.6	1.5	19.6	284.0
1912	0.8	4.0	47.0	22.7	8.8	14.7	46.0	37.9	9.8	30.5	3.7	14.8	240.1
1913	10.0	42.7	6.9	14.1	3.3	16.8	36.8	34.7	19.0	3.4	35.7	15.9	239.7
1914	24.4	20.6	11.4	13.4	15.1	30.6	65.0	39.1	20.2	27.9	11.2	66.2	344.6
1915	45.5	31.8	32.9	27.1	6.7	2.0	42.0	27.7	27.1	1.4	9.9	34.9	289.0
1916	69.0	10.6	22.2	8.4	13.1	1.9	33.3	47.1	23.8	30.2	1.8	12.4	273.9
1917	31.6	10.7	2.4	14.8	18.4	1.2	45.5	39.6	18.2	0.4	0.9	0.1	183.6
1918	19.3	13.5	31.6	2.3	8.0	14.6	33.4	39.0	15.2	17.1	19.9	30.9	244.7
1919	9.3	15.1	24.3	19.4	11.9	12.6	76.7	35.6	65.9	18.0	45.4	7.3	350.3
1920	34.7	33.8	26.5	4.1	10.8	23.3	20.3	47.8	13.3	21.4	1.9	1.9	250.6
1921	17.6	7.5	13.0	3.1	12.6	13.6	62.5	63.9	34.8	22.5	3.8	35.6	294.8
1922	30.2	9.5	17.8	12.3	12.3	11.1	23.5	44.9	19.5	12.5	17.2	8.3	219.1
1923	11.4	21.4	18.0	14.1	2.4	5.4	38.1	48.0	28.7	6.8	36.1	45.8	276.2
1924	1.4	5.9	26.1	12.8	5.1	1.0	32.0	13.1	14.0	4.8	2.8	21.7	140.7
1925	2.2	3.0	11.1	14.0	14.2	17.8	41.1	48.3	26.5	49.1	8.7	10.1	246.0
1926	10.0	7.8	38.8	42.8	21.5	6.2	31.8	23.2	36.1	18.6	8.2	53.5	298.6
1927	3.9	41.7	24.7	6.1	1.1	12.4	45.2	44.7	45.1	19.0	6.0	31.1	281.0
1928	2.7	23.6	4.5	3.6	25.3	3.0	23.4	44.5	8.8	21.2	10.2	10.7	181.6
1929	9.5	10.0	9.6	8.1	16.5	6.4	43.2	49.6	28.8	13.7	5.2	2.6	203.2
1930	25.7	6.5	32.3	8.3	22.6	12.1	54.9	36.2	14.2	18.5	22.1	6.8	254.8
1931	15.8	66.9	5.4	35.3	8.8	9.7	37.2	79.9	20.6	11.6	31.7	33.3	361.4
1932	10.7	49.3	6.0	4.0	11.1	11.9	42.8	45.1	27.9	18.6	0.7	33.5	263.9
1933	30.6	8.8	1.4	13.7	7.5	22.4	32.1	35.7	20.2	15.4	10.1	5.8	207.7
1934	5.7	6.8	6.1	6.1	7.5	6.9	24.1	51.9	6.3	7.8	11.4	27.8	168.5
1935	25.4	39.2	19.8	5.4	14.0	6.4	19.3	66.8	27.9	2.4	14.8	17.1	258.3
1936	13.0	24.5	10.6	3.9	13.5	5.0	41.4	39.5	31.3	27.7	12.8	33.7	257.1
1937	18.0	21.3	35.0	1.9	15.2	11.7	28.2	23.2	24.3	14.0	3.3	22.8	218.9
1938	12.9	23.0	37.8	4.8	4.7	24.8	41.8	25.4	24.6	4.8	1.7	38.5	244.8
1939	27.3	14.5	13.4	12.3	2.2	3.5	30.2	47.8	93.3	10.8	20.6	7.5	283.5
1940	13.8	31.4	6.5	12.1	17.7	28.8	17.4	37.8	36.2	18.1	22.4	49.2	301.7
1941	33.4	37.0	51.0	46.3	21.5	20.6	43.5	52.5	49.3	34.8	12.5	30.5	444.7
1942	9.3	12.3	6.9	23.0	2.5	4.3	24.9	57.8	16.5	14.6	1.0	18.5	200.5
1943	29.6	7.2	21.9	9.8	5.1	19.5	28.1	40.4	23.8	9.3	5.0	33.5	241.2
1944	14.1	39.2	14.3	8.0	7.9	10.6	28.7	39.1	29.5	13.4	32.1	16.2	258.9
1945	14.9	8.6	30.5	2.9	0.7	0.8	39.5	50.4	6.6	34.1	0.6	15.5	207.8
1946	26.1	2.1	5.3	6.5	5.6	5.7	42.6	47.3	36.4	18.4	27.6	20.0	241.5

Precipitation

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

SOUTHERN DESERT

Area-Average Annual Precipitation Amount (continued)

Year	Precipitation (mm)												
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1947	9.0	3.4	6.8	1.6	11.0	6.7	15.3	44.4	8.0	11.0	11.0	21.0	149.1
1948	2.6	20.6	11.0	4.1	3.6	13.8	21.8	26.3	9.4	18.7	2.0	25.4	159.2
1949	60.8	11.9	7.0	12.6	11.1	14.4	30.8	22.5	32.0	16.0	5.1	18.3	238.6
1950	7.0	10.7	7.5	1.1	2.8	14.2	58.0	15.3	23.1	8.4	6.8	1.6	151.8
1951	19.9	6.7	11.1	22.7	9.3	4.3	30.3	71.2	9.6	22.5	13.7	23.3	243.9
1952	22.1	4.9	43.9	27.3	7.1	23.0	32.0	22.9	19.2	0.1	29.6	22.9	246.0
1953	1.9	10.5	14.6	7.7	3.1	5.8	47.2	24.6	0.7	7.1	2.5	4.5	129.4
1954	22.4	7.1	31.8	3.8	10.8	13.2	38.4	48.5	26.0	9.7	3.5	3.9	218.8
1955	37.2	3.5	4.8	2.5	5.2	12.9	71.5	54.4	4.8	11.5	7.7	10.9	224.6
1956	11.4	8.6	0.1	5.6	1.9	8.3	35.6	18.3	2.0	10.1	0.2	3.3	104.1
1957	33.0	17.5	16.7	8.6	19.0	6.6	36.8	60.7	4.2	53.9	16.2	7.7	278.0
1958	13.1	35.9	54.3	19.5	16.1	14.1	25.4	48.1	55.3	26.0	13.3	0.4	319.8
1959	3.1	19.2	0.7	3.3	7.6	15.3	39.3	63.7	5.1	24.4	8.3	40.6	239.1
1960	31.6	11.9	5.3	3.6	4.0	8.1	41.4	28.5	16.2	22.3	15.1	18.2	206.2
1961	16.0	1.0	14.5	1.9	1.9	19.0	31.1	54.1	21.4	7.2	16.5	26.2	210.8
1962	22.9	21.7	10.3	2.4	2.4	11.1	46.6	13.3	36.1	9.4	5.8	17.0	198.8
1963	10.5	23.1	9.0	8.9	6.0	6.1	17.7	62.4	36.3	19.9	22.3	2.0	224.2
1964	4.8	1.9	15.7	9.4	5.5	5.3	38.3	33.0	32.5	6.8	11.0	12.4	176.6
1965	18.8	18.8	20.4	37.5	8.0	10.1	33.6	32.6	22.4	3.5	37.5	70.3	313.6
1966	14.1	16.8	6.5	5.6	5.5	17.7	28.5	45.6	36.0	15.0	11.1	31.3	233.5
1967	11.4	3.0	9.0	8.1	6.2	21.0	35.5	48.0	29.8	4.0	21.5	50.6	248.3
1968	9.9	21.3	24.9	6.6	5.3	7.7	51.6	46.1	9.2	6.2	21.8	12.1	222.8
1969	47.1	30.6	11.2	4.6	14.3	6.8	43.8	32.8	19.2	15.9	21.9	15.4	263.8
1970	5.9	17.2	36.8	3.0	5.2	8.7	35.6	41.9	27.7	11.2	10.2	13.4	216.9
1971	2.6	6.4	0.7	5.8	11.0	3.4	24.6	59.3	19.7	29.8	6.3	25.1	194.7
1972	2.7	0.7	0.8	1.8	10.6	23.6	23.5	45.2	29.9	69.6	23.2	15.5	247.1
1973	20.2	40.6	46.0	2.4	8.9	11.2	46.0	20.7	6.5	1.6	11.2	0.6	217.9
1974	35.6	1.1	16.2	4.8	2.7	2.2	46.3	35.0	44.8	38.6	10.3	17.1	258.8
1975	12.9	11.3	20.6	11.2	4.2	2.9	42.1	16.7	38.1	6.2	10.7	12.2	191.7
1976	3.2	42.0	6.4	18.9	16.0	8.0	41.9	16.1	60.9	21.7	8.6	5.0	257.5
1977	21.3	3.4	10.4	8.4	16.6	11.3	31.6	44.8	22.4	23.8	5.0	20.7	219.7
1978	55.4	39.5	47.6	12.9	13.8	10.6	21.7	40.3	24.6	32.0	47.8	46.0	392.2
1979	49.4	17.1	31.1	3.2	13.5	12.5	30.0	45.9	8.8	4.3	2.5	13.4	231.8
1980	49.9	63.5	22.0	11.0	11.9	4.1	21.0	28.9	35.3	8.1	5.1	6.8	267.4
1981	16.0	13.3	34.3	11.1	12.8	11.6	32.9	45.3	23.9	20.9	18.6	2.1	242.9
1982	22.4	15.3	26.6	7.9	15.4	6.6	25.6	57.8	34.1	3.8	27.5	46.8	295.1
1983	29.6	29.6	40.7	14.3	3.4	1.8	23.3	50.5	49.5	45.9	19.8	23.3	339.9
1984	8.6	1.0	3.0	7.0	9.7	24.9	61.0	63.6	26.4	27.8	23.9	74.0	334.8
1985	26.3	14.3	15.7	11.5	5.0	10.1	28.9	18.5	36.3	38.7	35.7	5.3	258.1
1986	9.5	25.7	24.0	4.2	7.6	22.4	34.7	46.6	28.8	32.3	24.8	38.4	303.9
1987	13.8	20.2	12.8	10.3	12.3	16.3	20.4	41.4	21.0	24.6	27.5	29.4	261.2
1988	19.3	14.6	3.8	31.8	3.9	9.2	39.4	61.9	23.6	14.0	8.4	11.2	247.8
1989	21.9	10.4	12.5	0.5	9.3	6.1	32.1	43.4	11.3	13.0	1.5	7.2	172.7
1990	17.9	13.6	11.4	10.4	10.3	5.7	57.4	48.6	47.6	14.8	16.4	18.7	278.9
1991	20.8	19.4	47.9	3.2	3.4	13.1	36.8	50.9	31.4	9.6	12.6	50.5	326.5
1992	26.9	35.1	52.3	8.8	44.2	8.8	24.7	52.7	9.0				

CITE AS: Karl, T.R., D.R. Easterling, and P.Ya. Groisman. 1994. United States historical climatology network—National and regional estimates of monthly and annual precipitation. pp. 830–905. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

NORTHERN ROCKIES

Trends

The annual precipitation time series for the Northern Rockies region shows no obvious long-term trends. One notable feature is that the three driest years of the century all occurred in the 1930s, when extreme drought conditions existed for several years over a vast area centered in the northcentral United States (Karl and Knight 1985).

Area-average annual precipitation amount for the Northern Rockies region of the United States.

CITE AS: Karl, T.R., D.R. Easterling, and P.Ya. Groisman. 1994. United States historical climatology network—National and regional estimates of monthly and annual precipitation. pp. 830–905. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Precipitation

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

NORTHERN ROCKIES

Area-Average Annual Precipitation Amount

Year	Precipitation (mm)												
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1900	26.4	30.2	37.2	48.4	47.9	12.0	9.8	22.1	35.6	55.4	52.1	35.2	408.6
1901	29.9	46.8	30.1	27.3	54.0	39.1	12.3	26.0	35.1	17.9	27.0	33.3	395.5
1902	18.3	48.6	23.4	35.2	64.6	29.1	33.9	16.4	18.4	11.5	51.0	36.8	403.6
1903	49.6	10.8	35.5	34.3	43.0	35.9	31.3	23.8	28.6	22.2	56.1	21.3	398.9
1904	28.9	54.8	76.1	28.4	30.8	28.6	21.3	18.5	6.9	25.8	11.3	30.2	366.7
1905	24.4	21.1	41.0	30.0	69.4	57.7	18.2	15.4	31.9	31.4	26.0	19.9	391.4
1906	34.8	32.3	36.8	27.3	75.9	40.5	12.8	53.5	19.1	18.3	52.3	61.0	468.8
1907	48.7	40.2	51.0	23.3	45.5	67.0	32.0	37.9	23.3	18.3	15.4	34.0	440.7
1908	17.6	28.1	35.0	19.7	103.1	66.2	20.6	30.0	31.8	55.9	15.8	18.0	436.3
1909	65.6	39.3	33.0	26.2	49.1	31.0	53.5	27.9	49.0	20.0	69.4	34.0	494.5
1910	38.9	40.2	24.1	26.9	42.3	15.8	18.9	12.8	32.6	37.7	53.0	27.0	374.4
1911	53.0	23.0	19.1	25.7	56.0	61.7	14.2	16.8	33.2	31.3	41.8	22.3	397.9
1912	36.6	28.6	36.4	46.6	54.7	34.1	47.6	45.5	32.5	52.9	35.5	25.8	476.7
1913	44.6	19.1	42.7	24.8	42.2	78.2	46.7	21.4	25.0	44.1	49.3	17.4	455.6
1914	51.1	27.7	18.1	45.7	38.7	67.6	24.8	8.5	36.5	47.4	20.0	13.2	399.3
1915	21.6	30.0	27.9	40.8	84.5	53.6	43.6	15.0	50.9	13.9	46.6	39.2	467.6
1916	53.9	44.4	58.3	25.8	41.0	47.7	35.2	26.1	20.1	41.2	27.4	44.4	465.4
1917	31.9	41.9	30.6	51.1	62.5	23.6	11.5	9.7	38.4	8.2	22.6	65.3	399.6
1918	53.5	33.1	32.1	25.9	34.6	30.7	38.4	26.2	39.9	41.1	24.8	16.4	396.6
1919	23.5	48.9	27.5	29.3	28.9	3.7	7.8	15.6	31.8	47.5	39.8	34.5	338.9
1920	22.1	17.7	45.4	54.2	44.9	32.2	17.1	31.3	34.6	56.0	32.7	40.2	428.3
1921	39.1	27.5	38.5	46.1	58.6	30.9	17.7	21.9	22.2	20.2	46.3	45.8	414.8
1922	28.2	35.9	30.5	49.3	32.9	27.7	23.7	45.6	11.5	18.9	27.4	51.2	382.8
1923	44.7	17.5	24.0	44.0	47.5	61.4	34.6	31.3	33.3	44.8	23.6	37.0	443.6
1924	23.3	25.5	35.0	14.7	19.1	19.8	26.6	14.0	23.8	43.0	38.9	43.3	327.0
1925	39.6	36.2	29.1	39.7	46.9	55.4	27.9	31.5	44.8	33.9	24.2	33.4	442.6
1926	23.9	41.9	16.1	23.9	49.1	25.0	28.0	42.9	39.4	23.6	66.0	33.3	413.1
1927	37.1	47.6	28.1	31.4	59.4	37.7	20.0	30.6	63.3	38.1	77.7	37.2	508.3
1928	34.6	13.2	45.8	29.6	26.4	47.0	26.2	16.2	9.0	39.2	27.1	26.6	340.8
1929	38.7	24.7	38.0	39.5	21.9	40.4	15.3	17.8	35.2	23.9	9.6	44.0	348.9
1930	30.4	31.7	28.2	31.5	42.7	24.7	25.9	55.1	34.8	44.0	27.8	11.5	388.4
1931	20.7	18.0	36.9	26.0	26.8	20.8	20.9	14.3	32.0	26.3	39.1	39.4	321.1
1932	36.0	29.6	50.7	39.6	41.7	43.5	29.6	29.5	5.4	32.5	38.8	34.8	411.6
1933	41.8	30.4	24.0	30.4	47.9	19.5	9.3	32.5	24.8	32.3	18.2	62.9	373.9
1934	31.8	21.3	35.5	19.4	15.7	48.8	17.7	12.1	19.8	39.7	39.8	35.3	337.0
1935	29.2	15.2	39.1	46.8	40.8	17.5	11.6	14.1	6.1	25.6	20.6	20.1	286.8
1936	57.1	58.9	27.8	25.4	20.0	52.1	31.6	28.6	19.6	22.4	8.3	35.7	387.7
1937	33.6	42.2	32.6	45.4	22.9	49.7	42.2	11.6	26.3	29.0	42.9	47.5	426.0
1938	27.9	34.2	58.7	32.2	61.0	36.9	31.1	18.0	15.4	57.5	36.3	24.9	434.1
1939	29.6	33.0	23.5	20.2	31.7	45.1	15.6	9.5	26.6	29.1	5.2	32.5	301.6
1940	45.8	56.0	38.1	51.3	18.3	28.0	22.5	7.2	68.9	42.0	39.1	29.5	446.7
1941	21.6	23.7	22.5	47.7	57.3	66.6	33.2	42.8	51.1	41.7	38.7	53.6	500.7
1942	27.6	27.7	20.4	33.1	76.7	38.0	17.4	10.9	19.9	28.3	65.8	42.6	408.4
1943	48.3	25.7	34.5	39.0	36.6	61.4	19.1	23.5	8.0	46.9	15.7	20.6	379.5
1944	20.3	25.4	29.3	47.2	43.6	95.7	18.2	10.5	23.7	13.9	36.1	24.6	388.4
1945	23.4	35.9	42.0	31.0	58.2	68.8	16.7	38.9	42.4	26.0	48.7	43.8	475.8
1946	31.0	25.0	42.4	24.1	43.1	33.3	23.7	24.0	34.2	69.7	53.4	38.5	442.4

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

NORTHERN ROCKIES

Area-Average Annual Precipitation Amount (continued)

Precipitation (mm)													
Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1947	26.8	18.6	32.7	33.1	36.5	82.4	11.1	33.6	47.1	55.2	43.6	29.3	450.0
1948	32.4	33.9	32.1	45.9	56.7	68.0	31.5	19.9	19.0	19.8	45.4	50.0	454.6
1949	29.5	42.2	28.6	19.1	52.4	36.8	16.4	15.0	30.2	49.7	31.2	36.9	388.1
1950	56.4	29.3	48.0	25.9	32.4	47.3	30.4	16.8	39.1	41.8	44.3	37.2	449.0
1951	37.4	33.2	30.2	29.6	39.8	33.2	27.5	43.5	16.4	64.2	33.2	60.4	448.5
1952	40.1	29.2	34.9	21.3	49.0	51.4	20.4	19.9	8.9	2.3	16.4	31.0	324.7
1953	68.2	29.4	25.9	39.6	54.3	38.4	9.3	24.6	8.7	15.1	31.0	31.9	376.5
1954	53.3	19.4	33.9	25.1	29.7	55.8	21.2	30.0	24.7	18.2	22.8	22.6	356.7
1955	27.3	29.7	26.1	37.4	41.0	46.1	33.1	14.2	31.6	39.1	50.6	76.3	452.5
1956	52.6	24.9	22.9	28.3	46.3	27.9	21.2	20.1	11.9	38.9	14.1	33.4	342.6
1957	32.1	33.0	38.2	45.0	82.5	50.5	14.8	25.7	12.4	39.7	30.2	40.1	444.2
1958	31.3	40.7	32.7	47.0	27.7	57.6	27.7	20.0	23.3	13.4	56.3	39.3	416.9
1959	42.0	38.1	25.3	30.0	52.3	44.2	11.0	27.2	64.0	34.4	31.8	20.6	421.0
1960	27.0	34.2	35.5	33.5	38.2	20.0	7.0	33.4	18.3	34.0	55.6	17.0	353.8
1961	14.9	41.2	34.8	28.1	45.1	18.6	18.2	29.6	61.3	46.6	33.4	36.3	408.0
1962	32.2	38.5	35.2	27.2	67.2	29.8	28.9	20.5	22.1	34.5	40.0	20.9	397.1
1963	30.9	30.6	29.1	53.8	33.3	70.7	12.3	21.0	41.3	24.7	42.8	26.8	417.2
1964	38.5	11.0	30.4	41.0	42.9	84.7	19.8	28.5	12.6	16.4	45.2	91.5	462.5
1965	48.6	19.1	13.3	45.8	41.5	55.1	26.5	46.3	39.5	8.6	38.0	26.9	409.1
1966	31.8	21.1	27.2	19.5	25.7	36.8	13.2	18.2	27.3	23.2	40.3	45.2	329.5
1967	52.5	14.9	38.6	42.8	45.0	76.2	20.5	8.5	19.2	46.7	23.8	41.4	430.3
1968	28.7	38.6	27.6	28.6	42.5	55.7	13.2	67.9	36.1	33.3	41.4	43.5	457.3
1969	72.1	32.0	11.4	34.8	25.1	78.0	17.5	11.7	26.0	33.6	13.1	34.3	389.5
1970	65.5	20.5	30.2	35.8	40.1	53.6	33.9	11.9	42.2	35.6	49.1	45.5	463.7
1971	50.0	26.0	29.7	45.9	46.7	46.9	13.2	27.5	33.8	45.3	35.1	53.1	453.4
1972	44.0	31.9	32.3	35.2	30.1	41.9	19.7	30.8	33.8	41.5	26.6	45.1	412.9
1973	29.8	17.5	31.0	29.6	27.0	34.6	24.8	22.3	55.8	24.6	72.3	55.9	425.3
1974	53.4	25.8	42.7	35.0	29.5	19.2	22.6	19.0	8.8	31.3	29.7	36.8	353.9
1975	48.1	38.5	41.8	42.9	52.4	51.9	38.5	30.7	7.9	69.2	38.4	38.4	498.7
1976	31.0	40.1	26.9	46.1	34.2	45.8	24.8	42.1	28.6	17.6	9.1	10.4	356.7
1977	17.6	11.4	30.0	10.0	63.0	27.3	37.3	43.4	42.9	20.3	37.0	64.3	404.4
1978	44.7	37.9	26.5	49.9	61.9	18.7	27.8	28.8	46.1	4.6	37.6	37.2	421.7
1979	31.4	41.1	27.3	30.2	32.6	20.9	13.3	34.0	5.4	39.9	22.0	26.8	325.0
1980	65.7	37.5	37.0	22.8	95.5	45.4	25.4	24.6	41.2	25.3	33.7	43.1	487.5
1981	17.6	28.2	34.6	30.8	87.3	50.6	21.7	12.2	22.1	53.6	39.4	54.6	444.3
1982	49.3	36.5	50.0	42.3	35.3	44.5	40.7	21.7	75.4	39.4	35.0	48.1	510.9
1983	31.9	40.5	47.6	32.9	41.7	49.4	45.0	46.2	42.3	32.9	71.3	59.0	536.7
1984	20.8	25.2	35.5	43.2	43.5	52.8	30.7	29.8	36.4	32.9	45.6	33.2	427.0
1985	11.5	25.8	31.9	16.2	38.6	26.3	25.9	23.6	58.6	29.6	47.7	17.1	344.9
1986	34.3	73.7	32.9	51.4	38.7	30.1	31.7	26.8	59.5	21.4	41.6	8.3	455.3
1987	26.6	21.9	35.1	15.5	67.4	31.0	59.3	31.7	6.0	9.0	25.5	38.3	371.4
1988	29.6	14.5	31.7	42.7	49.8	25.6	8.4	7.9	22.5	9.7	59.7	26.9	334.0
1989	39.6	25.3	54.7	26.1	48.3	29.2	17.6	41.1	22.9	33.2	32.2	20.1	396.9
1990	42.3	23.1	24.4	43.3	54.3	32.4	24.4	29.3	15.1	39.0	39.1	27.7	399.6
1991	25.1	15.8	38.1	48.5	71.4	48.3	15.5	21.9	33.8	27.4	55.1	19.4	423.6
1992	20.8	24.1	19.9	35.3	30.9	59.8	37.8	15.6	23.6				

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Precipitation

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

SOUTHERN ROCKIES

Trends

The annual precipitation time series for the Southern Rockies region shows a generally decreasing trend from ca. 1905 to the mid-1950s, followed by an increasing trend toward the end of the record. The general dryness of 1950s (especially 1956), is associated with the severe to extreme drought conditions that covered much of the southwestern United States during the early to mid-1950s (Karl and Knight 1985). The wettest years of the century, 1905 and 1941, were both El Niño/Southern Oscillation (ENSO) years (Ropelewski and Halpert 1986). Redmond and Cayan (1994) have shown that the southwestern United States is typically wetter than normal during ENSO periods.

Area-average annual precipitation amount for the Southern Rockies region of the United States.

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United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

SOUTHERN ROCKIES

Area-Average Annual Precipitation Amount

Year	Precipitation (mm)												
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1900	8.6	7.5	13.4	47.8	31.3	14.5	23.3	32.8	56.7	21.5	18.2	7.6	283.1
1901	12.3	15.8	12.8	15.1	44.8	6.9	50.0	47.1	30.3	31.5	18.9	7.2	302.1
1902	8.7	7.0	10.9	3.8	25.1	10.3	18.2	60.4	26.9	10.4	19.2	21.2	221.3
1903	5.7	21.3	31.2	22.3	17.1	61.3	35.6	51.0	45.4	7.7	0.7	3.5	302.8
1904	5.2	7.1	17.8	6.0	21.8	20.2	35.7	71.3	66.3	40.8	0.7	18.0	314.3
1905	26.3	46.1	69.3	69.4	26.0	14.8	35.9	31.6	59.5	10.4	68.2	15.4	478.9
1906	16.5	11.8	45.2	40.3	24.4	7.5	65.0	64.9	50.5	35.2	33.8	48.9	449.2
1907	27.3	14.7	15.5	38.5	43.2	23.3	55.5	119.0	28.1	55.0	16.6	12.4	453.2
1908	10.1	22.2	13.0	28.4	18.9	10.7	57.2	74.7	12.6	32.9	15.3	30.1	326.6
1909	24.5	21.1	25.2	18.9	12.2	10.3	54.0	92.4	56.5	10.9	21.0	36.8	387.9
1910	17.6	10.1	15.5	18.5	8.3	20.2	42.1	57.5	15.2	27.9	26.4	15.3	276.2
1911	23.9	43.7	28.5	17.0	15.6	27.8	102.8	35.9	57.6	73.1	15.2	13.9	455.1
1912	5.0	11.7	61.5	25.9	15.9	35.3	61.4	45.2	15.3	45.9	6.0	9.8	338.9
1913	15.1	31.3	20.7	19.1	6.1	44.4	44.2	45.1	42.1	16.2	34.9	33.1	352.3
1914	28.6	12.9	10.8	33.3	40.8	33.9	104.9	79.4	14.2	49.2	4.6	32.0	444.5
1915	22.8	27.3	19.6	68.9	34.6	14.9	59.7	33.7	42.4	6.3	20.6	27.3	378.2
1916	61.4	9.7	34.6	33.6	10.9	2.7	59.1	65.4	21.9	79.4	3.9	11.6	394.3
1917	26.1	13.9	8.3	30.8	37.5	5.5	49.4	28.2	25.2	3.4	5.6	1.4	235.3
1918	34.0	21.9	35.6	12.3	7.1	25.2	59.9	48.4	36.5	43.0	30.7	33.0	387.5
1919	3.7	26.1	49.2	38.6	31.7	16.0	83.6	38.2	49.6	34.2	43.2	15.0	429.1
1920	16.5	29.8	30.5	25.1	36.8	24.1	29.7	54.7	28.4	43.4	11.9	12.5	343.3
1921	18.2	9.0	22.5	23.1	33.1	44.3	83.9	73.9	9.1	16.9	9.3	25.7	368.9
1922	25.6	15.4	27.5	24.2	18.8	17.7	29.1	40.4	17.5	9.5	36.8	16.3	278.9
1923	12.7	16.6	27.1	22.5	16.4	16.0	54.3	78.0	39.7	36.3	29.6	34.4	383.7
1924	6.0	7.8	47.5	22.2	19.0	3.6	52.1	23.3	20.2	21.0	7.1	37.5	267.2
1925	5.5	9.8	20.9	10.1	16.4	27.1	45.7	55.0	46.2	41.6	12.7	10.2	301.1
1926	10.7	10.9	44.2	64.1	45.4	16.0	46.8	25.5	33.5	25.4	12.7	38.1	373.3
1927	8.2	39.9	33.2	15.2	7.1	56.1	46.9	64.8	80.0	17.0	10.2	19.5	398.2
1928	3.6	27.3	24.7	21.3	45.9	8.8	31.7	65.4	9.8	50.9	34.1	12.4	336.0
1929	13.7	18.2	25.5	14.8	41.0	2.8	78.0	76.1	61.7	16.9	10.4	2.2	361.3
1930	28.4	8.7	26.4	20.6	30.0	9.8	77.5	56.0	29.9	19.0	28.6	2.9	337.8
1931	5.3	32.3	22.7	40.0	19.8	18.9	46.8	47.6	55.0	25.6	45.9	20.6	380.4
1932	16.4	34.4	18.5	24.0	23.8	19.5	53.0	56.6	20.9	22.7	1.0	23.8	314.4
1933	18.2	11.0	7.8	22.0	17.3	32.2	52.7	47.3	35.5	24.2	21.6	10.2	300.0
1934	5.3	20.2	7.0	18.8	35.6	9.7	25.8	57.6	23.6	5.0	23.2	14.2	246.0
1935	28.4	19.6	25.7	26.3	47.2	4.2	35.3	75.3	47.8	11.0	16.2	13.5	350.4
1936	14.8	31.8	21.2	6.8	19.0	17.0	53.8	62.1	39.1	21.3	9.1	25.2	321.1
1937	19.1	29.0	41.0	10.8	33.1	27.6	42.1	34.8	43.9	15.6	6.2	18.6	321.9
1938	16.4	27.2	50.1	16.3	17.2	44.6	30.5	35.4	60.3	28.0	8.7	21.0	355.8
1939	27.4	16.0	23.7	19.2	9.8	4.0	31.0	33.9	51.9	13.5	13.2	9.4	253.1
1940	26.4	31.8	16.1	26.0	27.6	17.9	29.6	49.4	60.7	25.8	35.7	46.7	393.6
1941	33.7	29.7	63.7	57.8	54.5	36.9	42.8	45.8	80.4	80.5	12.5	24.1	562.4
1942	10.3	17.0	17.8	60.9	5.6	7.9	24.8	45.7	36.2	26.8	3.6	25.5	282.1
1943	28.9	11.1	30.0	8.3	26.3	26.5	30.4	66.0	19.6	19.5	10.5	28.1	305.3
1944	21.1	22.7	24.9	49.9	22.0	9.9	32.5	31.8	20.8	22.6	26.7	15.5	300.4
1945	20.7	12.8	34.9	26.3	10.5	12.7	35.2	55.3	15.0	22.1	4.3	21.0	270.9
1946	12.5	5.3	25.8	28.4	17.9	4.0	47.9	72.6	38.6	33.4	30.7	12.0	329.1

Precipitation

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

SOUTHERN ROCKIES

Area-Average Annual Precipitation Amount (continued)

Year	Precipitation (mm)												Ann
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	
1947	8.9	8.8	11.9	13.7	32.4	25.6	23.4	74.5	18.9	41.3	16.5	27.7	303.4
1948	16.0	36.7	30.9	12.9	22.8	33.1	30.4	42.8	17.2	27.6	7.3	27.1	304.7
1949	47.2	13.4	25.0	23.3	33.1	45.8	54.6	33.8	37.2	24.9	4.2	17.1	359.7
1950	13.3	13.6	14.0	10.6	5.9	18.9	60.2	21.7	34.5	3.3	6.6	5.9	208.4
1951	19.5	11.5	11.5	27.6	20.4	7.3	31.4	66.7	11.6	23.3	20.5	42.8	293.8
1952	38.6	11.9	31.0	36.5	17.4	15.1	45.9	46.0	31.8	0.1	29.8	14.4	318.5
1953	9.6	11.5	24.7	20.7	18.4	14.4	61.0	47.1	1.3	27.2	20.6	10.2	266.6
1954	12.6	6.4	37.2	4.6	29.0	10.3	50.1	38.7	40.6	22.4	7.4	12.6	272.0
1955	22.9	17.8	5.1	13.2	35.2	18.4	42.6	73.3	8.7	7.5	11.7	12.2	268.6
1956	29.4	15.3	6.4	14.0	13.1	10.5	40.8	30.1	1.2	14.3	5.2	8.1	188.3
1957	45.7	12.7	25.0	38.0	46.6	19.4	57.1	89.2	4.5	73.7	36.0	9.4	457.4
1958	11.9	26.2	49.0	30.1	18.2	13.9	20.0	43.1	47.5	25.0	13.8	5.4	304.2
1959	6.7	22.4	5.6	23.9	23.0	21.7	39.9	65.0	18.1	55.1	9.1	38.7	329.0
1960	23.7	20.9	20.7	13.1	12.9	20.7	35.7	29.7	21.0	64.0	9.0	25.7	297.2
1961	10.1	9.0	38.5	22.8	12.0	11.8	40.2	80.7	45.5	31.0	20.8	22.1	344.3
1962	18.9	24.7	14.8	10.2	9.6	13.2	39.5	16.7	45.5	26.4	19.7	17.8	257.0
1963	15.2	19.9	18.2	11.3	10.1	12.1	29.2	87.2	34.3	24.1	15.0	5.6	282.3
1964	8.6	10.0	25.1	27.2	16.1	8.3	50.1	49.6	36.9	2.1	26.3	24.7	285.2
1965	22.3	20.2	27.2	42.1	34.7	33.5	65.7	42.1	48.2	22.8	27.8	55.2	441.8
1966	10.4	16.6	6.0	12.7	12.8	23.2	43.9	59.9	23.4	14.0	14.0	33.7	270.4
1967	9.0	5.7	11.7	9.2	21.7	32.7	62.8	71.5	32.9	7.0	9.4	51.1	324.6
1968	10.7	20.0	20.1	23.4	15.6	6.1	57.7	65.6	6.7	15.4	16.8	18.2	276.3
1969	34.0	23.5	22.3	10.6	26.8	36.1	50.1	56.7	33.9	55.3	14.5	15.6	379.4
1970	7.8	6.7	44.9	16.4	6.1	17.0	36.4	47.3	45.5	23.1	15.0	11.6	277.8
1971	7.0	13.8	4.7	13.5	18.9	6.7	38.1	59.8	36.9	48.2	18.4	29.6	295.6
1972	3.7	1.6	4.7	6.0	12.7	33.3	37.3	48.1	32.5	105.4	27.3	29.0	341.7
1973	19.0	21.5	53.3	20.8	31.2	21.3	46.4	30.7	16.4	9.0	13.6	10.3	293.4
1974	39.0	4.4	16.8	16.0	3.2	9.2	48.1	32.0	24.1	61.5	14.3	15.4	284.2
1975	20.1	21.0	36.7	25.6	14.2	9.6	58.8	22.2	44.1	7.9	23.8	13.1	297.1
1976	5.4	25.8	14.6	20.0	29.0	10.5	45.9	36.0	41.7	9.9	7.5	2.7	248.8
1977	22.1	8.3	12.3	23.7	15.9	15.2	55.3	57.4	27.8	17.9	16.2	13.4	285.6
1978	42.1	30.2	42.1	14.9	34.5	20.9	26.7	29.2	15.3	28.6	65.9	51.9	402.4
1979	49.4	16.7	34.6	11.4	44.6	24.3	24.7	43.8	12.4	19.1	19.0	17.1	317.1
1980	46.9	48.2	32.8	24.2	28.3	3.7	27.5	43.3	33.7	19.3	8.5	9.7	326.2
1981	8.5	9.0	38.1	14.7	32.6	18.0	58.5	56.2	38.9	37.5	17.7	6.9	336.5
1982	29.0	24.4	31.1	9.0	31.6	16.2	36.9	80.1	53.6	10.8	34.1	34.0	390.7
1983	29.7	27.0	42.1	17.9	18.9	21.6	48.4	49.6	45.7	27.4	31.2	37.6	397.1
1984	9.6	7.2	20.2	21.7	14.2	28.5	55.4	77.4	32.0	58.1	14.4	45.7	384.5
1985	26.4	12.5	38.7	36.2	21.2	13.8	50.0	32.2	62.7	43.5	36.3	11.1	384.6
1986	3.5	26.6	22.5	25.5	24.1	42.3	53.0	59.0	45.5	48.2	45.7	25.3	421.2
1987	25.3	36.9	24.0	14.4	28.1	21.6	35.9	66.6	16.0	27.5	35.7	23.2	355.1
1988	24.6	16.8	9.8	39.6	19.9	39.4	43.1	74.0	35.6	11.8	21.2	15.2	350.9
1989	25.4	19.0	16.3	5.0	12.3	12.3	48.9	45.0	21.8	24.9	2.4	8.1	241.4
1990	17.3	21.2	23.5	35.7	18.0	8.2	57.6	52.9	63.6	22.1	29.5	27.4	376.9
1991	19.4	8.2	47.6	6.5	19.7	21.0	51.6	54.8	47.0	18.4	40.7	35.6	370.5
1992	15.7	18.1	39.1	8.3	64.3	18.7	44.9	71.2	21.2				

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United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

NORTHERN STEPPES

Trends

The annual precipitation time series for the Northern Steppes region indicates a generally decreasing trend (even considering several wet years) from ca. 1905 to the 1930s. This series (with its four very dry years in the 1930s) perhaps characterizes the severe drought of the "Dust Bowl" period (Karl and Knight 1985) as well as any of the regional time series. After the 1930s, the series depicts a quick return to more "average" conditions; thereafter, the series shows no evidence of long-term trends.

Area-average annual precipitation amount for the Northern Steppes region of the United States.

CITE AS: Karl, T.R., D.R. Easterling, and P.Ya. Groisman. 1994. United States historical climatology network—National and regional estimates of monthly and annual precipitation. pp. 830–905. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Precipitation

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

NORTHERN STEPPES

Area-Average Annual Precipitation Amount

Year	Precipitation (mm)												Ann
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	
1900	2.4	29.7	10.4	122.0	35.6	16.8	37.8	24.3	25.7	10.0	4.9	8.4	350.4
1901	3.3	18.7	31.6	50.4	75.1	64.3	17.6	29.7	33.3	20.4	3.0	28.9	399.0
1902	7.5	11.0	19.5	23.9	50.0	52.6	44.3	31.6	88.9	16.6	6.0	34.3	401.4
1903	5.8	24.3	12.3	25.7	57.4	35.8	60.1	41.6	33.5	12.5	8.8	5.7	336.7
1904	6.3	13.6	14.2	22.0	57.3	45.5	47.7	23.9	30.9	19.2	1.3	8.6	304.6
1905	17.0	12.0	28.5	71.5	87.0	63.8	70.7	25.5	34.9	23.3	7.2	1.1	473.2
1906	9.5	6.5	34.0	51.1	85.1	45.2	28.7	44.0	38.1	36.3	20.4	14.8	430.1
1907	18.9	12.9	15.8	23.7	66.6	65.5	57.9	34.6	28.3	5.7	7.3	8.0	361.7
1908	6.7	8.2	14.5	23.1	120.9	83.1	54.6	35.4	19.1	49.7	10.7	15.3	457.2
1909	14.1	16.2	21.4	23.1	63.4	96.8	52.3	32.2	44.2	9.6	18.0	23.7	424.6
1910	9.5	10.1	11.3	24.3	50.7	42.2	26.9	21.7	43.5	17.0	11.8	9.1	278.2
1911	16.8	11.8	5.2	32.5	44.0	54.4	25.0	49.0	46.5	33.0	13.2	12.2	343.4
1912	15.0	17.1	25.1	40.8	60.4	34.6	71.4	52.0	52.6	33.8	6.9	6.9	416.4
1913	12.0	12.4	17.6	24.1	48.0	59.5	49.2	25.3	33.4	31.2	10.2	25.9	348.7
1914	5.8	13.9	11.3	48.5	57.8	70.2	25.7	29.1	21.1	36.7	3.0	7.7	330.9
1915	15.2	17.1	26.3	49.0	79.4	91.7	82.0	29.2	56.6	25.6	6.7	12.6	491.3
1916	19.2	11.7	14.1	24.3	71.2	64.1	49.0	35.4	24.7	31.2	12.1	16.7	373.7
1917	13.0	15.3	17.9	35.8	80.8	33.7	16.2	19.8	42.9	10.2	3.5	24.3	313.4
1918	20.4	9.2	13.4	42.3	50.6	27.7	59.4	50.1	41.3	18.1	11.3	10.3	354.1
1919	2.7	13.6	15.6	23.0	31.1	40.9	33.3	14.3	31.7	32.0	19.7	11.5	269.2
1920	11.5	8.7	11.9	73.5	60.8	57.0	29.4	39.5	17.5	25.1	5.7	7.6	348.1
1921	12.5	4.1	15.8	27.9	60.0	62.5	48.9	23.6	21.1	10.4	19.1	16.7	322.7
1922	12.2	11.6	9.2	58.0	66.4	54.5	56.3	25.4	10.5	10.7	30.4	14.4	359.6
1923	8.1	12.8	16.1	34.4	70.6	107.4	67.7	49.5	42.6	46.8	8.1	10.7	474.6
1924	8.0	13.6	24.6	21.0	38.4	54.2	25.4	23.4	33.1	34.6	10.5	20.1	306.8
1925	6.3	7.1	17.7	46.2	35.9	75.5	32.9	27.5	40.9	42.0	6.4	18.3	356.7
1926	10.8	6.5	10.0	17.5	52.5	59.3	51.1	34.0	42.8	15.9	19.5	8.1	328.1
1927	7.6	9.8	23.5	54.0	110.7	62.3	44.1	56.0	27.3	18.0	22.8	12.2	448.2
1928	9.4	9.1	13.8	13.8	39.3	94.8	70.3	32.7	11.1	24.7	11.9	8.9	339.8
1929	11.6	11.3	31.2	46.0	50.2	49.9	26.2	24.8	48.9	26.2	17.2	17.6	361.1
1930	10.7	6.7	17.1	45.0	52.3	29.8	27.6	60.1	29.4	39.7	14.3	3.3	336.1
1931	3.1	8.5	18.8	17.4	34.5	36.7	40.8	21.4	27.5	16.6	14.3	8.1	247.9
1932	9.0	8.4	26.1	50.4	44.8	72.9	38.7	44.3	7.1	25.6	8.4	10.5	346.3
1933	6.0	6.9	17.9	55.0	78.6	31.4	16.7	76.6	19.9	11.4	9.3	15.7	345.6
1934	4.8	12.4	20.0	17.1	20.0	70.0	22.3	19.1	28.6	13.6	6.1	9.9	244.0
1935	5.6	6.2	23.9	46.4	89.5	35.4	32.0	17.0	20.5	13.4	8.8	5.8	304.5
1936	10.9	16.3	13.8	27.5	24.0	44.0	23.4	28.8	18.9	16.4	9.7	11.7	245.6
1937	9.6	7.1	22.9	19.5	29.4	63.2	52.6	13.8	24.2	17.5	10.8	17.4	288.1
1938	9.1	6.3	23.2	34.6	85.6	54.7	51.6	23.9	44.0	19.2	15.2	8.9	376.3
1939	9.7	10.6	14.9	19.3	43.1	61.8	16.9	26.7	20.8	20.3	1.2	8.1	253.5
1940	12.3	11.8	22.2	53.5	26.5	46.5	32.4	13.8	43.1	25.0	12.8	5.8	305.7
1941	6.6	5.1	15.9	54.4	40.7	92.5	38.8	44.3	55.6	24.6	12.7	13.7	405.0
1942	6.3	12.4	16.7	55.4	93.1	76.1	35.2	24.2	34.2	38.9	18.9	5.6	417.0
1943	13.7	7.1	16.8	39.1	52.7	80.9	35.5	25.0	7.5	23.0	6.0	5.3	312.7
1944	12.1	11.5	30.0	31.7	48.4	98.2	52.4	29.2	14.9	6.7	20.3	9.1	364.7
1945	10.2	10.3	21.5	37.8	52.7	88.6	23.9	43.3	43.3	11.9	6.5	13.5	363.5
1946	4.6	4.6	24.4	15.8	72.1	56.5	39.4	26.9	53.2	41.6	19.3	9.8	368.3

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

NORTHERN STEPPES

Area-Average Annual Precipitation Amount (continued)

Year	Precipitation (mm)												
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1947	6.9	8.6	18.1	29.6	43.4	117.1	25.1	27.5	33.6	20.7	23.1	7.9	361.6
1948	11.6	12.1	15.0	28.1	57.6	95.2	45.8	26.5	17.9	9.2	15.5	13.5	347.7
1949	26.6	7.1	23.2	20.0	69.2	62.2	37.1	19.1	15.0	30.6	1.9	8.1	320.0
1950	11.2	4.3	25.4	30.8	42.6	50.8	48.4	30.8	43.2	8.2	14.0	6.5	316.2
1951	8.1	8.9	14.3	34.5	40.6	71.5	46.2	54.1	42.6	33.2	7.4	18.1	379.7
1952	6.5	15.1	20.9	13.8	72.3	41.3	31.5	30.0	13.7	5.9	16.7	5.0	272.6
1953	10.8	20.0	14.5	46.6	77.9	75.6	37.4	38.2	9.7	13.3	9.3	10.0	363.2
1954	10.0	4.9	30.1	15.8	40.7	52.4	27.5	46.1	29.8	19.5	5.4	4.1	286.3
1955	8.7	14.3	17.3	35.0	80.9	56.8	45.5	22.1	26.3	7.7	21.2	15.3	351.3
1956	8.4	5.9	8.4	22.7	49.3	44.0	50.9	39.4	7.2	9.3	14.8	9.0	269.4
1957	11.2	7.4	16.8	40.6	98.5	76.9	31.0	44.1	24.0	31.5	11.8	3.0	396.7
1958	4.6	16.2	23.0	39.9	34.5	82.8	68.2	22.8	13.1	10.8	17.0	17.1	350.0
1959	13.7	14.3	20.8	22.4	67.6	59.3	13.8	16.9	42.8	28.2	16.7	3.0	319.3
1960	8.4	12.1	9.8	28.7	46.3	35.5	16.7	35.3	12.9	11.8	13.1	10.4	240.9
1961	2.1	8.1	29.2	28.5	76.0	32.9	48.1	18.4	49.7	16.7	13.0	6.6	329.3
1962	13.4	12.4	13.0	15.3	110.7	81.0	63.2	30.5	12.2	25.3	9.3	5.5	391.8
1963	17.6	8.2	13.5	35.0	47.2	80.4	32.5	29.2	33.5	15.7	4.0	9.8	326.5
1964	6.5	9.7	16.5	49.4	64.8	82.5	26.0	29.4	10.2	4.1	10.6	16.8	326.5
1965	15.1	8.3	11.3	31.4	68.5	102.9	50.0	33.3	55.2	8.2	8.0	8.4	400.5
1966	10.0	7.4	13.3	32.4	20.3	51.7	43.2	37.6	27.9	24.0	15.7	10.3	293.8
1967	11.1	7.6	21.8	50.2	65.2	96.0	33.0	14.4	35.7	18.7	11.3	19.0	384.1
1968	9.3	7.1	12.9	30.7	64.9	69.3	24.5	66.3	33.3	10.8	10.5	14.4	354.1
1969	21.0	8.1	9.4	30.1	43.5	84.0	44.5	10.5	9.7	43.5	7.6	6.8	318.8
1970	11.4	7.8	23.2	49.1	54.8	73.4	42.9	11.3	26.0	19.9	13.4	8.6	341.9
1971	21.2	12.8	16.7	48.7	68.7	41.6	16.8	26.4	40.1	31.9	6.7	11.9	343.4
1972	16.7	6.9	15.4	30.4	53.1	57.1	44.7	46.5	22.4	20.4	12.9	14.0	340.4
1973	7.1	4.7	29.1	59.7	31.0	41.9	42.9	19.7	69.0	16.1	24.2	21.9	367.3
1974	12.1	6.5	18.6	30.3	51.9	31.7	38.1	54.8	16.7	21.7	8.6	5.3	296.3
1975	14.3	7.9	26.6	53.4	82.7	74.3	42.9	40.0	12.3	37.7	14.1	13.9	420.0
1976	10.2	8.3	9.4	42.9	46.1	64.6	42.9	37.6	21.6	9.7	7.8	4.4	305.6
1977	11.2	3.8	27.3	32.5	58.5	41.3	47.2	41.3	35.9	17.0	15.3	20.2	351.5
1978	16.3	17.9	6.9	33.3	111.3	36.2	64.5	33.8	35.2	12.6	21.6	19.9	409.6
1979	10.9	12.0	23.2	32.9	41.6	57.6	40.3	43.1	11.4	22.8	13.9	7.7	317.4
1980	15.8	14.2	26.8	22.4	67.6	53.6	25.2	36.6	22.1	35.2	8.0	10.4	338.0
1981	5.5	4.3	26.0	17.2	104.6	40.1	58.6	39.4	12.3	31.7	7.4	7.9	355.1
1982	14.9	8.8	23.8	17.2	93.0	72.4	59.5	34.3	56.4	28.5	12.4	19.0	440.1
1983	3.2	3.0	38.5	30.3	60.1	53.3	50.2	32.4	20.8	19.5	28.2	12.5	352.3
1984	8.3	9.4	22.2	50.4	25.8	58.1	32.8	24.9	24.8	23.4	6.9	14.1	301.1
1985	6.8	4.4	17.8	26.1	42.1	29.7	35.6	52.4	59.4	22.9	25.7	12.7	335.7
1986	6.6	18.2	15.3	49.0	57.8	74.2	33.2	27.6	66.5	29.0	16.9	5.1	400.7
1987	2.8	17.9	34.8	12.5	88.3	41.5	61.9	41.3	20.0	4.9	12.2	10.7	347.2
1988	10.5	9.3	16.7	22.5	67.5	43.7	32.7	15.2	37.9	8.6	8.7	10.2	281.5
1989	13.2	15.7	21.3	38.5	48.6	43.8	36.3	52.4	42.7	17.7	11.5	18.2	363.6
1990	9.3	7.0	34.7	32.3	64.1	32.0	54.6	40.0	15.1	13.3	16.6	8.4	324.9
1991	8.0	8.2	15.0	46.1	77.3	104.9	24.6	28.9	30.6	14.1	16.6	2.7	379.3
1992	9.4	5.8	26.7	20.4	38.4	83.3	68.6	37.7	12.1				

CITE AS: Karl, T.R., D.R. Easterling, and P.Ya. Groisman. 1994. United States historical climatology network—National and regional estimates of monthly and annual precipitation. pp. 830–905. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Precipitation

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

SOUTHERN STEPPES

Trends

The annual precipitation time series for the Southern Steppes region shows no obvious long-term trends. A notable feature of the series is the generally dry period during the early to mid-1950s, which was associated with the severe to extreme drought conditions experienced in much of the southcentral United States at that time (Karl and Knight 1985). Also, there is some indication of a general increase in precipitation since the relatively dry mid-1960s.

Area-average annual precipitation amount for the Southern Steppes region of the United States.

CITE AS: Karl, T.R., D.R. Easterling, and P.Ya. Groisman. 1994. United States historical climatology network—National and regional estimates of monthly and annual precipitation. pp. 830–905. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

SOUTHERN STEPPES

Area-Average Annual Precipitation Amount

Year	Precipitation (mm)												
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1900	25.5	13.8	32.8	178.4	84.6	36.3	92.3	61.5	105.9	46.7	11.5	9.5	696.0
1901	7.9	23.7	20.3	56.0	81.0	19.2	51.3	38.5	42.2	30.2	23.3	7.1	387.5
1902	9.8	10.6	42.9	23.6	129.7	40.3	81.4	39.5	42.3	49.0	56.3	22.9	530.7
1903	17.6	89.0	22.4	39.9	67.7	95.7	82.5	47.3	28.0	33.9	7.2	4.9	532.4
1904	4.8	10.6	8.0	34.2	94.1	97.5	67.0	66.0	82.9	33.7	2.9	18.1	517.8
1905	22.0	26.5	83.1	124.8	82.3	67.4	72.8	40.4	57.8	32.5	60.2	19.2	679.6
1906	12.4	13.9	19.6	88.8	60.0	53.1	109.9	69.6	71.1	52.8	41.8	20.4	602.5
1907	23.4	4.8	9.8	43.2	83.4	74.0	86.1	51.3	22.5	83.5	39.8	25.8	543.1
1908	10.3	24.9	15.6	59.9	83.6	77.3	73.4	66.9	38.7	37.3	46.5	3.1	526.4
1909	5.0	6.0	32.8	15.9	52.9	70.0	70.7	30.1	36.9	49.3	83.4	18.9	467.4
1910	9.5	7.6	14.0	43.9	46.9	24.0	45.1	66.2	12.9	20.3	7.2	11.5	308.4
1911	4.2	67.0	12.0	46.8	66.4	16.1	86.7	58.6	33.1	38.1	15.8	56.1	500.4
1912	1.6	43.6	31.1	53.5	47.4	76.3	38.9	55.7	43.1	30.9	8.7	14.8	441.6
1913	11.2	28.5	25.0	53.5	47.4	80.5	37.0	19.1	86.7	49.6	73.1	75.6	584.0
1914	2.2	9.4	11.4	71.6	146.9	41.0	60.6	86.6	20.6	57.8	15.0	30.1	556.2
1915	15.0	49.2	25.8	137.6	84.3	79.5	63.0	86.9	85.5	49.1	5.3	13.5	690.9
1916	24.8	0.6	10.6	69.7	27.7	76.6	31.9	57.0	43.1	48.5	20.2	9.0	414.6
1917	10.7	8.9	7.0	45.1	50.7	28.5	42.4	92.5	54.8	3.9	13.6	1.2	358.9
1918	13.7	10.8	29.8	41.8	64.7	49.5	41.6	30.3	53.6	84.8	31.3	70.6	518.3
1919	13.1	26.7	69.3	96.4	95.5	92.8	75.6	53.4	71.2	83.0	33.6	8.2	714.7
1920	26.1	7.2	21.8	26.6	101.2	61.3	61.8	107.9	67.0	70.1	36.9	17.2	598.0
1921	27.6	17.5	27.2	42.7	57.3	135.4	68.9	41.3	57.4	5.3	3.2	8.6	491.5
1922	16.5	16.0	58.8	109.9	85.4	43.2	43.0	16.7	29.5	22.5	28.7	3.8	473.2
1923	8.0	26.1	37.0	69.5	82.2	95.4	40.0	57.7	100.7	175.1	36.3	31.6	750.9
1924	4.6	16.5	49.4	53.9	49.5	46.5	41.9	52.3	40.7	29.8	14.9	13.5	411.0
1925	9.5	7.5	2.4	57.5	64.7	41.3	73.4	56.9	100.0	46.8	33.4	5.8	494.9
1926	20.4	3.5	59.4	73.2	75.6	68.2	62.7	66.8	81.6	61.3	14.0	42.2	624.3
1927	14.7	23.2	25.2	50.0	26.3	82.1	87.3	93.4	53.8	28.0	1.6	15.1	496.5
1928	4.6	34.7	21.7	39.2	116.9	89.4	75.7	54.6	28.9	58.7	53.2	25.4	604.2
1929	12.5	17.5	56.3	29.5	118.1	39.3	64.9	42.0	63.2	40.4	45.2	5.6	531.9
1930	19.4	4.5	16.5	47.5	84.6	61.7	42.7	31.4	36.0	117.9	36.1	22.0	519.9
1931	17.4	32.4	51.3	63.9	59.1	34.5	55.6	47.9	22.1	44.9	46.6	26.7	500.7
1932	41.1	29.2	17.8	55.5	53.2	121.2	41.0	71.7	61.0	20.4	3.4	48.9	565.5
1933	10.1	17.8	19.3	30.0	67.4	15.8	45.3	89.6	39.7	20.6	21.4	19.1	396.6
1934	18.7	18.6	33.8	28.8	45.4	37.6	21.6	42.4	37.3	21.0	25.9	9.5	338.6
1935	9.2	17.9	29.5	17.3	138.9	72.4	40.2	49.0	71.6	27.6	32.7	20.2	521.2
1936	13.1	2.6	6.0	16.9	121.6	50.4	37.5	17.6	130.2	32.3	8.7	17.8	454.9
1937	11.0	5.6	35.0	25.1	90.6	70.4	36.8	47.1	48.8	39.2	12.9	27.5	446.5
1938	17.1	39.1	40.3	44.0	82.8	70.7	57.8	15.9	48.7	20.1	17.6	11.8	464.6
1939	53.5	14.0	26.8	32.3	57.0	81.0	48.6	41.1	8.7	20.6	16.5	22.1	421.6
1940	13.3	31.1	12.9	57.9	75.6	51.5	38.4	63.7	36.4	25.9	84.0	23.9	513.4
1941	24.4	39.6	52.8	85.9	165.9	100.7	66.2	66.9	91.5	150.9	11.7	14.8	869.7
1942	5.9	14.5	26.7	137.4	26.3	78.4	42.7	93.0	87.5	84.5	7.1	34.3	637.9
1943	3.3	3.7	19.0	29.6	98.9	52.8	43.4	27.8	37.8	21.7	13.5	47.8	396.6
1944	38.4	28.4	32.0	70.2	98.4	43.7	70.5	71.3	47.1	35.7	39.1	42.2	618.3
1945	32.2	22.2	27.6	55.2	20.2	70.1	70.7	62.1	75.1	35.3	6.4	12.8	487.9
1946	24.4	25.2	25.3	31.3	67.3	53.9	29.7	72.9	60.1	77.0	57.8	16.5	537.5

Precipitation

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

SOUTHERN STEPPES

Area-Average Annual Precipitation Amount (continued)

Year	Precipitation (mm)												Ann
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	
1947	20.8	3.5	24.3	72.9	126.8	50.1	39.8	36.4	9.2	22.0	25.8	36.3	466.8
1948	14.4	44.4	40.4	15.8	66.2	88.5	54.7	62.0	19.4	24.5	25.7	5.1	462.2
1949	61.1	25.9	27.5	54.0	132.5	95.1	69.2	48.5	47.2	50.4	0.8	18.5	636.6
1950	6.5	16.3	1.9	26.0	69.8	54.7	159.7	75.7	70.7	14.0	3.9	1.1	501.1
1951	15.6	23.3	23.9	24.5	118.7	93.5	47.3	37.0	49.3	34.0	18.4	3.8	486.3
1952	13.4	13.6	27.1	69.6	58.3	19.3	46.2	40.0	45.1	0.1	35.7	27.3	395.7
1953	5.3	13.7	29.8	30.8	45.8	32.2	76.5	66.1	18.7	64.9	21.2	17.1	422.0
1954	6.2	3.5	6.8	38.0	119.6	20.8	26.1	42.2	14.4	38.3	8.6	9.0	333.5
1955	16.9	21.1	8.0	24.6	156.2	58.6	38.5	37.6	54.5	43.1	5.1	4.5	468.6
1956	8.5	18.1	4.5	8.5	69.0	23.9	58.9	33.9	3.6	27.0	10.9	14.3	281.2
1957	10.7	23.9	65.9	106.1	159.0	73.9	33.2	34.2	53.3	74.2	42.5	4.0	680.8
1958	29.4	20.0	63.4	49.4	75.8	73.2	93.8	48.8	66.0	25.5	15.5	10.6	571.4
1959	8.2	12.6	16.2	36.0	103.4	72.9	73.4	60.5	53.3	94.9	9.8	55.8	596.9
1960	32.1	42.1	23.9	22.7	45.5	70.8	108.8	48.3	61.7	122.5	5.4	42.6	626.5
1961	11.8	28.0	49.3	16.8	42.0	98.1	90.6	61.3	63.0	40.5	55.7	14.2	571.3
1962	9.8	5.9	13.8	44.5	31.7	135.8	83.2	34.1	82.7	38.9	23.1	20.4	524.0
1963	3.7	14.5	18.3	23.6	64.9	65.6	42.1	50.6	52.3	21.7	28.7	11.0	397.0
1964	15.1	37.5	14.7	16.6	77.6	44.5	17.5	49.5	66.4	16.6	67.3	15.3	438.5
1965	12.4	26.6	19.4	34.0	88.9	109.1	39.2	59.0	91.7	62.3	5.7	32.6	580.8
1966	16.1	20.7	8.1	44.6	20.5	51.3	52.4	111.3	63.4	11.9	1.9	9.0	411.0
1967	3.9	5.7	14.0	43.0	55.6	71.2	68.8	49.3	69.2	27.8	13.0	19.9	441.4
1968	33.0	22.1	28.3	34.8	90.5	57.2	79.9	70.2	31.8	43.3	51.5	12.7	555.4
1969	3.3	37.4	44.3	40.9	105.0	66.1	46.7	86.2	81.9	73.1	13.0	22.1	620.1
1970	4.8	14.2	45.1	47.9	43.9	32.2	40.9	48.7	82.2	36.7	7.0	3.8	407.4
1971	9.8	29.2	3.3	24.1	53.4	60.9	70.3	101.8	87.1	69.2	38.9	33.3	581.4
1972	6.4	3.6	7.1	30.8	87.3	54.3	68.7	80.1	71.7	63.8	53.2	10.4	537.6
1973	37.8	22.7	110.5	63.3	41.5	46.2	82.7	27.1	120.1	50.2	15.2	19.4	636.6
1974	10.9	10.3	28.1	36.3	50.3	49.3	24.8	123.1	93.8	83.0	32.4	21.7	564.1
1975	21.1	39.2	22.3	31.1	105.8	68.7	85.5	57.8	37.5	18.6	44.5	16.1	548.1
1976	2.1	4.3	21.5	94.0	70.9	37.0	56.9	27.7	85.4	59.9	10.1	6.4	476.4
1977	13.1	19.5	17.4	76.4	120.8	49.1	39.8	97.6	32.2	26.8	29.3	3.5	525.4
1978	11.5	36.9	11.8	22.9	131.9	75.5	30.5	57.7	72.5	14.5	54.0	15.4	535.3
1979	28.0	14.9	54.2	38.8	92.9	79.8	91.6	58.8	17.8	39.6	20.8	22.2	559.4
1980	27.1	16.8	40.8	53.6	136.0	32.0	13.5	45.0	72.4	16.2	25.5	22.6	501.7
1981	8.1	11.9	49.4	42.9	80.9	84.3	72.1	80.6	52.1	86.1	32.5	6.3	607.2
1982	16.5	17.0	24.0	30.3	144.0	92.1	70.3	26.0	41.6	24.1	36.5	31.8	554.1
1983	25.4	34.4	45.4	34.8	82.2	83.3	15.3	29.9	23.6	103.4	31.0	15.2	524.0
1984	12.2	17.3	42.8	42.0	37.9	67.0	36.9	43.9	24.6	84.8	32.1	62.2	503.7
1985	21.7	38.7	55.2	63.0	52.4	94.1	49.6	45.3	93.1	87.9	28.9	9.6	639.5
1986	3.2	16.8	11.2	33.4	87.7	97.8	51.1	82.8	119.4	135.7	53.8	35.1	728.0
1987	23.6	52.2	44.6	13.1	148.9	108.6	40.0	71.8	72.5	15.0	20.7	40.4	651.4
1988	16.0	6.2	44.0	64.9	51.6	62.9	66.1	31.9	109.0	17.2	12.3	10.2	492.3
1989	25.3	23.1	30.9	13.0	86.9	138.0	40.1	79.8	67.6	22.7	3.2	6.9	537.6
1990	30.6	50.3	53.2	65.8	70.4	31.2	90.7	49.2	79.8	24.1	40.7	12.1	598.0
1991	28.1	5.7	27.8	25.9	92.8	81.5	72.0	77.8	81.8	32.8	35.9	89.5	649.6
1992	29.9	35.7	35.8	30.0	96.8	126.7	81.2	84.8	18.7				

CITE AS: Karl, T.R., D.R. Easterling, and P.Ya. Groisman. 1994. United States historical climatology network—National and regional estimates of monthly and annual precipitation. pp. 830–905. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

NORTHERN PLAINS

Trends

The annual precipitation time series for the Northern Plains region shows evidence of a dramatically decreasing trend from ca. 1905 to the mid-1930s. The dry years of the 1930s, especially 1933 and 1934, led to vast regions of severe to extreme drought conditions that were generally centered in this region of the United States (Karl and Knight 1985). After the 1930s, the series depicts a quick return to more moderate conditions; thereafter, the series shows no evidence of long-term trends.

Area-average annual precipitation amount for the Northern Plains region of the United States.

CITE AS: Karl, T.R., D.R. Easterling, and P.Ya. Groisman. 1994. United States historical climatology network—National and regional estimates of monthly and annual precipitation. pp. 830–905. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Precipitation

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

NORTHERN PLAINS

Area-Average Annual Precipitation Amount

Year	Precipitation (mm)												Ann
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	
1900	8.0	15.5	39.0	53.0	32.9	56.3	119.6	132.1	112.9	60.9	13.9	8.8	654.4
1901	8.5	11.9	40.7	38.6	36.8	136.0	67.2	45.6	102.0	44.1	14.5	14.8	560.1
1902	11.0	16.1	40.5	36.0	114.5	101.0	119.8	104.7	49.7	37.1	26.6	34.5	695.2
1903	8.7	16.5	28.7	55.3	125.2	56.7	108.4	120.1	83.3	44.1	9.3	14.6	671.5
1904	9.7	15.8	33.0	50.2	67.2	110.0	89.7	66.4	54.4	51.9	3.1	18.7	569.6
1905	15.4	17.2	32.5	46.9	136.4	135.0	89.0	80.2	62.5	46.7	48.2	4.4	719.5
1906	22.7	12.8	31.9	61.5	124.3	95.4	62.4	111.6	75.2	47.4	36.5	24.8	708.0
1907	25.7	12.4	19.9	22.0	59.3	96.9	109.5	72.2	55.2	23.2	9.0	15.2	527.0
1908	6.4	26.2	32.8	50.8	129.1	141.4	83.9	67.1	35.3	48.6	26.5	13.9	665.4
1909	21.7	24.7	15.6	45.4	97.8	92.2	91.8	92.2	52.5	32.0	50.8	37.4	656.5
1910	20.6	11.5	11.4	34.3	40.0	52.5	47.6	69.5	58.9	17.9	8.2	11.6	385.7
1911	15.7	25.0	13.8	51.6	78.1	71.8	72.9	96.7	72.8	67.4	21.2	25.6	614.2
1912	9.6	8.3	24.8	57.3	87.8	46.2	103.1	91.3	62.0	28.5	9.7	16.0	544.6
1913	8.8	10.9	35.1	51.1	95.3	73.3	88.3	61.2	59.6	51.6	15.2	11.4	560.8
1914	14.1	12.2	27.8	55.3	73.6	170.6	54.9	71.5	72.4	46.3	5.8	15.0	617.2
1915	19.9	43.7	20.1	41.4	117.1	139.1	115.7	50.3	84.2	38.3	29.7	14.0	713.5
1916	38.4	10.4	33.0	51.5	89.8	101.8	68.2	87.8	61.2	27.9	14.2	22.8	606.9
1917	23.5	14.5	35.7	66.3	52.2	81.4	57.9	46.0	51.4	24.3	5.3	14.0	472.6
1918	17.2	11.3	17.3	51.5	104.8	68.0	77.6	84.1	25.4	46.7	38.0	24.8	566.5
1919	6.3	32.2	26.8	62.8	76.3	111.7	82.6	57.7	45.4	46.6	50.2	9.5	608.2
1920	14.4	8.4	43.8	67.3	76.4	111.1	71.6	59.8	54.3	36.4	28.9	17.0	589.4
1921	8.7	11.5	31.9	54.0	89.7	72.0	84.9	75.9	94.3	23.5	17.6	14.1	578.1
1922	17.5	33.5	26.9	50.3	78.1	77.7	82.4	45.1	38.9	24.0	68.3	11.7	554.4
1923	16.8	10.3	27.3	49.4	62.5	118.6	71.5	85.7	80.9	21.1	10.9	12.8	567.7
1924	7.6	15.3	35.5	48.9	36.0	128.9	70.4	96.0	62.7	30.8	9.8	24.3	566.2
1925	9.6	10.7	13.9	47.3	34.5	153.4	55.4	54.5	72.8	27.0	13.8	16.4	509.3
1926	17.6	10.9	14.2	12.3	58.9	71.3	69.3	77.8	109.6	38.4	30.0	18.3	528.7
1927	9.4	14.6	37.3	84.0	120.6	71.1	65.2	66.4	66.9	35.6	21.5	25.5	618.2
1928	5.4	19.2	22.1	35.3	44.0	101.7	95.9	108.2	46.5	52.4	29.2	11.7	571.6
1929	29.0	16.9	27.8	63.4	61.8	56.8	60.9	36.6	72.8	51.4	14.9	12.4	504.5
1930	15.5	22.4	11.4	53.2	92.5	93.3	34.1	47.2	50.4	42.5	41.3	5.8	509.6
1931	6.3	8.8	32.6	25.0	55.0	75.2	54.6	56.4	72.4	41.0	59.8	24.3	511.4
1932	27.6	13.9	25.5	50.6	81.3	98.3	58.5	80.2	30.9	37.1	24.5	14.5	542.8
1933	17.2	9.1	45.1	36.8	88.1	39.0	66.3	47.6	52.3	20.1	13.5	23.5	458.6
1934	10.2	6.0	22.8	19.5	18.6	89.4	60.2	45.5	65.0	36.2	39.1	13.6	426.1
1935	18.3	13.1	32.8	74.3	72.7	103.4	79.8	80.8	26.9	29.3	27.6	17.9	576.9
1936	21.3	27.9	26.0	25.4	54.9	45.6	16.7	63.9	54.9	16.8	17.9	24.8	396.2
1937	30.5	17.2	29.4	69.1	75.2	93.1	69.6	71.8	41.2	29.9	11.8	15.0	553.8
1938	16.7	19.9	35.7	64.2	115.4	85.0	84.4	48.2	84.7	11.9	34.1	11.5	611.7
1939	23.1	28.2	15.4	33.2	54.3	118.9	52.1	72.9	21.4	29.2	2.1	10.9	461.5
1940	8.0	17.4	42.3	70.4	39.1	89.9	73.8	86.1	21.4	53.9	40.7	19.5	562.6
1941	22.6	10.5	19.2	75.3	69.9	125.7	48.1	65.1	112.1	63.2	18.3	15.6	645.6
1942	5.9	14.2	51.6	52.3	121.7	110.1	71.4	92.4	80.7	22.2	14.6	18.2	655.4
1943	19.3	15.4	30.5	33.9	79.4	136.6	84.3	83.9	29.4	38.8	20.2	3.0	573.2
1944	18.2	16.8	32.9	59.5	111.5	150.4	82.8	121.0	42.5	12.1	43.5	8.2	699.4
1945	13.1	22.5	41.2	61.6	77.8	100.1	74.6	71.8	64.8	8.1	21.3	26.0	583.0
1946	13.2	15.8	53.2	25.0	76.0	111.1	59.8	52.3	100.3	79.5	30.4	15.0	631.6

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

NORTHERN PLAINS

Area-Average Annual Precipitation Amount (continued)

Year	Precipitation (mm)												
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1947	16.4	7.9	16.8	70.4	53.5	167.8	45.2	60.4	49.1	45.9	44.3	15.8	593.6
1948	8.4	30.1	25.8	59.3	42.5	106.2	90.2	68.5	30.9	26.5	36.9	23.5	548.7
1949	36.3	9.3	43.1	20.6	73.3	88.1	111.2	51.7	43.4	54.7	11.8	19.5	562.9
1950	26.9	16.2	39.2	48.2	102.0	85.9	91.0	50.6	57.6	29.2	15.0	17.7	579.5
1951	11.2	29.2	50.9	58.2	76.5	114.5	78.5	119.0	61.1	51.4	18.1	28.1	696.7
1952	24.5	17.5	34.2	22.4	50.7	97.7	95.5	86.7	12.6	2.1	24.1	11.1	479.1
1953	16.7	23.2	34.8	79.5	95.2	135.1	79.8	82.4	25.0	17.3	27.8	24.7	641.5
1954	11.6	18.1	33.1	61.4	69.0	123.4	58.3	86.5	60.4	47.4	7.6	6.8	583.7
1955	10.5	23.6	14.0	47.0	62.0	81.7	101.5	52.0	44.1	22.5	13.6	16.2	488.9
1956	15.5	7.6	25.2	34.2	68.4	81.7	88.8	89.6	21.4	29.1	34.8	9.9	506.2
1957	7.8	10.2	24.9	50.6	97.3	121.8	94.7	78.9	63.8	46.5	32.3	10.6	639.4
1958	8.3	16.7	12.6	51.8	39.0	85.3	98.9	47.1	34.4	17.4	33.2	6.8	451.5
1959	9.1	18.1	24.9	25.9	118.7	88.4	56.8	97.0	71.6	52.5	24.5	20.5	608.0
1960	22.0	12.4	21.8	60.6	104.9	89.0	46.5	102.5	44.9	21.7	19.1	15.4	560.8
1961	3.6	18.2	35.3	41.6	75.3	49.3	90.0	51.8	97.8	38.8	19.8	18.7	540.2
1962	10.6	33.1	31.1	35.9	140.4	94.4	137.1	81.5	52.9	26.4	7.3	8.2	658.8
1963	11.3	11.0	30.4	58.2	68.2	99.0	107.5	66.4	48.1	19.8	14.2	10.8	545.0
1964	7.9	7.1	26.6	88.4	67.3	109.9	71.8	94.3	72.1	6.3	18.0	18.8	588.5
1965	12.4	18.3	38.7	68.6	125.8	105.3	79.2	71.2	146.0	20.7	23.3	24.1	733.6
1966	13.6	17.8	42.8	41.2	44.7	96.7	87.4	102.3	29.9	40.4	10.4	16.8	543.9
1967	26.8	12.8	16.5	67.9	43.0	144.3	37.7	48.9	39.6	36.3	6.5	17.8	498.1
1968	12.2	3.1	20.6	85.9	57.0	123.9	82.2	82.7	77.8	65.5	14.6	37.9	663.1
1969	39.2	23.5	14.1	38.1	67.1	117.6	111.9	41.0	43.9	58.8	8.7	27.6	591.6
1970	8.6	5.1	30.7	73.5	87.6	76.8	68.9	34.5	76.7	72.3	42.1	16.6	593.4
1971	17.7	34.1	19.3	41.4	64.7	122.6	69.9	37.9	57.5	101.8	41.0	17.6	625.4
1972	14.7	13.2	24.5	48.8	114.1	73.2	119.8	74.1	65.6	45.6	24.4	29.2	647.2
1973	15.5	11.5	53.4	53.2	82.9	66.3	79.7	50.7	115.7	49.4	36.2	22.8	637.3
1974	10.3	11.3	22.8	56.5	101.4	73.4	56.7	91.4	16.4	32.6	22.0	13.4	508.2
1975	33.3	11.7	46.2	82.4	61.3	142.1	46.3	70.1	37.7	23.2	49.9	11.4	615.5
1976	15.6	14.6	43.7	55.2	36.4	82.6	44.9	34.3	30.6	14.8	2.6	8.8	383.9
1977	11.0	18.5	69.7	51.3	88.0	83.8	79.8	102.8	97.8	56.5	47.0	24.4	730.6
1978	8.8	14.0	11.8	70.4	90.1	92.2	112.4	88.0	70.6	13.9	29.6	17.4	619.2
1979	22.1	19.6	57.6	54.0	67.7	86.1	98.2	97.1	28.4	59.0	27.7	7.2	624.9
1980	19.4	13.2	18.8	20.3	43.3	81.4	50.4	137.8	52.5	43.4	8.5	8.6	497.5
1981	3.5	19.1	25.0	43.2	53.6	112.1	100.8	100.9	43.0	55.3	25.5	18.8	600.7
1982	29.9	7.0	39.1	37.5	127.7	66.3	97.7	63.1	56.7	102.5	40.1	34.0	701.5
1983	13.1	11.5	56.2	37.1	78.6	118.7	82.3	60.7	60.2	45.8	56.7	17.4	638.3
1984	10.3	20.0	30.6	93.9	59.3	146.9	54.3	49.8	37.8	103.8	21.4	26.9	655.1
1985	9.8	9.2	44.8	59.2	90.6	74.2	56.6	100.8	88.3	44.6	37.7	18.6	636.4
1986	10.1	17.2	29.2	110.5	86.5	96.4	104.6	75.2	125.1	38.9	27.8	5.7	730.1
1987	7.9	15.7	60.3	17.8	83.5	50.3	125.6	85.8	49.6	13.6	26.5	21.2	557.1
1988	18.9	6.5	21.7	31.4	56.8	42.7	47.6	85.1	80.7	11.2	36.1	18.9	457.7
1989	19.3	10.4	29.7	50.2	54.7	71.6	62.5	75.6	60.4	24.8	16.6	7.9	484.3
1990	9.1	9.6	51.7	48.3	74.8	141.7	85.5	74.9	34.1	39.1	13.3	20.3	604.5
1991	8.7	13.2	42.2	91.8	121.3	107.4	68.1	58.8	81.8	41.8	52.1	14.9	709.1
1992	17.1	17.0	36.4	45.0	42.4	89.6	120.8	79.6	63.9				

CITE AS: Karl, T.R., D.R. Easterling, and P.Ya. Groisman. 1994. United States historical climatology network—National and regional estimates of monthly and annual precipitation. pp. 830–905. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Precipitation

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

SOUTHERN PLAINS

Trends

The annual precipitation time series for the Southern Plains region shows no obvious long-term trends. Notable features of the series include the dry years of the mid- to late-1930s, and especially the early to mid-1950s, which led to extreme drought conditions over the central United States (Karl and Knight 1985). There is some indication of a generally increasing trend over approximately the past 30 years of the record.

Area-average annual precipitation amount for the Southern Plains region of the United States.

CITE AS: Karl, T.R., D.R. Easterling, and P.Ya. Groisman. 1994. United States historical climatology network—National and regional estimates of monthly and annual precipitation. pp. 830–905. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

SOUTHERN PLAINS

Area-Average Annual Precipitation Amount

Year	Precipitation (mm)												
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1900	17.4	63.8	28.5	112.1	90.1	109.0	107.1	83.9	126.7	86.9	34.7	14.9	876.9
1901	19.4	30.8	70.6	77.7	51.6	56.9	58.7	64.1	81.4	50.3	28.2	37.0	626.8
1902	28.2	25.2	68.1	46.8	153.5	166.7	131.3	120.4	116.3	70.1	77.2	53.6	1062.6
1903	18.3	71.1	61.6	66.2	226.5	62.4	87.0	125.1	74.8	76.9	25.7	22.2	922.5
1904	42.3	12.2	52.7	98.8	124.7	157.0	132.6	97.6	74.8	36.1	5.8	25.2	859.9
1905	39.2	35.3	71.2	88.4	154.0	99.2	164.6	87.3	137.7	81.9	56.6	26.8	1042.3
1906	45.5	36.0	73.6	84.0	69.2	113.1	106.1	124.6	104.4	46.1	52.2	39.5	894.3
1907	74.0	24.4	41.4	65.8	113.0	137.9	95.6	83.3	60.9	79.0	38.3	38.9	852.5
1908	23.7	75.1	47.3	97.0	176.8	183.2	90.4	101.2	55.3	94.2	81.1	8.2	1033.5
1909	25.4	43.7	53.4	62.1	116.6	126.3	118.2	20.9	95.4	59.5	125.4	60.6	907.4
1910	32.2	27.3	11.6	54.9	135.2	66.3	76.8	106.9	91.2	40.4	5.7	22.8	671.3
1911	11.1	83.5	23.8	91.4	57.8	31.2	114.7	115.9	117.5	57.0	39.1	70.3	813.2
1912	15.1	53.6	101.9	105.6	74.4	109.5	60.0	94.2	68.7	84.4	25.5	13.0	805.9
1913	50.2	50.3	66.0	71.6	102.0	66.6	53.8	20.8	115.5	77.8	58.3	90.2	823.1
1914	17.7	40.2	56.6	61.1	74.6	82.1	67.2	107.9	109.6	68.9	12.0	47.2	745.1
1915	43.1	80.4	53.9	89.9	184.1	178.1	137.1	154.5	125.4	54.0	41.5	36.7	1178.9
1916	122.9	14.3	45.4	78.8	104.6	142.5	29.2	71.3	65.3	52.6	50.0	27.8	804.7
1917	21.8	9.3	38.4	113.3	100.4	88.4	58.1	112.7	81.6	18.0	29.7	11.7	683.4
1918	36.0	20.4	31.8	98.7	120.5	70.3	54.6	69.7	87.9	104.2	72.8	73.9	840.7
1919	12.1	53.5	47.8	96.0	110.0	135.9	52.5	71.9	81.7	139.1	79.8	15.0	895.3
1920	33.7	12.3	79.9	93.0	115.6	73.0	94.0	105.8	94.9	98.1	35.6	41.3	877.2
1921	35.8	24.0	73.1	113.4	71.0	135.0	79.3	102.4	113.0	30.3	32.3	27.0	836.6
1922	25.5	33.5	110.4	135.7	103.1	50.1	125.3	45.6	52.7	37.1	88.1	23.5	830.4
1923	39.0	25.6	69.9	84.0	150.0	141.2	63.0	72.3	140.4	116.1	45.0	53.2	999.8
1924	26.2	31.1	66.4	66.1	81.0	116.0	117.4	79.7	90.0	26.4	34.2	64.6	799.3
1925	21.7	28.9	33.2	97.8	53.0	113.1	84.6	78.5	121.5	78.7	49.5	20.7	781.1
1926	43.7	25.2	53.9	41.4	69.7	91.1	80.1	108.9	181.9	95.2	52.4	48.5	891.9
1927	44.9	32.0	104.4	175.5	89.5	140.1	99.4	136.6	79.7	73.0	41.6	41.8	1058.6
1928	15.1	49.1	38.6	96.1	86.1	198.4	103.4	95.4	42.5	94.7	105.9	43.0	968.4
1929	52.0	38.1	48.7	124.3	154.0	120.6	92.6	39.8	71.9	118.2	38.4	21.0	919.4
1930	64.5	28.4	20.7	79.4	135.8	105.5	35.9	75.1	84.4	85.8	70.2	27.3	813.0
1931	12.7	48.4	71.6	71.1	96.4	68.4	85.4	101.0	72.5	79.5	131.5	40.4	878.7
1932	79.8	36.8	34.5	58.4	63.5	144.8	90.6	91.8	52.2	55.3	25.0	82.4	815.0
1933	32.8	22.6	68.3	81.0	133.2	29.2	79.1	118.9	101.9	46.0	24.0	45.5	782.5
1934	25.2	30.0	40.8	50.1	58.2	66.7	27.5	55.5	145.3	43.0	110.8	24.0	677.2
1935	36.3	28.1	79.8	58.5	214.7	186.0	38.0	70.7	88.7	82.8	75.6	27.2	986.3
1936	20.8	19.5	17.6	41.1	97.6	38.2	32.1	24.9	162.8	68.5	18.4	46.4	587.9
1937	80.9	22.7	50.5	60.4	85.2	100.4	86.7	62.7	62.4	57.0	35.5	32.6	737.0
1938	46.7	69.5	87.2	82.0	167.8	107.3	74.9	67.0	60.3	17.2	64.6	19.8	864.5
1939	45.1	51.6	54.7	82.5	90.4	131.8	48.4	91.7	13.8	34.0	38.6	28.4	710.9
1940	25.4	37.2	39.8	102.4	77.3	96.2	61.8	122.4	45.0	40.6	86.6	45.3	780.0
1941	60.2	29.5	21.5	119.9	76.0	136.8	67.6	88.6	146.4	216.4	37.9	42.2	1043.0
1942	23.8	42.9	43.6	127.0	93.9	167.1	52.6	105.8	133.0	63.9	53.4	64.8	968.9
1943	5.8	18.0	47.9	64.7	199.8	135.3	59.1	47.0	68.1	62.1	11.1	47.6	764.0
1944	29.4	59.1	86.2	162.0	107.2	97.1	92.6	135.7	55.8	51.9	63.4	52.8	992.6
1945	22.9	63.1	114.6	155.6	117.3	166.2	86.2	59.5	185.1	33.0	18.0	26.4	1040.9
1946	57.4	41.2	67.5	64.8	132.7	83.5	51.5	87.2	79.3	82.1	114.3	42.9	899.6

Precipitation

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

SOUTHERN PLAINS

Area-Average Annual Precipitation Amount (continued)

Year	Precipitation (mm)												Ann
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	
1947	20.4	7.5	55.2	150.3	122.3	162.7	49.6	45.1	65.9	54.1	47.7	52.0	832.8
1948	27.4	52.3	84.0	40.8	95.1	173.4	127.1	77.4	41.8	38.4	62.0	35.0	845.1
1949	113.9	46.0	71.1	52.7	149.9	151.0	93.7	71.4	94.0	92.1	6.7	46.5	982.5
1950	54.3	44.9	29.2	56.3	150.3	87.5	185.4	140.1	56.9	30.1	16.9	5.5	857.4
1951	34.8	77.0	57.8	74.6	122.8	218.6	132.7	106.0	125.2	78.6	55.9	19.9	1104.0
1952	24.0	38.0	77.2	96.3	88.2	47.6	78.5	105.3	23.9	4.3	72.6	34.9	690.8
1953	18.9	31.4	84.0	94.4	80.3	56.5	87.1	43.5	39.3	53.4	48.2	37.1	674.2
1954	24.9	29.5	29.7	82.2	121.2	70.9	27.5	118.4	46.4	107.6	7.7	47.6	713.6
1955	28.2	53.1	45.3	56.1	132.8	103.3	51.0	58.9	93.3	54.6	8.7	9.7	695.0
1956	24.0	39.8	16.3	52.8	78.4	76.5	92.0	56.0	18.9	39.7	43.4	34.7	572.4
1957	34.2	37.7	80.2	147.0	191.0	171.1	64.8	69.1	98.5	72.8	69.3	40.1	1075.8
1958	31.7	36.0	85.3	68.2	91.8	124.9	212.6	73.1	105.7	17.5	54.1	14.7	915.5
1959	25.2	31.1	72.7	60.8	136.1	70.1	119.7	74.4	107.2	130.2	23.7	49.8	900.9
1960	47.2	51.6	42.6	71.8	129.6	104.7	103.6	90.1	52.4	86.3	24.0	53.0	856.9
1961	6.6	38.0	97.7	64.3	173.1	91.6	129.8	79.7	164.5	68.3	87.0	43.5	1044.1
1962	37.1	40.2	54.3	41.7	79.9	124.2	111.9	61.4	131.0	79.6	31.8	24.1	817.1
1963	16.4	5.9	71.3	46.6	86.2	86.0	90.7	72.0	73.8	22.2	38.1	18.2	627.5
1964	13.5	33.0	68.9	108.3	94.0	125.8	51.6	118.1	86.1	15.0	85.8	25.2	825.2
1965	46.1	39.9	49.1	81.2	111.2	163.4	96.0	96.2	172.1	32.8	14.7	47.3	950.0
1966	25.2	49.5	22.1	83.2	58.4	86.0	85.5	105.5	62.6	30.8	19.7	36.1	664.5
1967	26.5	13.5	32.8	108.6	116.9	189.6	93.3	43.0	105.9	109.5	21.1	50.1	910.8
1968	31.6	20.0	53.3	84.1	123.0	83.5	106.3	109.4	79.4	78.2	89.2	57.5	915.4
1969	48.0	42.5	53.6	94.1	113.8	131.9	102.4	77.9	76.0	128.0	12.3	44.4	925.0
1970	8.7	17.6	55.6	109.3	88.7	111.3	40.3	84.4	177.7	93.8	25.2	28.1	840.9
1971	34.9	52.1	19.3	50.5	104.2	85.6	115.7	46.9	84.2	92.7	58.3	86.8	831.1
1972	13.2	13.7	31.0	82.5	100.6	65.1	102.6	85.3	94.3	94.7	109.4	42.6	835.1
1973	64.3	34.5	192.8	120.7	119.2	86.7	121.0	42.9	209.6	107.6	85.3	69.6	1254.3
1974	32.6	32.5	64.6	82.6	111.0	94.7	33.2	129.1	88.6	90.3	79.0	43.2	881.4
1975	48.9	54.4	77.9	70.0	121.0	131.7	53.7	94.5	72.7	23.7	76.4	37.3	862.0
1976	11.7	23.3	73.8	115.3	95.0	71.6	74.4	40.5	70.8	68.8	10.1	12.0	667.1
1977	26.8	22.9	90.9	67.6	135.9	104.5	66.8	150.9	124.6	62.9	56.0	21.9	931.9
1978	25.0	41.8	58.0	91.4	134.5	86.5	87.2	74.6	68.1	24.1	91.9	34.2	817.3
1979	55.8	30.9	99.6	83.0	110.3	112.2	117.4	73.7	34.6	84.9	65.9	27.9	896.3
1980	34.0	29.4	88.8	58.7	82.5	78.5	37.8	93.6	65.5	65.1	22.0	40.2	696.1
1981	7.2	32.3	58.8	63.3	159.5	131.1	129.0	92.8	57.1	109.5	76.8	22.7	940.0
1982	60.3	25.1	57.2	58.1	202.0	120.6	86.3	107.2	46.8	53.0	69.7	102.3	988.6
1983	21.1	35.7	81.5	112.2	129.8	113.9	27.0	42.2	66.0	104.7	101.4	40.2	875.7
1984	14.1	47.3	110.0	122.0	104.3	109.4	57.9	41.3	64.1	149.2	61.3	96.6	977.4
1985	39.6	67.9	85.5	90.5	111.8	126.7	74.9	111.3	109.0	110.8	97.6	35.8	1061.5
1986	1.2	40.2	39.5	100.8	120.3	109.2	88.9	98.0	199.5	143.5	52.7	35.0	1029.9
1987	30.6	65.2	110.9	40.9	143.1	98.9	85.3	119.7	73.4	41.9	86.4	89.8	989.8
1988	26.8	24.7	68.1	75.2	59.9	45.3	92.2	63.4	96.9	31.9	79.2	34.7	703.7
1989	38.4	51.8	60.5	19.8	108.7	139.8	102.1	115.9	105.5	46.1	5.3	15.3	824.4
1990	59.0	68.3	123.3	88.3	180.4	97.2	90.6	77.0	65.3	60.0	61.1	56.4	1046.0
1991	36.9	9.9	55.6	105.2	121.9	75.6	70.1	57.3	78.8	83.0	87.2	77.5	864.9
1992	31.5	37.1	66.2	62.7	66.4	128.0	180.2	77.1	99.8				

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United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

SOUTH COASTAL PLAIN

Trends

The annual precipitation time series for the South Coastal Plain region shows evidence of a generally increasing trend over the entire period of record. The most notable departure from this trend is the period of several dry years in the 1950s, when severe to extreme drought conditions were experienced across much of the southcentral and southeastern United States (Karl and Knight 1985).

Area-average annual precipitation amount for the South Coastal Plain region of the United States.

CITE AS: Karl, T.R., D.R. Easterling, and P.Ya. Groisman. 1994. United States historical climatology network—National and regional estimates of monthly and annual precipitation. pp. 830–905. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Precipitation

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

SOUTH COASTAL PLAIN

Area-Average Annual Precipitation Amount

Year	Precipitation (mm)												Ann
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	
1900	65.1	153.2	115.5	216.5	81.2	203.3	137.7	75.1	95.7	110.9	74.0	105.9	1437.7
1901	89.7	106.2	112.0	97.6	107.9	76.4	91.0	151.6	89.7	40.3	47.6	130.0	1141.0
1902	63.8	108.2	191.4	64.0	84.9	70.0	136.9	78.2	111.0	78.3	129.7	115.8	1226.2
1903	86.2	226.8	151.0	41.0	122.2	111.8	135.2	119.0	65.3	44.8	22.4	62.6	1191.8
1904	78.6	67.5	89.8	67.2	69.1	106.0	117.8	127.8	44.7	22.4	55.1	95.8	942.6
1905	106.2	156.6	118.6	166.7	141.3	119.5	136.1	122.5	63.6	87.1	69.3	145.6	1416.6
1906	95.8	54.8	167.5	51.5	113.1	104.6	185.9	109.4	145.5	85.0	66.3	99.3	1286.5
1907	47.3	86.8	57.0	136.5	204.1	82.2	119.5	87.0	87.6	61.5	140.0	116.8	1220.7
1908	87.2	148.5	98.8	153.2	156.2	88.1	125.8	121.9	74.3	34.9	45.4	82.9	1223.1
1909	37.2	133.9	145.8	113.1	162.8	155.8	98.8	92.9	59.7	43.4	42.5	112.3	1203.0
1910	74.2	103.5	31.5	94.9	101.6	158.7	138.0	78.9	52.6	70.4	47.6	82.7	1027.8
1911	71.6	76.6	59.3	162.4	54.2	88.4	160.9	149.6	56.8	59.4	92.3	221.7	1250.9
1912	110.6	94.6	210.7	193.2	96.7	151.9	116.1	149.4	69.0	53.7	37.3	163.4	1446.0
1913	129.8	115.7	163.2	90.5	85.6	86.3	116.9	60.4	173.6	78.2	57.9	94.4	1250.4
1914	36.8	98.3	124.9	106.3	62.5	70.3	90.0	214.3	76.4	56.9	100.9	120.1	1162.3
1915	132.4	122.3	69.2	56.2	135.1	110.3	105.7	152.9	70.7	97.5	77.5	116.0	1238.8
1916	116.1	61.6	57.3	82.5	128.8	98.0	279.7	75.7	47.7	48.2	46.2	84.7	1125.6
1917	126.1	104.0	145.6	103.1	54.3	61.6	127.2	126.6	95.1	24.8	38.4	42.1	1043.8
1918	126.5	45.0	30.5	171.1	48.4	105.4	84.2	95.2	78.9	154.8	135.9	126.5	1207.4
1919	121.4	137.3	125.1	90.3	160.9	130.8	158.5	158.5	45.0	158.4	131.9	121.1	1532.2
1920	144.5	75.6	144.2	167.1	139.1	90.0	148.1	157.6	71.5	51.7	81.5	163.3	1438.3
1921	72.0	90.1	128.1	179.8	60.4	100.6	133.5	76.2	61.6	34.3	61.9	78.3	1071.5
1922	126.2	134.6	223.6	134.7	151.1	107.2	111.1	82.1	35.3	55.0	76.5	122.8	1360.9
1923	98.9	141.5	155.8	165.5	172.0	144.0	113.3	125.0	64.8	76.6	96.5	156.6	1511.8
1924	130.6	91.6	99.4	118.5	108.8	80.5	65.5	52.0	119.2	10.8	17.5	139.3	1033.4
1925	223.1	65.3	53.3	40.1	78.0	65.7	102.9	42.4	78.0	147.9	122.6	68.6	1081.8
1926	163.8	77.5	189.0	88.3	92.1	106.7	138.7	140.1	65.5	77.2	84.9	144.9	1364.2
1927	44.0	134.0	137.8	107.6	81.4	145.8	119.3	90.8	50.2	64.4	70.3	168.0	1208.1
1928	31.2	99.4	122.7	208.2	104.8	226.7	136.9	131.1	67.2	65.2	66.3	74.4	1333.1
1929	126.7	160.4	197.1	98.6	148.2	88.2	100.5	48.9	113.6	111.8	176.6	88.5	1467.1
1930	124.0	62.9	103.0	44.0	176.9	44.0	84.9	77.9	121.1	90.4	142.3	80.2	1146.5
1931	84.5	85.1	92.7	57.6	98.2	57.2	148.3	101.4	25.7	53.3	84.0	212.1	1094.4
1932	209.5	126.4	96.1	68.0	101.7	114.5	120.0	110.9	119.5	110.6	84.6	202.9	1470.5
1933	74.5	137.1	119.6	150.1	106.6	45.9	179.2	101.8	60.2	34.0	29.2	85.0	1116.8
1934	84.0	111.8	145.8	91.1	96.1	113.7	110.1	90.7	70.6	72.1	138.4	88.8	1211.8
1935	89.6	91.1	146.4	121.3	158.1	114.4	103.3	96.8	88.4	52.5	88.7	97.6	1250.3
1936	159.1	118.4	63.6	121.4	86.2	43.5	132.1	100.4	91.1	67.0	52.7	147.2	1186.6
1937	202.6	92.1	105.4	123.2	84.7	105.3	102.9	120.0	70.7	138.9	90.8	89.8	1327.5
1938	98.8	68.7	119.9	203.9	81.3	120.7	149.0	82.9	45.3	18.6	81.5	82.0	1154.9
1939	129.7	200.8	111.4	84.4	121.4	146.5	110.2	141.5	62.3	27.3	49.3	91.5	1282.9
1940	81.6	138.2	90.6	145.5	81.0	156.5	209.7	118.2	43.8	32.0	150.6	162.6	1408.4
1941	60.7	81.2	114.9	91.3	63.8	139.7	168.7	119.1	66.1	117.3	62.0	142.1	1225.3
1942	79.8	92.0	150.4	114.9	104.3	135.4	87.8	138.0	106.0	71.1	40.5	147.0	1266.8
1943	80.4	42.9	191.1	80.3	110.7	91.9	90.5	53.2	104.1	35.1	66.2	100.1	1050.3
1944	112.7	158.2	210.7	160.7	138.0	55.7	87.0	130.0	79.6	28.2	109.8	116.0	1381.3
1945	89.0	161.0	148.5	152.2	83.6	127.6	161.2	88.2	92.9	111.4	61.8	135.9	1414.8
1946	181.4	138.9	148.9	74.1	194.1	111.2	150.7	103.3	80.8	51.6	142.8	58.6	1433.0

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

SOUTH COASTAL PLAIN

Area-Average Annual Precipitation Amount (continued)

Year	Precipitation (mm)												Ann
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	
1947	197.5	37.5	162.4	167.4	130.2	109.8	58.7	90.1	72.1	51.5	176.3	123.8	1382.9
1948	109.5	126.4	194.9	99.2	93.9	78.0	108.1	92.5	80.9	45.9	261.0	102.1	1391.8
1949	167.0	131.5	147.8	121.5	101.7	121.8	150.2	104.8	71.2	123.2	11.3	82.3	1336.3
1950	131.2	128.1	146.1	92.2	136.6	98.1	169.0	97.2	94.1	52.0	40.8	91.3	1273.2
1951	112.5	83.8	171.6	88.8	40.3	127.5	109.8	56.7	115.6	35.6	69.4	145.1	1153.0
1952	76.0	104.2	121.7	104.1	138.9	37.2	67.3	83.5	52.3	12.7	102.8	116.9	1019.8
1953	99.0	152.0	121.7	173.9	223.5	74.2	147.4	83.5	64.7	36.6	59.3	192.1	1431.7
1954	91.6	51.3	69.3	83.2	120.5	42.6	79.5	50.8	32.7	68.3	68.6	83.0	841.2
1955	103.2	129.2	72.9	169.8	126.3	75.7	156.1	79.8	52.1	45.2	68.2	53.5	1132.6
1956	60.1	178.6	130.7	101.6	76.7	89.3	90.0	70.0	65.3	70.4	61.4	116.3	1112.8
1957	90.0	87.8	122.7	191.1	146.5	153.3	91.2	55.4	180.9	98.1	203.6	81.4	1498.9
1958	90.1	93.8	129.5	156.8	103.7	133.4	165.7	90.0	130.7	47.1	71.8	50.3	1260.5
1959	90.6	123.3	112.6	99.7	127.9	120.8	138.4	84.2	93.7	157.3	55.8	101.1	1308.8
1960	131.9	112.5	128.1	72.4	84.2	83.8	98.0	136.8	80.7	89.8	43.3	101.6	1163.3
1961	101.8	217.3	215.2	95.4	82.0	162.1	131.0	97.9	80.5	36.5	145.5	231.5	1596.8
1962	151.3	81.9	98.2	149.8	47.8	140.7	85.8	64.9	93.3	88.2	93.3	62.9	1158.1
1963	119.3	68.5	81.9	82.2	75.1	114.4	143.7	67.8	67.3	4.8	99.3	105.9	1030.2
1964	137.7	97.5	169.9	201.2	73.0	68.3	127.9	112.6	112.1	97.3	94.6	121.1	1413.2
1965	87.5	158.4	137.7	47.0	72.3	108.8	113.5	85.3	127.2	47.9	54.8	87.2	1127.8
1966	144.6	199.4	65.3	169.9	114.1	63.6	89.9	136.6	100.8	85.4	59.5	100.5	1329.6
1967	72.5	92.7	54.2	84.0	168.0	80.7	140.1	113.2	74.9	75.4	59.3	193.9	1208.9
1968	134.6	59.2	93.8	127.4	134.6	80.2	115.2	93.4	90.9	41.2	119.7	158.4	1248.5
1969	59.8	101.0	132.3	129.0	125.3	60.3	106.1	100.0	84.2	78.6	58.1	151.9	1186.5
1970	59.8	94.8	147.9	97.7	100.4	91.3	102.6	125.5	79.3	161.8	44.2	90.8	1196.3
1971	62.9	138.2	153.7	77.0	124.3	79.5	172.6	108.9	119.8	58.9	65.6	210.6	1372.0
1972	179.8	66.9	114.3	57.7	94.7	99.6	103.7	60.1	80.6	106.7	120.0	165.6	1249.8
1973	143.4	104.9	224.4	188.1	125.6	116.7	132.5	83.1	122.6	91.3	127.5	139.0	1599.1
1974	203.7	113.6	81.5	152.7	108.8	127.3	93.8	159.2	165.3	64.5	103.8	138.5	1512.8
1975	142.4	146.4	158.9	143.5	179.3	131.8	146.0	126.1	85.1	102.2	76.0	85.7	1523.5
1976	88.1	60.1	205.3	54.8	175.5	103.9	106.8	58.1	87.5	101.5	92.4	109.2	1243.3
1977	117.7	75.8	189.6	132.7	51.4	61.7	121.9	103.0	115.9	69.8	145.9	74.7	1260.1
1978	146.4	62.6	79.6	74.7	170.8	92.4	77.9	132.1	48.3	16.6	95.7	113.0	1110.0
1979	213.5	166.7	124.5	243.7	134.4	62.0	173.8	94.6	154.5	52.6	116.0	90.4	1626.7
1980	129.3	67.1	260.8	157.7	148.3	74.5	72.6	41.2	113.6	95.2	81.8	41.0	1283.1
1981	34.7	109.3	126.7	60.9	119.0	116.9	99.6	86.1	64.8	123.1	42.2	111.0	1094.3
1982	117.4	138.4	74.6	147.6	92.4	142.1	114.0	106.6	51.8	85.3	144.4	256.1	1470.6
1983	98.4	172.5	154.4	189.2	179.5	149.7	52.6	85.6	92.5	58.2	157.3	180.7	1570.8
1984	82.1	126.3	127.2	101.4	119.0	82.8	122.9	123.9	35.5	190.3	100.9	67.7	1280.1
1985	82.9	142.8	84.2	79.7	77.3	87.8	124.7	106.2	90.5	194.6	90.8	88.0	1249.5
1986	38.4	84.4	76.9	57.2	132.7	113.0	74.6	94.7	86.0	116.4	210.0	116.0	1200.4
1987	139.7	187.5	120.2	23.0	128.2	129.5	75.0	90.2	62.1	19.0	136.7	114.6	1225.2
1988	89.1	103.3	119.2	94.5	43.4	51.7	140.4	95.9	142.8	99.4	120.4	96.7	1196.6
1989	115.4	110.5	141.4	79.6	179.6	251.0	176.8	65.9	98.1	50.9	94.4	112.1	1478.0
1990	216.7	170.2	160.4	107.4	149.5	79.7	77.5	64.0	57.9	94.0	86.6	139.0	1400.6
1991	178.8	124.2	145.5	239.6	204.4	115.5	103.0	119.6	88.0	79.2	79.1	145.9	1625.9
1992	141.6	137.5	110.7	72.7	72.5	159.3	136.7	137.1	87.9				

CITE AS: Karl, T.R., D.R. Easterling, and P.Ya. Groisman. 1994. United States historical climatology network—National and regional estimates of monthly and annual precipitation. pp. 830–905. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Precipitation

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

GULF COAST

Trends

The annual precipitation time series for the Gulf Coast region shows no long-term trends but, following the dry period of the 1950s, shows some evidence of increasing precipitation over the remainder of the record. Six of the first seven years of the 1950s had precipitation amounts below the long-term mean. This period is associated with the severe to extreme drought conditions experienced throughout much of the southcentral and southeastern United States during the mid-1950s (Karl and Knight 1985).

Area-average annual precipitation amount for the Gulf Coast region of the United States.

CITE AS: Karl, T.R., D.R. Easterling, and P.Ya. Groisman. 1994. United States historical climatology network—National and regional estimates of monthly and annual precipitation. pp. 830–905. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

GULF COAST

Area-Average Annual Precipitation Amount

Year	Precipitation (mm)												
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1900	114.6	126.5	147.7	212.3	116.9	194.7	223.1	168.7	79.1	86.5	40.9	124.6	1635.7
1901	64.3	94.3	83.7	124.7	63.7	87.5	188.6	131.5	74.8	34.0	41.5	97.0	1085.7
1902	36.5	81.9	101.6	73.8	80.6	60.6	101.3	73.6	127.2	55.8	94.4	119.2	1006.5
1903	120.0	193.6	173.6	26.1	73.8	146.4	239.0	124.0	67.6	44.5	33.7	73.4	1315.7
1904	62.8	54.6	63.8	55.2	90.3	103.3	181.6	130.1	90.2	32.0	34.9	79.5	978.2
1905	99.4	141.9	156.5	172.4	146.4	182.0	169.8	115.6	105.1	103.5	83.3	144.6	1620.5
1906	63.0	64.5	123.2	53.5	51.5	66.5	194.9	113.5	146.8	53.7	31.0	63.6	1025.6
1907	38.5	75.6	32.4	165.8	281.4	56.0	126.1	115.0	101.8	83.5	119.2	135.0	1330.3
1908	75.8	92.6	53.3	109.5	140.6	104.6	247.9	140.6	147.2	33.2	35.2	53.2	1233.8
1909	37.0	67.2	79.4	104.9	125.1	171.8	143.2	163.0	83.8	53.1	37.7	119.5	1185.7
1910	47.0	85.0	44.6	51.8	102.0	123.5	150.9	86.3	75.1	68.2	47.4	79.6	961.4
1911	44.2	34.2	87.8	165.9	81.9	93.4	169.8	159.3	66.5	84.7	70.0	164.7	1222.5
1912	74.8	103.7	138.6	164.7	131.7	181.7	140.7	100.6	88.4	71.6	53.7	174.7	1424.8
1913	90.0	84.3	120.4	82.4	88.8	120.6	133.7	112.6	220.3	132.6	67.7	89.4	1342.8
1914	29.8	106.5	99.9	114.7	127.9	54.1	128.1	193.2	89.2	90.7	97.1	89.4	1220.6
1915	131.1	96.6	67.8	67.6	113.2	56.2	103.9	139.9	114.0	99.4	30.2	65.2	1085.0
1916	95.6	36.1	21.9	74.0	140.9	85.3	244.7	149.8	66.4	72.7	32.7	104.5	1124.5
1917	87.8	61.8	63.8	60.7	60.9	31.9	125.9	110.6	71.2	15.8	18.8	38.9	747.9
1918	68.5	46.6	44.9	161.4	70.5	110.0	90.1	136.0	68.7	171.6	104.2	154.7	1227.1
1919	130.8	128.3	103.5	127.3	183.2	196.2	228.1	125.1	97.2	166.5	85.5	56.7	1628.3
1920	130.8	69.3	43.3	101.9	108.0	126.0	130.2	161.1	92.4	58.5	65.1	125.2	1211.6
1921	51.9	40.0	106.0	100.0	72.1	132.4	135.9	89.3	95.3	46.0	54.5	70.0	993.4
1922	95.7	71.2	162.6	87.8	180.1	137.2	116.2	121.5	94.0	84.3	58.6	118.8	1327.9
1923	57.4	107.8	110.0	88.1	138.1	138.1	168.2	152.1	94.8	89.9	109.9	125.6	1380.0
1924	117.9	101.4	62.5	80.1	122.8	128.2	55.8	45.3	96.2	11.6	9.2	109.6	940.6
1925	103.0	45.4	31.2	26.2	74.3	112.2	102.9	71.3	103.0	147.9	67.6	81.0	966.0
1926	144.4	55.9	224.6	150.4	120.8	103.7	118.7	204.7	89.7	92.7	62.5	67.0	1435.1
1927	22.8	109.0	119.8	80.0	65.1	186.8	97.1	94.3	59.0	72.0	48.1	115.0	1069.1
1928	22.4	128.9	93.4	134.3	97.3	215.7	123.4	134.8	145.7	49.7	61.7	100.0	1307.4
1929	121.0	104.6	129.9	76.5	185.9	132.3	174.3	85.3	105.9	84.0	148.1	76.2	1424.0
1930	117.1	55.2	101.8	55.7	94.4	70.7	110.9	97.4	140.2	103.3	126.7	59.6	1133.0
1931	116.2	82.5	97.8	49.8	84.2	98.3	184.1	119.3	35.3	51.6	44.0	159.8	1123.0
1932	146.1	67.6	62.3	94.1	150.6	86.2	111.6	180.3	164.6	97.5	61.7	94.2	1316.8
1933	60.4	116.8	108.7	142.0	85.9	64.1	168.7	103.6	57.8	38.9	36.6	54.7	1038.2
1934	135.3	86.7	97.9	97.9	90.2	103.9	149.8	126.9	75.4	62.2	118.9	69.9	1214.9
1935	48.1	95.7	110.0	129.1	179.5	129.1	133.0	124.9	150.2	28.5	36.5	131.0	1295.5
1936	133.9	78.2	53.1	105.2	172.6	64.9	199.8	126.8	98.6	50.9	51.0	76.0	1211.0
1937	87.6	43.8	119.4	103.6	92.7	130.0	92.0	121.6	77.3	148.4	48.5	106.0	1171.1
1938	84.5	53.3	49.9	121.5	76.8	108.3	135.5	103.4	71.0	28.8	45.9	78.7	957.4
1939	61.7	83.0	33.8	65.9	159.7	127.2	156.0	144.7	85.5	24.7	51.3	56.2	1049.7
1940	46.8	136.9	82.9	138.4	54.5	255.3	168.6	148.1	61.9	44.2	108.8	170.6	1417.0
1941	63.6	76.9	117.3	106.5	137.1	169.6	165.5	95.5	122.5	91.6	39.4	85.6	1271.1
1942	63.5	141.5	107.9	89.2	95.3	194.2	200.7	170.0	147.8	83.5	25.3	89.6	1408.4
1943	67.9	38.4	169.2	43.5	108.5	109.8	126.2	69.9	195.9	20.6	65.2	97.3	1112.3
1944	132.7	68.3	149.3	106.7	158.3	72.9	113.1	192.8	125.3	22.3	128.1	76.6	1346.3
1945	92.0	99.7	92.1	128.8	72.1	112.2	151.5	177.1	96.3	77.5	32.6	114.2	1246.1
1946	125.5	75.2	200.0	98.0	229.5	179.8	152.5	125.2	165.7	46.7	93.0	60.4	1551.5

Precipitation

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

GULF COAST

Area-Average Annual Precipitation Amount (continued)

Year	Precipitation (mm)												Ann
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	
1947	133.6	34.4	197.2	150.7	152.5	84.7	48.5	136.8	98.6	41.7	173.2	129.4	1381.1
1948	85.3	63.4	197.1	74.7	73.1	65.3	130.5	118.8	176.2	41.7	160.1	83.4	1269.7
1949	66.4	98.3	148.2	206.1	60.9	145.5	205.3	105.7	101.7	148.6	10.6	92.5	1389.7
1950	52.2	77.1	93.7	135.6	93.6	128.3	136.7	94.5	59.8	23.7	21.5	88.3	1004.9
1951	65.3	49.7	156.1	80.1	82.8	126.2	110.6	63.5	180.3	27.0	65.2	63.6	1070.6
1952	36.2	130.7	76.7	115.7	141.6	61.5	120.9	80.8	117.8	0.9	86.7	107.1	1076.5
1953	52.3	112.8	80.9	137.7	107.4	133.3	123.9	185.1	70.1	48.2	104.4	194.6	1350.5
1954	53.4	24.4	41.7	77.7	95.0	82.7	168.2	42.6	78.5	80.5	36.1	64.5	845.3
1955	88.5	98.1	13.5	106.0	111.5	80.1	150.9	135.2	92.3	40.8	51.9	56.2	1024.9
1956	57.4	103.1	76.2	61.4	91.0	113.9	102.2	96.6	130.2	53.6	35.1	98.1	1018.7
1957	23.9	72.6	138.4	185.9	123.4	158.4	86.4	98.6	258.1	82.0	123.5	58.6	1409.7
1958	142.1	105.6	119.8	89.7	129.9	124.0	167.2	101.2	179.0	76.7	35.1	50.1	1320.4
1959	66.1	156.6	72.4	106.3	204.3	129.7	170.1	131.2	109.8	171.9	41.2	62.9	1422.4
1960	70.3	95.1	69.7	114.6	62.7	131.0	118.6	198.4	80.3	144.1	43.4	114.0	1242.3
1961	95.5	169.3	113.0	78.8	81.3	211.4	130.4	123.0	152.1	29.7	146.5	138.4	1469.6
1962	84.1	34.4	62.8	110.1	31.5	170.9	51.7	79.4	107.6	59.6	49.5	79.1	920.7
1963	73.6	87.3	25.7	33.3	64.6	144.8	140.1	77.0	105.4	16.7	122.2	91.5	970.1
1964	141.2	102.6	117.0	141.0	84.7	85.4	170.3	127.5	126.4	114.2	75.7	82.9	1368.8
1965	90.2	132.2	80.5	40.0	126.2	123.1	113.4	136.0	151.0	54.5	63.8	126.7	1237.6
1966	161.0	187.4	46.1	121.1	159.5	94.4	118.8	152.9	108.2	60.3	32.9	77.5	1320.2
1967	70.4	82.6	39.1	84.4	103.4	66.6	141.1	167.3	197.3	97.5	29.7	143.8	1223.2
1968	79.7	64.1	60.9	73.6	108.1	119.8	111.6	86.5	121.5	48.9	105.2	118.6	1098.6
1969	41.7	102.0	135.5	136.0	132.2	44.2	173.7	148.2	94.0	73.2	46.5	104.9	1232.1
1970	73.8	71.7	124.3	41.9	162.1	117.8	112.9	174.0	140.7	133.5	26.5	72.2	1251.4
1971	34.5	86.7	55.1	33.3	77.5	125.3	138.1	171.2	262.0	68.6	48.3	154.6	1255.2
1972	135.5	88.0	104.8	39.6	211.5	97.3	121.3	97.7	92.0	61.1	121.1	131.8	1301.7
1973	90.7	93.6	169.8	196.8	76.4	172.5	128.3	109.5	264.8	129.8	86.1	114.0	1632.2
1974	126.6	63.3	110.5	96.0	152.3	72.9	100.5	183.2	152.9	47.1	116.9	84.9	1307.1
1975	102.8	54.3	96.6	121.9	195.1	159.7	185.6	148.5	117.3	80.8	66.6	74.2	1403.4
1976	54.3	48.1	98.9	83.0	147.3	99.7	160.8	75.4	101.6	171.4	119.9	127.4	1287.8
1977	110.8	52.7	89.7	144.6	56.9	55.9	99.0	182.8	143.6	85.9	151.4	63.7	1237.0
1978	159.9	61.1	67.2	73.9	138.4	164.6	156.2	146.6	125.4	17.6	111.9	71.0	1293.8
1979	131.3	155.0	99.5	194.0	141.7	77.3	226.6	99.5	158.8	27.1	80.3	68.0	1459.1
1980	97.3	38.1	179.9	207.3	211.9	55.0	99.1	104.9	140.3	85.0	96.1	26.1	1340.9
1981	38.2	124.3	65.8	51.8	138.0	182.1	117.7	144.6	69.6	112.2	32.6	92.8	1169.8
1982	60.1	136.4	71.1	91.0	105.3	97.9	124.1	116.5	83.2	78.9	103.3	169.4	1237.2
1983	94.0	151.3	137.7	169.3	105.6	160.6	94.5	126.4	141.7	76.8	95.5	110.0	1463.3
1984	87.7	92.6	64.5	43.4	93.3	87.6	131.0	143.7	56.9	156.6	59.8	72.4	1089.5
1985	102.3	106.0	106.4	66.4	76.2	122.3	141.2	129.6	132.0	240.7	70.3	81.0	1374.3
1986	56.8	76.2	58.3	41.5	133.7	133.3	68.7	108.2	115.5	141.8	137.1	148.3	1219.6
1987	119.1	154.6	91.8	27.7	176.9	247.5	124.7	141.8	73.2	18.5	98.5	64.0	1338.3
1988	54.3	153.9	141.9	98.1	39.7	79.0	154.8	170.8	172.7	68.1	38.2	70.8	1242.3
1989	80.2	23.8	92.7	58.7	123.2	230.5	142.0	75.5	85.3	46.6	133.4	102.3	1226.6
1990	119.6	149.4	135.7	78.1	92.1	71.6	117.2	69.7	90.3	62.5	62.8	77.4	1145.6
1991	271.4	88.7	104.0	189.7	250.5	145.6	150.8	121.5	113.1	70.0	50.4	135.6	1728.7
1992	217.4	181.0	106.3	93.9	117.3	169.2	127.8	168.5	89.8				

CITE AS: Karl, T.R., D.R. Easterling, and P.Ya. Groisman. 1994. United States historical climatology network—National and regional estimates of monthly and annual precipitation. pp. 830–905. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

GREAT LAKES

Trends

The annual precipitation time series for the Great Lakes region shows a generally decreasing trend from the beginning of the record through the 1930s, followed by a generally increasing trend through the end of the record (with a significant break of three consecutive dry years in the early 1960s). In these respects, it is essentially similar to the series for the contiguous United States presented at the beginning of this section. The longest dry period in the Great Lakes series, from 1930 through 1937, is associated with the severe to extreme drought conditions that covered much of this region, primarily in 1931 and 1934 (Karl and Knight 1985).

Area-average annual precipitation amount for the Great Lakes region of the United States.

CITE AS: Karl, T.R., D.R. Easterling, and P.Ya. Groisman. 1994. United States historical climatology network—National and regional estimates of monthly and annual precipitation. pp. 830–905. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Precipitation

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

GREAT LAKES

Area-Average Annual Precipitation Amount

Year	Precipitation (mm)												Ann
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	
1900	34.8	73.9	50.0	46.6	60.8	64.6	143.3	107.4	77.1	79.6	76.7	19.0	833.7
1901	35.1	32.1	69.7	40.4	67.9	89.3	96.0	58.8	62.6	58.2	36.8	55.7	702.8
1902	20.3	30.6	54.3	42.4	106.3	160.5	164.3	44.4	107.5	54.6	57.7	59.0	901.9
1903	30.8	53.5	59.0	89.7	80.4	70.7	127.3	132.9	91.1	61.4	36.4	39.1	872.2
1904	56.9	46.4	90.7	61.6	97.9	61.5	103.8	83.2	92.2	61.7	7.3	52.1	815.3
1905	35.2	34.6	48.2	65.6	129.1	142.9	100.8	99.8	75.3	67.8	55.2	35.3	889.9
1906	52.2	26.8	58.6	46.5	74.5	91.0	81.4	100.9	81.5	77.1	73.1	60.4	823.9
1907	83.7	12.5	66.0	58.7	77.2	89.9	105.2	77.8	110.5	40.5	44.7	56.9	823.5
1908	33.7	71.2	74.0	78.9	136.9	73.5	89.2	64.3	28.9	27.9	41.4	38.7	758.5
1909	49.4	76.0	43.7	111.7	79.5	100.9	75.2	85.6	66.8	41.0	86.2	67.5	883.6
1910	54.2	43.8	6.7	81.9	77.2	30.3	59.3	70.8	94.6	57.5	44.5	37.3	658.1
1911	42.8	49.9	32.0	64.9	70.9	88.7	72.3	99.5	112.6	108.7	75.3	57.0	874.7
1912	32.2	33.9	42.0	69.6	117.8	49.3	124.4	112.4	82.4	70.0	43.2	37.0	814.1
1913	69.3	32.6	114.2	58.1	113.0	58.2	108.5	70.7	61.5	80.4	51.9	17.2	835.4
1914	45.5	28.3	48.6	75.3	101.7	120.2	58.0	97.0	70.7	56.5	30.9	48.1	780.8
1915	46.2	49.5	20.1	26.0	101.4	91.3	117.2	92.4	111.2	44.8	65.2	37.6	802.7
1916	83.4	22.3	61.3	60.2	107.1	144.0	31.6	67.7	86.9	72.6	49.4	48.1	834.6
1917	40.2	20.7	59.3	74.2	82.4	129.5	71.9	71.4	56.7	109.8	14.2	24.2	754.5
1918	50.5	42.3	40.9	60.9	122.8	65.1	57.7	67.2	77.1	69.1	53.4	65.4	772.5
1919	17.3	40.0	69.3	81.0	93.8	80.9	69.9	82.6	73.8	111.4	62.6	21.2	803.8
1920	34.6	14.1	72.8	87.4	53.1	114.3	78.6	73.8	52.8	51.5	58.7	66.4	760.2
1921	25.9	26.8	93.1	103.8	61.9	61.7	69.3	94.4	111.0	61.5	70.0	55.2	834.7
1922	28.7	53.2	80.5	94.1	97.2	86.6	90.4	54.9	76.7	42.3	53.9	41.3	799.8
1923	45.0	25.5	73.0	45.5	76.8	83.6	79.9	78.2	80.6	56.5	36.8	67.3	748.7
1924	45.8	36.1	58.5	75.6	86.2	128.9	79.2	125.8	94.9	12.6	33.1	58.0	834.6
1925	19.9	41.0	46.3	50.9	36.2	96.5	99.1	58.7	121.8	71.6	55.1	32.5	729.7
1926	31.9	55.7	49.2	59.9	73.2	99.8	83.2	112.0	170.3	89.8	69.8	39.1	933.8
1927	31.4	35.7	61.4	81.4	114.0	65.6	93.1	44.4	93.2	67.1	109.1	62.6	858.9
1928	28.0	46.7	45.4	61.7	53.9	126.9	98.2	100.1	61.0	79.0	70.1	38.7	809.8
1929	83.7	28.0	59.6	129.8	87.9	96.3	86.1	47.8	69.3	78.1	47.4	46.9	860.8
1930	69.6	42.2	44.8	59.8	66.6	95.6	51.8	40.9	68.7	52.4	37.5	17.9	647.8
1931	25.5	21.4	51.4	49.2	72.4	103.3	56.8	70.5	118.8	72.3	88.1	46.3	776.0
1932	72.9	33.5	49.2	45.4	77.6	71.3	87.6	75.2	56.3	86.0	54.8	61.5	771.4
1933	31.1	33.3	69.1	79.3	129.9	57.5	62.0	53.4	87.1	60.1	33.2	37.8	733.7
1934	25.9	14.9	47.9	49.8	28.9	74.8	53.3	73.0	118.6	41.2	95.3	37.8	661.5
1935	52.0	35.0	54.1	49.0	87.9	106.4	89.9	99.8	57.8	44.8	67.2	34.1	778.1
1936	35.1	47.1	53.8	46.3	53.0	50.9	34.5	95.1	109.9	68.2	41.1	52.9	688.0
1937	88.7	41.2	28.8	107.8	78.2	117.3	78.2	75.4	60.6	75.2	40.8	37.8	829.9
1938	45.9	68.6	82.6	66.0	99.2	106.3	91.7	104.6	116.5	24.3	54.5	38.6	898.6
1939	53.8	62.2	53.0	79.3	48.5	126.2	57.7	85.3	54.1	60.6	16.4	24.2	721.5
1940	34.5	34.6	43.1	75.9	95.2	137.1	52.0	128.6	38.6	61.4	74.1	50.8	825.8
1941	39.3	20.9	30.2	53.2	79.6	72.4	69.5	86.2	105.4	128.4	49.5	36.9	771.5
1942	28.7	39.6	77.6	49.6	114.7	101.0	103.2	84.6	110.0	59.0	73.9	61.1	902.9
1943	41.6	27.0	60.2	67.5	155.3	108.3	88.5	87.5	59.4	48.8	49.4	11.9	805.4
1944	22.0	38.9	75.0	82.5	95.1	102.1	52.6	81.1	62.8	24.1	55.5	36.4	728.2
1945	23.8	41.3	76.8	88.6	123.5	111.0	72.8	84.3	129.3	62.2	70.5	40.9	925.0
1946	39.6	37.1	56.3	24.4	97.9	123.2	40.4	61.2	69.3	68.4	63.1	48.4	729.2

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

GREAT LAKES

Area-Average Annual Precipitation Amount (continued)

Year	Precipitation (mm)												Ann
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	
1947	59.9	13.3	44.7	120.4	117.0	109.2	71.9	79.3	94.6	37.4	61.5	36.6	845.9
1948	29.2	47.0	86.7	69.6	80.7	90.0	72.3	54.2	59.4	40.0	82.8	50.7	762.7
1949	69.7	41.1	53.9	50.1	71.1	100.0	107.6	69.6	59.2	62.2	36.7	61.3	782.4
1950	105.1	61.6	65.0	106.1	55.9	105.1	105.7	65.8	84.4	48.7	69.4	50.9	923.7
1951	38.9	55.3	82.6	93.7	77.0	103.6	105.5	84.8	80.7	90.1	69.0	64.5	945.6
1952	62.2	28.0	70.9	66.1	83.8	81.3	114.9	86.5	46.9	15.9	60.2	42.8	759.6
1953	39.1	37.7	59.7	76.2	81.5	83.0	90.5	75.4	50.6	20.3	33.9	44.9	692.8
1954	35.7	43.8	71.4	112.4	59.9	106.9	75.0	83.2	77.7	141.4	39.7	41.6	888.7
1955	31.2	39.0	64.2	71.1	75.6	76.9	92.4	82.5	46.0	106.6	56.9	23.0	765.4
1956	21.6	41.3	59.3	80.5	108.7	75.9	95.5	109.7	35.2	18.6	51.6	40.9	738.8
1957	35.0	32.6	32.8	105.2	98.0	109.3	96.2	72.0	75.8	60.0	70.7	61.7	849.3
1958	30.4	16.7	15.4	62.3	50.6	118.4	119.7	86.6	81.5	47.1	70.2	16.6	715.6
1959	57.5	54.5	62.9	89.2	87.7	64.0	93.7	103.0	96.4	113.3	60.7	62.9	946.0
1960	54.3	44.7	28.0	77.2	116.1	94.9	80.1	96.6	61.5	53.7	48.9	18.3	774.3
1961	9.9	45.4	79.6	100.4	57.0	85.1	101.9	73.4	132.5	67.8	66.7	38.6	858.2
1962	53.3	47.2	38.9	44.7	89.3	72.3	88.7	75.3	69.5	59.0	29.3	31.1	698.6
1963	19.0	17.1	69.5	70.3	64.7	62.4	90.3	60.2	55.5	15.9	57.6	29.4	612.0
1964	30.4	17.1	74.3	107.7	76.8	68.3	83.6	83.1	78.8	17.4	52.1	46.5	736.2
1965	67.1	46.4	62.6	89.5	72.3	63.6	69.0	111.3	137.1	64.8	61.9	67.7	913.4
1966	34.6	34.2	67.1	70.8	64.3	65.5	76.6	89.4	53.8	44.5	87.6	70.8	759.3
1967	49.3	34.4	43.5	98.2	69.5	121.2	62.8	69.1	66.2	99.4	54.1	67.3	835.0
1968	39.6	22.4	36.3	74.1	118.5	129.5	78.6	82.9	105.1	52.9	72.0	79.3	891.2
1969	70.4	7.7	30.6	90.7	88.8	139.0	111.3	37.3	67.9	88.1	51.7	40.3	823.9
1970	24.4	18.7	47.3	82.0	124.2	87.5	104.8	45.8	144.2	89.5	68.5	45.8	882.8
1971	32.9	68.0	41.7	31.0	70.8	81.1	86.7	58.2	82.4	57.5	54.9	90.9	756.1
1972	30.4	27.8	67.4	84.2	79.6	88.4	98.1	134.9	150.6	65.9	70.5	72.8	970.6
1973	36.2	29.6	92.2	95.5	133.8	105.1	82.4	67.8	68.7	77.8	61.2	70.3	920.6
1974	60.1	38.7	71.0	77.6	114.6	104.4	51.9	92.4	59.7	42.8	72.4	55.7	841.3
1975	60.8	52.1	62.7	75.0	78.7	118.3	58.9	154.7	72.7	35.4	78.3	58.3	905.8
1976	48.1	55.9	106.3	79.1	73.5	77.9	84.2	47.9	52.9	53.5	17.5	21.1	717.7
1977	23.9	30.8	99.5	75.5	46.5	86.3	105.7	132.2	128.1	62.9	72.7	73.0	937.2
1978	55.0	12.3	33.0	84.6	90.1	91.0	99.7	91.9	104.2	53.7	56.7	60.8	833.0
1979	63.1	32.8	77.6	81.6	80.0	87.9	78.4	133.0	39.5	71.8	76.0	50.6	872.3
1980	33.0	22.8	56.3	68.6	62.8	119.9	96.3	145.9	114.1	57.4	30.8	47.8	855.7
1981	11.0	67.6	20.5	113.7	76.1	134.0	82.9	115.2	105.8	82.7	38.5	42.2	890.3
1982	72.0	24.7	72.1	62.5	91.8	92.2	112.3	67.9	71.7	53.7	120.5	85.2	926.6
1983	24.7	25.0	62.8	85.8	112.8	68.9	76.1	93.0	88.5	86.7	108.5	71.0	903.8
1984	21.0	37.7	57.7	87.9	103.9	93.6	72.6	80.8	95.3	87.6	74.0	70.6	882.8
1985	41.0	56.8	88.5	53.2	74.6	74.0	83.5	114.6	90.6	89.0	152.3	50.0	970.6
1986	24.1	53.5	48.5	65.1	82.3	119.3	126.6	78.4	194.0	83.8	40.3	36.8	957.1
1987	35.2	6.0	46.1	55.8	79.4	85.7	94.5	135.2	78.5	50.8	68.3	76.2	817.0
1988	36.9	32.8	47.0	60.6	35.4	25.1	74.8	104.4	85.8	77.2	101.2	44.6	726.5
1989	32.1	24.3	53.0	51.0	120.3	101.4	76.8	78.7	85.6	53.7	54.4	28.1	763.4
1990	40.8	70.1	62.8	67.5	122.6	123.2	92.5	119.9	89.9	102.3	66.8	94.4	1064.7
1991	32.8	22.8	75.9	94.5	100.0	55.9	94.2	65.7	80.7	116.0	85.9	42.6	875.4
1992	35.8	32.3	58.2	82.4	50.0	54.7	161.5	81.9	137.5				

CITE AS: Karl, T.R., D.R. Easterling, and P.Ya. Groisman. 1994. United States historical climatology network—National and regional estimates of monthly and annual precipitation. pp. 830–905. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Precipitation

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

EASTERN PRAIRIES

Trends

The annual precipitation time series for the Eastern Prairies region shows slight evidence of a generally increasing trend over the period of record; however, this is obscured by large interannual variability, seen principally after the mid-1920s. The major drought of the 1950s, experienced mainly across the southern United States, extended into the Eastern Prairies region during the dry years 1952–54 (Karl and Knight 1985).

Area-average annual precipitation amount for the Eastern Prairies region of the United States.

CITE AS: Karl, T.R., D.R. Easterling, and P.Ya. Groisman. 1994. United States historical climatology network—National and regional estimates of monthly and annual precipitation. pp. 830–905. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Grouisman (continued)

EASTERN PRAIRIES

Area-Average Annual Precipitation Amount

Year	Precipitation (mm)												Ann
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	
1900	56.8	111.5	60.4	80.0	100.0	157.1	102.3	64.3	62.6	77.7	113.2	51.7	1037.7
1901	55.8	43.7	92.7	89.9	72.9	91.1	41.5	101.2	68.5	40.5	36.6	113.4	847.9
1902	80.1	41.8	124.3	68.1	95.4	133.1	67.4	78.0	97.7	53.6	98.4	136.2	1075.2
1903	67.2	144.2	99.2	108.6	95.2	89.8	80.7	87.8	33.7	54.3	53.0	65.2	980.8
1904	85.8	52.5	182.9	91.9	88.1	85.0	89.9	71.2	80.0	17.5	22.7	103.3	974.4
1905	72.0	61.0	87.9	94.9	140.5	106.3	112.9	100.2	71.3	121.5	61.6	88.3	1118.4
1906	87.5	43.4	144.8	49.5	70.4	83.7	108.4	108.3	141.2	50.2	117.6	113.9	1118.9
1907	153.4	50.0	119.4	90.4	127.9	103.0	124.5	104.2	66.0	61.4	77.2	86.0	1163.6
1908	59.8	134.1	126.9	139.5	149.2	72.4	85.3	62.5	31.0	12.9	57.9	64.2	995.8
1909	74.3	158.6	104.6	148.0	138.6	118.9	125.9	52.3	70.7	64.5	66.2	83.6	1206.1
1910	95.4	93.7	10.9	105.3	125.2	100.0	145.9	50.1	90.4	107.4	38.7	68.2	1031.2
1911	81.3	71.6	62.5	177.4	55.8	84.4	68.5	113.4	140.0	83.6	84.4	144.6	1167.5
1912	67.5	73.8	157.6	180.6	105.3	85.7	122.2	122.5	78.1	49.2	33.1	77.4	1153.1
1913	222.7	71.3	193.2	87.1	75.2	55.2	81.1	64.8	82.9	87.9	78.1	51.3	1150.8
1914	49.8	90.1	79.8	94.1	51.6	57.4	58.6	133.9	69.8	85.4	32.8	118.8	922.1
1915	108.9	61.3	46.7	36.2	156.3	107.4	124.8	162.0	91.2	59.7	95.3	139.3	1189.0
1916	181.4	55.7	79.9	68.5	121.4	130.7	87.2	91.6	62.8	54.0	44.4	94.3	1071.9
1917	118.0	50.0	149.2	126.4	113.2	120.4	95.4	73.6	54.0	83.8	23.4	38.0	1045.4
1918	103.5	47.0	43.0	131.9	115.1	80.0	68.0	79.9	87.7	83.2	56.3	112.3	1008.1
1919	60.5	50.8	142.1	79.8	149.6	106.3	66.3	90.7	54.1	198.8	132.5	68.4	1199.9
1920	112.5	42.6	120.1	172.8	121.3	91.1	97.3	101.2	78.0	39.6	52.9	87.6	1116.9
1921	65.3	72.6	159.3	129.1	61.4	86.7	68.4	133.2	134.8	53.0	145.6	93.9	1203.3
1922	60.5	68.2	208.0	142.9	103.8	63.3	101.5	57.7	49.2	52.9	61.0	134.5	1103.7
1923	110.8	83.4	132.5	109.6	137.8	94.6	84.4	130.6	77.1	60.9	73.2	150.1	1245.0
1924	100.8	62.1	86.7	94.4	135.2	126.4	72.3	78.6	97.0	9.4	38.1	121.2	1022.1
1925	52.6	77.7	77.2	68.5	54.4	93.4	99.1	59.4	92.8	140.1	115.9	36.0	967.1
1926	78.8	72.3	88.2	78.6	62.6	83.3	85.1	155.5	155.2	124.2	82.0	124.5	1190.3
1927	108.8	60.0	160.4	175.5	173.0	109.4	95.0	82.4	89.4	69.5	134.2	98.7	1356.5
1928	52.1	68.7	74.3	118.9	85.9	207.2	92.1	94.9	37.1	98.6	83.9	55.1	1069.1
1929	117.3	77.8	115.8	131.3	180.4	103.5	109.1	56.3	82.9	98.1	96.4	81.8	1250.6
1930	142.4	78.6	67.1	49.2	83.5	50.8	35.7	54.5	82.1	44.2	58.6	47.0	793.7
1931	28.8	70.1	93.3	92.5	85.9	71.0	102.5	114.5	93.4	65.1	99.3	141.0	1057.5
1932	174.1	76.2	97.0	87.4	43.5	109.7	116.7	100.4	116.4	103.4	65.7	130.9	1221.4
1933	91.8	80.8	156.2	119.2	205.9	39.6	90.7	83.5	99.8	53.2	35.8	98.8	1155.3
1934	47.4	39.3	111.8	50.1	40.5	108.1	80.8	106.3	131.3	29.9	98.1	56.1	899.6
1935	111.3	50.4	166.1	91.5	174.4	136.5	102.3	85.9	69.2	66.2	91.2	46.9	1192.0
1936	61.5	59.9	101.3	90.3	46.4	31.8	93.3	55.0	102.5	103.3	81.5	100.7	927.6
1937	307.2	55.2	44.5	120.4	104.8	114.0	84.7	86.8	64.5	116.0	48.9	79.0	1226.1
1938	84.9	66.0	168.1	92.1	143.6	118.7	129.9	94.3	71.7	20.0	81.2	47.4	1117.9
1939	121.1	156.6	129.3	156.0	58.3	166.5	108.0	77.1	30.9	52.5	34.9	53.5	1144.7
1940	43.3	94.7	97.1	136.7	89.0	97.0	70.0	94.8	31.9	37.7	95.0	74.3	961.5
1941	60.9	24.3	41.0	78.9	51.1	121.8	115.5	87.5	56.0	157.1	69.4	61.1	924.6
1942	57.8	89.4	109.0	90.3	98.2	126.0	100.3	105.8	67.0	56.4	110.4	118.7	1129.5
1943	35.6	43.2	153.7	89.7	174.0	88.5	91.6	46.8	82.3	39.5	46.7	52.6	944.1
1944	35.7	120.2	148.8	158.9	102.2	51.0	49.9	112.8	91.6	30.6	62.7	98.9	1063.3
1945	68.4	127.6	197.3	133.8	124.2	143.6	77.1	73.7	144.2	57.9	121.1	71.8	1340.7
1946	97.8	113.5	107.0	59.8	168.1	105.1	95.5	99.3	57.7	67.6	112.8	75.8	1160.1

Precipitation

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

EASTERN PRAIRIES

Area-Average Annual Precipitation Amount (continued)

Year	Precipitation (mm)												Ann
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	
1947	127.1	17.5	66.3	153.9	141.1	129.1	72.3	80.1	76.6	66.7	80.2	51.7	1062.6
1948	76.4	124.1	155.8	118.6	94.1	99.8	127.3	56.2	72.1	58.2	171.8	100.1	1254.5
1949	203.4	87.9	121.2	70.7	82.1	139.1	96.0	101.3	61.8	123.5	27.4	121.2	1235.8
1950	274.1	132.7	103.9	101.0	111.9	125.5	117.5	111.9	112.0	38.0	119.5	55.6	1403.5
1951	145.1	110.2	127.8	96.7	68.1	133.3	86.7	60.6	85.2	57.7	124.4	154.3	1250.0
1952	110.4	71.5	144.4	89.6	98.7	78.3	64.2	79.8	67.7	30.2	70.8	79.2	984.8
1953	100.5	70.7	135.0	109.7	129.1	62.7	100.2	35.6	33.6	26.8	31.1	67.6	902.5
1954	110.9	57.6	70.7	100.9	85.0	70.1	60.2	104.0	61.7	97.3	40.3	101.4	960.0
1955	52.6	129.1	149.6	121.5	114.3	92.7	113.8	62.6	80.9	86.9	79.8	29.3	1113.0
1956	67.5	167.2	87.2	116.1	114.8	89.1	101.8	87.1	47.8	40.6	52.7	107.6	1079.3
1957	117.8	93.9	61.2	163.8	150.9	162.6	80.7	53.3	93.7	75.6	157.3	132.5	1343.3
1958	56.1	38.5	69.7	119.2	110.6	133.5	201.1	86.3	108.3	31.6	94.9	22.4	1072.2
1959	116.4	84.4	78.0	81.8	112.2	67.1	110.5	93.4	77.6	101.2	76.6	97.0	1096.2
1960	73.1	79.4	75.2	59.1	105.4	134.3	76.7	80.6	52.9	63.5	69.5	58.6	928.2
1961	40.3	104.9	146.9	112.3	149.0	111.2	131.7	82.4	70.5	54.9	105.1	117.1	1226.3
1962	116.6	136.0	102.0	68.9	105.3	93.9	108.2	62.9	92.2	74.0	61.8	49.0	1070.9
1963	34.1	33.5	190.4	76.5	81.7	66.2	125.4	80.0	30.0	10.5	61.1	40.6	829.8
1964	67.9	61.3	213.4	171.5	58.7	83.1	98.3	81.1	72.7	26.4	79.7	109.0	1123.2
1965	91.3	101.1	118.3	113.0	62.4	90.3	103.5	92.5	144.9	52.9	39.2	38.6	1048.0
1966	86.1	94.5	40.4	133.6	106.1	46.1	84.6	92.2	94.9	52.8	88.2	116.6	1035.9
1967	39.0	56.5	106.6	104.4	159.2	75.6	138.4	80.8	57.0	85.5	83.4	137.9	1124.4
1968	75.4	30.3	112.6	107.4	178.0	75.3	95.3	79.8	81.7	50.4	109.0	97.3	1092.6
1969	114.2	57.9	54.2	131.4	82.5	113.6	131.7	83.0	78.9	82.0	82.9	113.1	1125.6
1970	31.2	62.0	101.4	176.9	98.7	125.3	82.7	93.2	105.1	111.0	58.2	82.2	1127.8
1971	68.3	123.6	60.7	50.1	114.3	89.3	135.0	71.5	100.4	42.0	43.7	120.6	1019.5
1972	87.2	64.4	95.9	148.2	85.0	83.2	112.4	80.2	117.6	71.7	144.0	140.7	1230.6
1973	74.2	57.5	195.8	150.5	133.3	139.8	133.0	60.6	62.5	89.2	152.8	100.8	1350.0
1974	147.6	68.2	105.9	101.3	169.3	130.5	61.1	152.7	113.0	43.7	88.5	93.8	1275.7
1975	109.0	112.7	187.3	103.7	116.2	96.3	93.7	114.9	114.4	94.2	78.7	91.7	1312.9
1976	81.2	81.4	115.7	42.5	96.4	113.0	103.5	63.1	81.8	105.6	26.4	31.5	942.4
1977	50.2	49.1	139.4	106.7	65.0	102.7	103.4	135.4	112.8	95.9	118.7	90.4	1170.0
1978	101.6	20.6	93.5	82.2	141.4	85.8	119.8	119.3	37.6	69.9	93.5	170.4	1135.6
1979	125.5	90.4	100.4	157.2	117.0	86.7	165.9	128.0	119.7	59.4	135.7	76.6	1362.5
1980	55.3	37.9	166.7	86.6	97.6	104.5	101.7	111.2	90.9	61.9	67.8	35.3	1017.3
1981	19.6	82.9	65.2	119.0	163.3	124.0	143.9	91.2	65.9	75.0	53.3	71.3	1074.6
1982	143.5	67.1	99.7	92.9	102.7	103.8	107.3	109.4	77.5	56.5	112.3	189.2	1261.9
1983	40.6	50.8	77.3	172.2	217.1	88.7	54.5	56.0	46.5	147.4	149.6	127.5	1228.1
1984	33.4	70.6	115.0	136.1	165.9	48.4	101.0	66.3	81.4	142.1	134.1	100.2	1194.4
1985	54.9	80.1	113.3	66.1	113.5	108.3	102.8	133.7	46.4	103.0	190.6	55.2	1167.8
1986	20.5	90.2	66.2	50.3	121.1	103.7	117.4	71.2	117.2	107.2	125.4	80.3	1070.6
1987	49.6	70.7	69.8	72.8	71.7	98.9	117.3	67.2	61.4	33.3	96.4	136.9	947.2
1988	67.7	83.1	85.7	74.7	50.8	19.9	123.9	71.0	97.1	72.4	153.4	88.0	989.0
1989	103.3	146.0	137.3	98.6	126.3	145.2	137.6	90.6	120.4	62.2	78.4	48.8	1291.4
1990	85.8	151.3	90.4	86.4	190.1	112.3	106.7	80.7	76.9	116.8	82.8	231.3	1411.3
1991	64.5	102.2	125.4	127.2	122.1	68.9	74.0	72.9	72.9	80.4	82.6	140.3	1137.1
1992	49.5	51.2	105.2	71.8	68.4	95.6	174.9	100.3	99.6				

CITE AS: Karl, T.R., D.R. Easterling, and P.Ya. Groisman. 1994. United States historical climatology network—National and regional estimates of monthly and annual precipitation. pp. 830–905. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

NORTHERN APPALACHIANS

Trends

The annual precipitation time series for the Northern Appalachians region shows evidence of a generally increasing trend from about 1910 through the end of the record, although a major dry spell is evident during the period 1964–67 and to a lesser extent through the early 1970s. The other two regions of the extreme northeastern United States—the Northern Piedmont and the Coastal Northeast—show similar increasing trends. The general trend in all three series is similar to that of the annual precipitation series produced by Groisman and Easterling (1994) for a region encompassing the northeastern United States and southeastern Canada (shown on p. 778).

Area-average annual precipitation amount for the Northern Appalachians region of the United States.

CITE AS: Karl, T.R., D.R. Easterling, and P.Ya. Groisman. 1994. United States historical climatology network—National and regional estimates of monthly and annual precipitation. pp. 830–905. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Precipitation

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

NORTHERN APPALACHIANS

Area-Average Annual Precipitation Amount

Year	Precipitation (mm)												Ann
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	
1900	89.4	106.6	95.3	36.3	59.2	73.8	109.5	75.9	54.2	85.9	142.4	53.8	982.3
1901	60.9	33.3	80.3	108.1	99.6	87.5	100.5	129.3	76.3	48.0	67.7	127.4	1018.8
1902	53.4	57.4	88.3	72.6	85.9	136.2	154.7	72.2	84.2	98.5	38.4	88.3	1030.1
1903	79.5	83.2	112.7	63.9	25.3	141.9	120.3	120.3	34.0	104.5	47.5	60.2	993.4
1904	86.3	51.3	78.9	83.4	99.5	71.0	112.9	93.0	104.7	70.1	19.4	54.6	925.2
1905	68.0	31.2	58.3	58.2	69.7	141.4	145.0	105.7	92.2	78.3	53.3	79.5	980.7
1906	50.2	32.2	75.5	46.7	86.0	118.3	92.8	94.9	76.1	104.6	55.4	78.4	911.0
1907	79.0	30.8	59.1	76.8	65.4	96.4	93.5	47.1	137.4	99.7	71.8	90.1	947.2
1908	59.1	90.3	73.0	74.6	115.3	72.7	87.5	70.5	30.0	47.1	33.4	62.8	816.2
1909	88.1	99.7	60.4	98.2	81.5	87.6	68.2	66.9	84.6	46.4	51.2	49.4	882.2
1910	85.4	94.7	22.9	80.3	94.6	71.2	78.8	79.4	95.7	66.6	68.2	64.7	902.5
1911	60.3	62.2	64.7	49.1	47.9	94.5	72.0	118.1	100.2	91.5	63.7	76.3	900.6
1912	54.3	53.0	74.2	88.6	115.1	50.1	98.1	129.7	129.7	73.6	73.1	56.4	995.9
1913	112.0	41.7	138.2	63.8	79.3	67.3	90.1	52.4	65.0	131.6	68.2	61.9	971.6
1914	63.3	44.7	72.9	110.6	71.1	84.3	68.5	122.8	45.9	50.3	58.1	69.4	861.9
1915	89.0	73.4	16.0	36.1	64.7	90.0	144.6	120.8	66.4	68.5	55.4	92.1	916.9
1916	58.1	78.3	67.7	73.8	99.1	132.2	75.1	70.7	107.2	57.8	64.6	69.9	954.8
1917	74.0	39.3	66.2	56.4	89.7	161.9	100.2	115.8	55.9	154.2	19.9	51.6	985.1
1918	58.9	63.4	58.6	66.1	100.5	98.8	84.7	81.9	140.1	123.5	59.1	63.6	999.4
1919	43.8	38.8	81.0	75.1	125.3	86.9	89.2	95.9	73.8	112.1	70.2	47.1	939.4
1920	52.4	63.3	61.6	103.4	39.0	93.8	124.9	90.4	116.7	51.0	91.6	98.2	986.4
1921	42.7	53.7	77.5	69.7	52.5	62.3	104.4	91.9	74.6	77.6	121.8	45.9	874.5
1922	55.5	61.6	89.0	81.6	66.4	192.7	67.3	116.8	50.5	58.6	41.2	61.2	942.5
1923	96.1	36.3	61.7	78.8	68.4	72.9	75.4	50.2	76.2	68.6	70.2	85.5	840.2
1924	81.1	56.6	34.0	97.8	102.0	87.7	88.2	83.8	164.6	9.7	54.7	49.8	910.2
1925	73.9	59.6	76.4	55.4	62.2	99.6	112.5	56.5	122.0	121.2	84.7	48.1	972.0
1926	60.4	76.0	48.4	69.9	37.5	103.4	78.9	123.4	110.9	122.8	92.8	55.5	979.9
1927	54.4	73.0	49.6	50.1	106.1	56.3	111.0	83.7	41.5	133.6	192.1	115.7	1067.1
1928	66.2	58.5	75.8	84.2	67.6	129.4	101.1	104.4	65.7	76.4	77.9	38.4	945.6
1929	82.2	49.7	73.1	131.5	115.5	92.1	95.6	64.3	66.6	98.2	73.4	83.3	1025.4
1930	78.3	38.1	92.9	55.0	90.0	114.2	77.7	48.6	57.7	44.4	44.7	44.2	785.8
1931	54.5	39.5	53.6	73.7	110.8	80.6	123.1	65.8	113.6	70.0	57.6	80.0	922.8
1932	96.3	46.5	92.9	64.0	72.4	65.1	128.4	83.3	62.6	121.8	97.8	53.1	984.1
1933	40.2	52.3	93.4	97.0	102.9	52.8	64.0	108.3	77.7	66.7	64.4	75.1	894.9
1934	62.2	35.5	67.4	76.7	29.6	83.8	75.8	67.8	101.1	58.3	74.9	63.2	796.4
1935	91.8	52.5	48.2	67.7	67.5	117.8	140.1	80.1	98.2	54.3	72.1	54.1	944.3
1936	77.1	48.0	139.7	84.9	80.4	65.1	69.3	94.9	77.9	118.1	77.5	75.7	1008.7
1937	115.1	57.3	55.6	93.0	109.5	124.2	91.6	124.8	54.8	119.1	66.8	60.7	1072.4
1938	59.9	76.0	66.6	65.2	74.1	84.9	128.1	90.9	144.9	36.2	64.6	69.9	961.3
1939	61.6	84.6	74.0	78.1	49.6	95.6	81.1	49.5	85.1	95.5	29.3	77.9	861.8
1940	35.8	63.5	92.4	95.2	101.4	118.0	88.4	55.8	92.3	46.6	88.9	86.5	964.7
1941	47.4	32.3	52.5	36.6	56.4	86.9	116.1	91.1	50.3	93.0	51.1	62.5	776.2
1942	43.7	64.9	104.3	65.7	92.8	96.3	96.2	77.0	119.8	78.9	80.5	116.2	1036.4
1943	42.0	56.1	64.7	84.8	132.5	98.5	99.6	107.9	42.2	123.2	82.8	29.0	963.3
1944	37.9	57.8	68.5	88.7	82.6	115.4	79.6	52.6	101.2	74.9	65.4	81.9	906.5
1945	72.4	59.6	79.0	99.2	136.4	92.5	121.1	58.9	171.5	122.9	112.5	54.5	1180.4
1946	47.9	61.3	43.9	50.1	125.1	99.0	78.2	95.5	86.4	106.2	68.7	80.7	942.9

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

NORTHERN APPALACHIANS

Area-Average Annual Precipitation Amount (continued)

Year	Precipitation (mm)												Ann
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	
1947	99.4	44.7	71.4	86.7	154.6	134.5	148.9	76.1	69.8	20.8	87.3	42.9	1037.1
1948	53.3	45.8	78.6	97.1	110.5	101.2	91.8	85.9	31.4	74.6	115.9	84.0	970.2
1949	78.7	56.0	56.3	76.5	77.4	52.5	91.7	98.9	84.6	44.5	68.4	69.3	854.9
1950	101.8	78.4	92.7	62.7	54.8	87.2	94.7	102.5	77.3	61.9	146.4	91.0	1051.4
1951	66.7	93.4	95.6	97.4	63.1	108.4	120.4	57.9	78.6	44.8	108.2	94.0	1028.3
1952	77.9	69.6	67.5	71.0	115.5	86.6	74.1	75.4	75.7	67.6	55.8	95.8	932.5
1953	70.4	46.3	97.5	76.9	122.9	57.9	86.7	76.5	80.5	45.1	54.8	70.5	886.1
1954	66.3	79.2	87.9	115.4	89.2	117.1	70.7	111.6	108.1	115.5	79.4	99.7	1139.9
1955	32.7	75.0	113.1	63.4	64.1	67.0	75.6	137.2	50.6	136.6	65.2	29.9	910.4
1956	51.6	76.5	99.0	80.9	107.8	74.3	109.1	116.7	92.4	44.0	57.9	74.3	984.7
1957	54.6	39.3	45.8	87.6	85.3	110.0	94.8	33.7	84.0	41.5	78.3	101.8	856.8
1958	100.0	64.6	45.1	80.6	80.6	116.7	137.4	91.0	114.8	86.3	69.7	32.5	1019.2
1959	89.3	63.4	67.1	67.3	56.3	96.0	78.8	113.8	42.5	159.8	118.8	88.8	1041.8
1960	65.7	97.9	38.4	68.5	111.6	95.1	75.9	54.1	68.7	71.1	46.7	41.4	835.0
1961	38.6	79.2	61.7	124.2	85.2	109.9	105.4	86.8	56.2	66.0	71.7	54.9	939.9
1962	65.6	56.4	43.1	88.1	52.0	71.4	115.2	94.2	98.0	96.9	58.7	61.0	900.7
1963	46.9	40.8	72.5	72.6	77.7	56.2	85.7	115.2	48.2	19.3	130.8	48.0	813.9
1964	69.6	35.4	93.5	82.2	81.4	62.3	93.2	108.3	33.8	45.5	62.9	77.8	846.0
1965	61.8	55.2	45.2	65.3	49.3	66.0	70.6	112.3	85.1	86.6	91.6	41.6	830.7
1966	71.1	55.1	71.8	48.0	63.2	71.7	68.8	88.0	85.7	45.1	90.1	70.0	828.6
1967	37.3	46.3	48.6	85.4	100.8	82.4	113.0	112.0	91.7	91.0	89.8	64.5	962.7
1968	52.1	25.4	72.3	62.1	109.5	85.7	71.0	74.1	73.4	82.1	119.5	106.0	933.2
1969	57.0	40.2	35.9	97.1	90.2	103.4	101.8	76.7	60.6	59.6	103.8	116.3	942.5
1970	27.5	63.2	52.6	72.0	89.6	82.4	92.5	100.2	101.8	98.4	85.7	87.4	953.2
1971	46.0	91.1	82.6	44.3	75.3	63.4	97.8	102.2	77.5	49.7	72.3	85.8	887.9
1972	49.4	81.2	85.1	69.3	93.1	198.0	109.2	73.0	67.5	74.0	116.2	112.7	1128.9
1973	59.8	53.3	69.0	107.6	119.4	129.5	86.5	81.3	96.1	69.4	77.1	128.7	1077.7
1974	64.6	47.6	104.4	86.0	110.3	98.0	106.2	90.1	103.8	32.8	96.1	78.3	1018.1
1975	66.0	69.0	76.0	55.9	64.5	98.7	91.7	104.7	146.4	83.2	75.4	91.5	1023.0
1976	86.4	79.7	87.2	76.8	110.0	121.5	113.5	99.6	92.1	133.1	38.7	56.4	1094.8
1977	46.6	44.0	92.3	85.1	40.5	104.3	111.3	139.7	163.5	121.0	98.5	107.1	1153.9
1978	133.0	20.3	58.6	63.6	73.5	103.7	75.0	85.5	71.5	92.9	40.9	86.0	904.6
1979	126.2	49.8	66.2	91.3	96.6	50.9	68.5	120.2	116.8	90.8	87.0	58.5	1022.7
1980	32.6	22.6	94.2	88.2	45.5	95.6	116.2	94.4	90.7	89.3	79.2	56.0	904.7
1981	21.1	106.3	36.4	86.8	72.8	111.6	107.6	106.8	129.6	135.0	61.9	67.3	1043.2
1982	71.3	56.2	61.8	57.4	64.0	136.2	72.2	85.7	89.2	39.5	114.7	54.6	902.8
1983	46.5	38.3	77.2	122.4	124.0	76.3	75.7	122.3	67.7	77.2	132.2	122.1	1081.8
1984	34.3	68.5	64.0	77.9	153.2	102.0	94.3	111.0	68.2	55.8	74.6	90.1	993.9
1985	38.3	53.8	82.8	48.3	79.3	94.3	83.8	75.3	93.7	76.5	153.7	55.9	941.8
1986	78.6	54.3	62.1	59.6	81.8	128.3	134.1	109.7	94.2	80.5	82.8	70.5	1044.1
1987	67.0	14.9	51.6	80.6	59.4	119.7	102.9	89.6	123.9	85.1	73.4	57.8	934.5
1988	33.3	61.7	42.1	77.6	67.3	49.0	105.8	116.7	61.0	85.8	105.0	40.8	851.8
1989	41.3	44.5	80.4	53.4	139.6	134.3	81.8	103.7	121.4	86.1	93.3	35.6	1026.2
1990	76.5	84.9	50.1	89.6	130.4	102.2	112.7	116.1	95.3	162.3	74.2	133.6	1233.5
1991	58.6	33.7	90.2	86.5	68.8	36.3	70.0	106.1	93.5	74.6	69.2	78.0	881.9
1992	57.4	51.6	73.4	77.2	69.0	61.2	157.5	114.8	100.0				

CITE AS: Karl, T.R., D.R. Easterling, and P.Ya. Groisman. 1994. United States historical climatology network—National and regional estimates of monthly and annual precipitation. pp. 830–905. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Precipitation

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

SOUTHERN APPALACHIANS

Trends

The annual precipitation time series for the Southern Appalachians region is similar to that of the adjacent Southern Piedmont region: no definitive decadal-scale or long-term trends are apparent in either region.

Area-average annual precipitation amount for the Southern Appalachians region of the United States.

CITE AS: Karl, T.R., D.R. Easterling, and P.Ya. Groisman. 1994. United States historical climatology network—National and regional estimates of monthly and annual precipitation. pp. 830–905. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

SOUTHERN APPALACHIANS

Area-Average Annual Precipitation Amount

Year	Precipitation (mm)												
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1900	70.2	165.0	120.5	113.9	57.8	181.1	93.0	54.6	78.2	96.0	104.1	92.8	1227.1
1901	101.0	51.3	123.8	166.9	179.2	171.3	91.8	277.5	105.1	27.1	34.4	213.5	1542.7
1902	78.7	157.4	116.4	59.6	57.4	100.8	70.7	75.1	100.2	92.4	92.9	116.8	1118.5
1903	97.0	218.7	168.8	109.5	58.1	153.4	82.9	103.3	59.7	59.8	51.1	49.1	1211.3
1904	67.5	81.1	98.6	57.1	78.1	107.3	95.0	139.3	44.8	15.5	62.1	91.0	937.5
1905	88.7	123.0	62.9	70.3	142.9	77.5	184.3	132.4	45.0	91.0	33.4	176.8	1228.2
1906	159.5	33.8	140.1	55.9	71.6	156.7	172.4	180.9	121.7	102.7	65.1	107.4	1367.8
1907	50.4	77.0	84.0	100.2	92.5	149.4	112.6	97.6	137.5	31.6	123.3	135.6	1191.6
1908	100.4	131.8	104.7	103.6	109.8	104.0	132.6	170.7	53.5	121.2	37.5	121.8	1291.4
1909	79.7	133.7	135.9	84.3	139.6	172.6	122.0	108.3	84.3	70.0	23.7	93.2	1247.3
1910	99.5	96.6	28.0	75.6	120.8	172.1	121.3	110.9	70.2	77.5	25.2	92.1	1089.9
1911	103.3	67.2	85.2	128.0	35.1	82.0	105.7	138.3	80.9	138.9	94.3	128.2	1187.0
1912	82.9	118.4	180.6	123.5	115.2	130.0	149.2	76.7	128.5	56.4	57.3	79.4	1298.1
1913	121.3	96.7	167.5	70.0	113.6	107.2	111.3	105.6	97.9	92.3	53.0	98.9	1235.3
1914	65.1	93.9	73.0	103.9	25.8	67.4	110.4	128.9	52.0	110.9	86.8	186.0	1104.0
1915	142.7	113.0	58.9	27.2	123.2	100.3	90.8	159.2	86.8	136.2	68.5	140.5	1247.3
1916	84.1	116.4	70.4	57.1	90.1	129.5	276.2	101.2	69.6	65.1	42.6	85.9	1188.0
1917	113.5	111.0	196.6	79.1	74.0	88.9	129.9	83.0	109.4	78.4	20.4	41.5	1125.7
1918	157.4	57.7	66.0	133.3	90.9	114.1	107.7	99.4	91.7	188.7	63.2	156.7	1326.7
1919	131.1	99.1	97.4	65.5	133.9	154.7	140.4	99.5	26.6	107.9	64.0	121.5	1241.7
1920	102.9	95.4	147.0	156.5	69.4	126.0	132.2	214.8	91.5	15.5	109.7	131.9	1392.7
1921	106.6	134.3	55.6	79.9	99.9	76.0	128.2	103.0	102.4	63.8	101.8	72.1	1123.6
1922	117.3	131.1	162.8	103.5	138.0	123.8	147.4	77.6	31.1	84.0	17.8	145.2	1279.7
1923	114.8	104.7	120.6	102.9	140.4	86.9	113.8	125.0	57.3	28.9	84.5	119.0	1198.7
1924	133.2	97.0	86.8	127.8	128.0	95.3	137.1	84.5	203.1	27.1	39.0	122.9	1281.6
1925	151.1	54.5	58.5	64.3	52.6	74.9	71.3	35.9	46.1	132.2	93.9	55.5	890.7
1926	134.3	106.8	99.2	56.0	43.4	75.0	136.3	131.2	73.8	78.1	103.6	153.7	1191.6
1927	49.9	130.4	77.0	104.3	80.7	115.6	136.3	102.3	40.4	83.5	69.8	180.9	1171.3
1928	56.0	68.8	108.3	124.8	120.9	153.7	129.5	232.7	138.3	70.9	36.2	38.9	1279.1
1929	91.9	155.1	165.8	116.5	139.9	120.4	111.7	62.4	161.5	163.4	129.5	73.1	1491.2
1930	79.8	44.8	83.8	46.5	72.3	80.6	71.3	58.0	71.9	35.7	89.3	88.5	822.4
1931	55.8	68.8	91.4	103.7	115.3	59.1	133.2	125.0	48.4	33.4	28.1	199.7	1062.1
1932	144.2	108.5	129.5	62.9	100.4	131.9	89.7	99.7	64.0	184.7	111.3	198.5	1425.2
1933	73.1	107.0	85.7	98.0	120.9	62.6	138.9	124.7	67.2	44.3	35.4	76.7	1034.5
1934	72.5	84.8	145.6	78.4	92.2	123.7	126.2	135.3	102.9	96.3	91.7	79.1	1228.7
1935	119.9	76.1	129.6	115.8	92.2	81.4	149.0	135.2	71.4	59.5	110.7	69.3	1210.0
1936	224.5	119.3	145.3	146.0	27.3	69.3	126.0	124.2	127.5	124.2	39.9	156.6	1430.1
1937	229.1	104.1	49.1	140.3	74.2	111.0	113.9	164.7	50.6	198.7	44.9	61.4	1341.9
1938	69.3	45.2	105.3	95.3	117.0	117.6	199.8	63.3	71.7	10.9	104.0	66.4	1065.8
1939	114.4	202.1	97.1	84.3	67.3	100.6	138.1	135.9	42.1	41.4	33.4	74.7	1131.4
1940	73.5	96.9	95.8	89.6	74.1	103.5	131.7	253.6	30.8	42.5	95.2	81.2	1168.4
1941	60.8	28.5	81.7	62.4	30.0	123.3	214.6	94.3	30.8	49.4	52.1	112.3	940.4
1942	72.7	95.2	131.5	33.8	140.6	130.8	123.5	167.2	123.0	90.8	57.7	161.2	1327.7
1943	121.6	63.6	125.1	101.4	92.2	112.9	169.9	80.9	69.0	46.2	49.0	70.4	1095.7
1944	73.2	174.2	190.0	103.3	78.7	72.5	90.2	80.3	126.0	75.1	70.5	85.6	1224.5
1945	75.3	140.2	86.7	107.5	103.3	95.3	143.4	101.7	181.3	54.9	87.1	149.5	1326.2
1946	143.7	118.3	115.3	76.1	137.2	86.2	110.1	79.1	64.9	88.9	58.6	65.1	1143.3

Precipitation

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

SOUTHERN APPALACHIANS

Area-Average Annual Precipitation Amount (continued)

Year	Precipitation (mm)												
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1947	198.4	46.9	91.9	70.6	72.4	132.7	85.9	106.5	72.0	111.4	132.1	53.8	1174.6
1948	95.5	115.9	146.4	75.8	108.7	103.1	117.7	126.3	90.3	52.5	233.5	124.5	1390.3
1949	122.9	101.5	76.0	128.5	98.2	132.3	161.8	168.2	90.6	120.9	58.3	76.8	1336.1
1950	106.6	74.6	113.5	37.1	133.6	108.3	153.7	90.5	105.7	85.0	56.9	86.7	1152.3
1951	67.5	77.8	135.2	100.3	51.9	147.0	101.2	71.4	92.2	40.5	98.1	168.3	1151.4
1952	115.4	75.8	205.2	97.2	89.5	70.4	70.5	148.1	58.1	30.1	83.2	94.4	1138.0
1953	128.6	141.0	119.3	77.1	104.2	105.3	102.7	57.9	108.6	24.6	37.4	136.4	1143.1
1954	152.5	59.8	134.9	68.7	90.2	70.6	91.3	87.7	28.6	76.0	82.3	107.5	1050.0
1955	60.9	127.7	116.7	104.3	94.8	91.1	122.0	115.4	45.9	70.8	66.4	31.9	1047.9
1956	52.2	183.0	110.8	122.4	74.6	71.3	151.8	81.5	138.5	73.8	49.8	104.8	1214.5
1957	129.8	136.3	71.1	143.8	83.7	150.4	59.2	54.0	166.7	86.2	155.9	106.4	1343.3
1958	88.0	99.0	105.7	149.9	104.7	77.7	160.9	107.2	52.5	43.9	54.9	83.7	1128.1
1959	84.3	76.7	108.3	117.7	117.0	74.1	136.7	101.4	140.1	165.1	68.7	84.1	1274.3
1960	123.6	134.5	111.5	62.1	106.5	94.2	93.9	138.3	105.8	78.1	36.1	58.1	1142.8
1961	73.9	178.5	120.3	114.0	85.6	151.3	106.2	143.4	41.4	53.8	84.4	193.4	1346.1
1962	124.4	118.9	128.9	103.9	64.8	128.0	105.8	68.1	102.4	70.4	113.7	87.5	1216.7
1963	78.7	60.2	204.6	100.0	82.7	130.0	97.7	61.1	91.1	4.1	109.0	68.4	1087.4
1964	139.9	112.2	154.5	184.3	55.8	83.6	142.8	156.2	79.8	140.3	76.8	104.1	1430.3
1965	76.7	109.2	159.3	111.9	68.6	110.8	97.6	74.6	73.4	94.9	53.6	15.1	1045.3
1966	115.0	153.1	70.8	116.3	105.8	50.6	88.1	115.8	134.4	103.4	84.1	81.1	1218.4
1967	73.7	92.6	97.9	70.3	142.6	105.4	144.4	171.4	71.8	71.5	87.8	145.9	1275.3
1968	100.1	20.3	104.4	85.5	121.3	98.0	116.1	77.9	72.5	106.9	94.9	87.2	1085.1
1969	88.1	102.7	88.1	106.7	63.8	129.0	134.6	148.7	108.0	45.2	67.3	137.7	1219.9
1970	54.4	70.9	93.2	112.1	68.8	88.8	106.8	140.9	71.0	134.8	65.0	79.6	1086.3
1971	104.5	141.3	110.1	68.4	130.5	80.8	154.4	100.6	125.4	119.0	80.0	85.4	1300.4
1972	143.1	99.2	97.4	86.7	149.7	169.2	110.5	74.8	81.9	92.0	127.0	160.6	1392.2
1973	97.8	94.6	172.0	143.5	151.5	106.2	107.1	97.1	107.2	78.6	76.7	158.9	1391.1
1974	160.2	101.3	94.4	104.3	139.8	113.2	99.5	136.8	86.3	30.9	77.0	117.9	1261.6
1975	127.6	141.8	212.2	54.9	170.3	109.7	96.5	94.9	185.3	105.0	78.2	95.9	1472.4
1976	100.6	53.1	138.1	28.2	175.5	136.5	100.9	66.8	112.1	189.5	55.3	108.4	1264.9
1977	69.0	42.2	162.8	108.7	64.2	99.9	64.8	111.7	135.4	131.8	155.3	87.1	1232.7
1978	172.2	16.6	112.0	76.8	124.8	87.0	114.2	149.8	45.5	29.5	75.2	125.0	1128.7
1979	164.4	140.2	115.9	164.3	117.1	97.6	146.5	100.5	175.9	86.5	132.7	42.9	1484.4
1980	119.0	37.9	230.3	118.5	114.4	88.6	97.8	70.8	116.7	74.1	80.8	27.3	1176.0
1981	20.8	119.0	72.1	68.3	112.5	96.7	115.6	57.6	93.2	88.2	36.2	117.8	998.0
1982	141.2	156.3	84.7	104.5	88.1	117.4	137.1	88.6	57.7	80.9	110.3	119.8	1286.6
1983	70.4	107.3	134.9	149.1	131.2	93.9	54.2	67.3	78.9	113.9	124.8	188.2	1314.2
1984	73.5	138.1	119.5	123.3	148.8	91.9	206.8	103.8	18.2	73.6	79.3	60.2	1237.0
1985	83.8	113.5	46.1	51.9	113.3	88.7	152.1	131.9	18.1	109.3	196.9	36.7	1142.4
1986	41.5	68.5	66.5	37.2	97.1	39.4	74.4	124.5	78.3	104.8	140.2	111.2	983.7
1987	111.6	106.1	104.1	114.0	72.3	114.9	69.5	60.3	127.7	22.7	80.6	90.0	1074.0
1988	82.5	48.1	53.3	87.7	71.1	43.9	95.4	96.0	105.4	65.3	103.0	42.5	894.1
1989	81.6	118.4	119.3	83.1	146.0	181.1	168.6	116.0	164.0	103.9	92.8	83.1	1457.8
1990	126.7	139.8	125.2	62.2	128.3	41.7	120.4	121.1	79.9	193.7	43.6	126.6	1309.3
1991	104.4	80.3	149.6	118.1	106.0	99.5	114.4	126.0	48.9	17.3	65.9	124.5	1154.8
1992	76.4	104.3	113.9	79.6	105.2	120.2	109.5	142.8	91.6				

CITE AS: Karl, T.R., D.R. Easterling, and P.Ya. Groisman. 1994. United States historical climatology network—National and regional estimates of monthly and annual precipitation. pp. 830–905. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

NORTHERN PIEDMONT

Trends

The annual precipitation time series for the Northern Piedmont region shows evidence of a generally increasing trend from ca. 1910 to near the end of the record, although a major dry spell during the mid-1960s led to severe to extreme drought in much of this region (Karl and Knight 1985). The other two regions of the northeastern United States—the Northern Appalachians and the Coastal Northeast—also show an increasing trend. The general trend in all three series is similar to that in the annual precipitation series produced by Groisman and Easterling (1994) for a region encompassing the northeastern United States and southeastern Canada (shown on p. 778).

Area-average annual precipitation amount for the Northern Piedmont region of the United States.

CITE AS: Karl, T.R., D.R. Easterling, and P.Ya. Groisman. 1994. United States historical climatology network—National and regional estimates of monthly and annual precipitation. pp. 830–905. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Precipitation

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

NORTHERN PIEDMONT

Area-Average Annual Precipitation Amount

Year	Precipitation (mm)												
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1900	90.3	142.1	107.0	45.5	79.2	81.2	97.3	76.7	62.5	70.3	107.7	62.0	1018.5
1901	54.7	22.7	117.9	141.6	139.7	59.1	121.8	149.2	86.2	56.6	58.0	177.8	1176.1
1902	65.0	106.9	120.3	82.1	53.2	133.4	143.5	88.4	139.2	130.2	37.9	141.1	1235.6
1903	92.6	103.0	130.9	64.1	19.0	188.8	111.4	150.3	50.4	144.4	49.7	79.6	1176.9
1904	92.4	56.2	83.0	96.6	84.9	96.3	107.2	116.2	126.2	83.9	36.4	62.5	1036.7
1905	108.3	38.9	77.4	58.2	45.6	111.9	109.9	115.0	125.2	74.4	62.0	90.8	1012.5
1906	64.0	55.8	108.2	82.8	108.7	119.8	118.9	98.4	59.2	113.9	53.5	99.1	1077.2
1907	82.5	50.2	58.3	70.1	78.7	97.6	89.8	51.8	210.8	114.1	114.6	111.4	1127.9
1908	66.2	110.9	71.0	63.5	140.6	50.6	113.8	97.8	39.1	73.7	27.1	70.3	920.8
1909	94.8	125.6	78.9	108.4	78.3	87.3	62.9	72.3	96.2	40.8	49.8	78.2	971.5
1910	127.6	103.1	25.3	108.1	82.0	95.5	50.5	68.2	97.1	40.7	76.5	56.5	927.6
1911	65.6	59.2	75.6	57.5	45.4	110.8	84.8	146.4	91.2	123.6	83.5	79.8	1019.9
1912	53.7	61.1	128.0	93.2	103.3	43.6	83.3	117.6	128.7	81.9	84.0	96.1	1071.9
1913	96.0	57.8	143.9	91.9	86.2	37.3	63.7	88.9	85.4	146.8	67.2	74.8	1038.9
1914	80.5	67.1	89.0	115.9	66.8	85.4	107.9	106.3	23.5	49.8	59.6	87.5	933.9
1915	134.7	114.5	14.9	55.8	70.5	83.9	179.7	175.9	73.1	75.5	59.8	118.3	1152.5
1916	47.1	89.9	86.8	84.5	89.9	120.0	124.8	52.8	113.5	47.8	72.7	84.8	1012.9
1917	80.4	50.8	87.3	48.8	86.3	150.4	98.5	111.7	44.0	157.8	22.7	64.7	1006.4
1918	92.2	58.1	56.6	97.1	100.6	88.6	99.3	80.3	132.5	65.8	56.4	85.6	1011.6
1919	67.6	58.6	107.4	64.8	123.4	72.9	147.7	101.1	84.2	92.2	112.1	53.2	1079.0
1920	56.8	100.2	82.9	117.1	52.2	110.4	124.0	120.2	139.8	46.3	101.6	118.3	1165.9
1921	55.9	73.9	80.6	93.1	76.6	72.3	121.3	84.8	75.5	55.5	144.0	55.1	985.9
1922	56.4	64.3	110.9	68.2	104.3	191.7	103.3	108.7	56.2	63.6	30.4	74.9	1025.6
1923	126.0	47.8	65.3	87.3	66.3	75.2	89.0	63.6	92.5	93.0	81.4	97.0	979.6
1924	96.7	75.9	42.4	123.5	117.9	84.0	81.3	103.4	157.2	13.0	59.1	49.3	1001.2
1925	94.7	64.5	92.8	62.8	71.9	99.8	146.6	58.0	98.4	115.7	95.3	63.0	1062.7
1926	67.6	105.0	54.5	65.3	46.4	79.0	98.8	119.8	99.7	122.1	131.0	65.8	1054.7
1927	59.3	81.9	45.3	63.3	107.6	78.6	113.8	137.0	56.1	169.1	151.1	120.6	1177.3
1928	66.6	80.5	67.4	116.8	70.5	173.0	139.6	154.9	74.0	43.8	54.4	37.9	1073.4
1929	87.3	79.5	73.2	162.0	101.3	84.3	52.2	75.5	81.0	111.9	75.8	92.6	1076.6
1930	65.7	50.1	89.1	57.8	84.3	96.7	74.6	58.1	68.9	41.0	65.6	56.3	808.3
1931	59.4	50.0	76.4	77.0	115.6	114.7	135.0	99.1	76.0	62.2	36.0	75.0	976.2
1932	111.2	57.7	104.3	51.6	76.2	81.8	101.6	96.6	69.8	160.7	155.5	45.5	1112.4
1933	49.0	72.0	110.0	125.6	85.7	56.7	79.8	214.6	147.9	75.9	37.0	70.5	1124.9
1934	74.2	52.4	76.9	94.0	80.2	108.8	93.0	80.1	216.1	55.0	85.2	78.1	1094.0
1935	112.3	61.8	53.2	69.7	53.9	115.8	150.0	54.5	101.5	68.2	124.0	42.5	1007.4
1936	133.5	65.9	168.3	88.9	68.3	85.0	64.0	122.0	60.6	108.1	55.9	132.3	1152.8
1937	136.5	69.4	67.2	102.6	97.5	137.4	88.5	140.0	70.9	136.8	100.1	59.5	1206.4
1938	91.0	63.4	57.7	64.7	83.7	128.5	167.6	101.7	212.5	54.1	76.7	92.1	1193.7
1939	75.5	103.2	88.6	105.2	38.6	84.2	59.1	88.7	76.8	106.3	30.1	69.1	925.5
1940	48.2	76.8	126.3	131.6	109.1	87.7	88.9	91.6	92.2	49.5	117.3	87.6	1106.9
1941	61.7	49.1	57.2	40.4	53.1	98.1	119.7	82.2	33.1	67.6	67.8	85.6	815.6
1942	59.3	64.2	123.0	44.2	111.6	100.9	143.6	113.6	114.3	94.0	99.2	137.3	1205.1
1943	67.3	49.6	75.4	83.3	139.1	86.3	104.3	84.2	31.7	153.7	105.7	25.3	1006.0
1944	50.7	58.7	108.5	95.1	62.7	122.2	64.5	57.2	132.5	72.0	103.7	80.6	1008.3
1945	99.5	76.1	55.5	106.6	144.3	120.2	183.1	88.9	131.7	84.8	129.9	86.0	1306.5
1946	48.2	70.8	52.7	44.9	155.9	107.5	116.6	105.0	102.0	63.4	37.3	72.0	976.3

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

NORTHERN PIEDMONT

Area-Average Annual Precipitation Amount (continued)

Year	Precipitation (mm)												Ann
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	
1947	88.1	50.3	77.7	96.7	156.0	110.9	141.4	57.9	66.5	38.2	134.7	58.8	1077.1
1948	86.2	56.1	86.2	99.4	147.2	126.4	85.3	89.3	28.9	63.0	125.7	131.6	1125.3
1949	116.1	61.1	44.0	93.2	100.9	40.4	106.2	95.2	98.5	63.2	57.8	75.6	952.3
1950	93.3	98.6	101.2	60.9	84.0	90.3	97.7	108.1	78.2	52.6	137.7	107.1	1109.8
1951	82.1	105.0	120.8	86.8	70.9	112.9	128.1	79.7	81.7	87.9	143.2	122.9	1222.2
1952	101.1	65.6	100.0	139.6	129.0	90.1	115.2	105.9	106.6	40.4	96.6	106.7	1196.6
1953	123.3	66.9	152.6	117.3	142.3	61.4	82.8	54.5	74.5	92.1	62.8	103.6	1134.0
1954	62.6	69.0	91.3	96.0	118.5	71.5	62.8	134.3	119.8	65.6	129.3	96.0	1116.6
1955	23.8	91.8	107.1	73.7	56.6	83.9	47.8	257.7	67.3	198.5	83.4	25.2	1167.7
1956	63.2	93.4	114.0	95.7	71.6	83.7	130.4	76.2	114.0	65.2	73.8	105.9	1087.1
1957	49.7	45.4	50.4	102.3	70.7	77.3	75.5	45.9	77.0	65.4	89.1	143.5	892.3
1958	126.5	85.6	83.4	120.2	91.8	79.1	125.0	79.9	114.7	104.1	87.7	29.5	1127.4
1959	82.0	61.0	86.9	80.0	41.7	104.1	89.6	109.7	55.4	159.2	121.9	100.9	1092.5
1960	74.9	108.7	55.1	97.7	120.5	106.5	137.9	101.8	154.8	60.1	55.7	54.2	1128.0
1961	56.1	83.3	85.8	124.9	91.7	97.7	113.5	92.8	59.9	49.0	95.8	73.6	1024.2
1962	77.1	95.8	55.5	105.1	48.4	69.6	69.5	93.4	81.4	115.4	87.8	79.0	978.1
1963	63.7	58.7	86.8	45.2	77.3	76.8	76.7	86.3	76.8	13.9	158.2	57.2	877.6
1964	106.3	60.8	84.5	106.0	35.9	54.0	75.4	63.8	37.6	36.6	61.0	99.9	821.9
1965	64.7	75.0	52.9	64.4	43.9	51.3	61.7	103.0	87.9	85.7	66.3	45.4	802.0
1966	75.9	82.9	66.9	57.1	77.4	54.3	60.5	64.5	134.6	78.9	94.8	80.7	928.5
1967	38.7	55.7	97.8	79.3	109.9	87.1	122.4	130.9	60.3	78.6	80.9	112.1	1053.7
1968	52.8	20.7	92.3	67.2	142.4	126.6	37.4	71.9	91.1	74.8	132.1	104.9	1014.2
1969	48.2	55.2	51.1	94.8	69.0	105.5	134.3	85.3	86.9	51.9	131.9	156.2	1070.1
1970	20.5	83.9	77.5	95.5	80.9	83.9	97.1	81.6	82.2	94.2	102.2	87.4	986.9
1971	57.1	122.2	73.8	49.2	102.4	56.3	115.4	150.1	92.9	77.4	109.6	72.2	1078.5
1972	55.9	104.3	103.3	85.9	137.2	255.1	90.5	57.1	62.2	86.7	194.2	146.2	1378.6
1973	86.5	66.4	74.9	150.1	135.0	140.3	79.9	77.9	94.1	71.0	57.2	192.5	1225.9
1974	81.9	49.8	110.6	86.0	106.1	101.0	89.2	100.2	147.9	42.5	81.9	101.9	1099.1
1975	101.9	83.7	90.3	66.0	96.9	128.8	151.1	116.7	198.9	107.5	102.7	87.3	1331.9
1976	116.1	73.0	74.2	77.9	111.0	103.0	118.9	128.8	92.9	170.1	27.7	58.9	1152.6
1977	52.1	60.6	154.1	103.4	54.7	102.9	77.0	95.0	164.4	139.8	130.8	132.9	1267.8
1978	181.6	29.1	79.0	50.9	116.7	96.5	79.7	108.3	64.8	71.4	50.5	96.8	1025.2
1979	212.4	77.4	82.8	105.9	125.4	50.5	80.7	118.7	141.1	112.2	96.2	48.4	1251.7
1980	29.9	23.9	142.3	123.4	51.4	99.8	79.2	54.7	66.4	90.2	87.5	32.4	881.1
1981	18.4	142.5	23.1	85.2	91.5	106.5	108.5	59.6	105.3	120.7	48.0	89.0	998.5
1982	90.0	76.7	66.1	101.5	76.5	174.8	69.3	73.1	65.7	39.0	98.3	45.9	976.9
1983	82.2	71.2	138.8	212.7	133.6	88.1	47.4	92.9	50.2	99.4	156.9	175.1	1348.5
1984	41.6	103.5	101.3	113.5	212.0	82.0	143.1	76.8	48.1	66.9	74.4	77.2	1140.4
1985	29.5	56.0	63.3	37.4	103.2	95.8	94.0	103.8	130.7	57.7	152.9	47.7	972.0
1986	91.3	82.8	81.1	78.4	67.8	112.8	145.8	115.1	59.7	63.8	137.5	102.0	1137.9
1987	100.2	16.3	62.7	129.2	56.5	93.7	96.7	96.9	164.5	98.5	75.2	52.8	1043.2
1988	54.8	82.0	48.4	61.4	111.5	30.8	153.5	114.3	60.2	64.4	138.8	32.0	952.1
1989	42.6	57.9	77.9	64.6	213.5	153.8	98.8	94.8	125.6	132.5	84.4	30.8	1177.2
1990	104.5	77.8	63.9	93.8	172.2	79.1	90.9	167.7	56.2	162.5	85.5	144.0	1295.6
1991	64.0	40.3	104.0	85.2	82.9	53.9	72.6	134.4	115.3	75.6	87.2	83.5	998.1
1992	55.8	50.6	91.1	66.8	85.2	93.5	135.6	97.6	92.2				

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Precipitation

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

SOUTHERN PIEDMONT

Trends

The annual precipitation time series for the Southern Piedmont region is similar to that of the adjacent Southern Appalachians region: no definitive decadal-scale or long-term trends are apparent.

Area-average annual precipitation amount for the Southern Piedmont region of the United States.

CITE AS: Karl, T.R., D.R. Easterling, and P.Ya. Groisman. 1994. United States historical climatology network—National and regional estimates of monthly and annual precipitation. pp. 830–905. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

SOUTHERN PIEDMONT

Area-Average Annual Precipitation Amount

Precipitation (mm)													
Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1900	63.1	139.2	120.1	129.7	60.8	149.5	108.1	47.5	67.6	80.2	99.4	107.4	1175.4
1901	76.0	47.4	97.9	173.5	189.7	157.3	106.5	254.5	130.7	30.8	33.6	149.9	1436.9
1902	67.2	145.5	101.1	60.9	55.2	117.2	63.3	104.1	104.8	126.4	90.2	102.6	1130.2
1903	88.2	183.7	173.0	98.4	56.8	193.8	67.7	133.5	72.2	69.9	39.0	44.7	1199.8
1904	60.0	83.0	72.1	39.5	70.1	99.7	137.4	149.7	46.0	24.6	70.9	82.9	924.1
1905	58.6	122.8	51.7	97.5	149.2	67.8	164.3	166.3	47.1	49.0	25.4	177.0	1170.4
1906	125.6	47.9	137.1	50.5	76.8	161.8	182.3	206.1	89.2	109.8	30.1	74.7	1280.5
1907	25.5	85.4	61.4	102.7	92.5	159.4	104.1	103.8	140.2	20.0	120.0	141.0	1142.9
1908	118.8	122.4	102.9	83.4	85.1	113.3	134.2	254.2	75.1	117.9	39.0	89.3	1314.2
1909	48.2	104.1	95.2	64.2	127.8	175.7	96.7	110.1	71.7	47.9	18.3	65.4	1015.8
1910	92.0	96.7	36.0	83.8	86.5	179.8	129.9	119.1	64.3	101.7	20.0	65.9	1060.5
1911	62.5	44.2	66.7	82.3	28.1	80.4	76.1	165.7	71.8	141.1	87.9	128.7	1020.9
1912	85.7	116.0	182.9	88.8	122.4	126.2	107.9	63.3	154.3	47.1	79.2	65.1	1223.2
1913	89.9	72.9	162.6	77.6	100.4	116.9	127.5	106.2	114.6	93.6	65.2	97.2	1213.4
1914	74.4	96.8	62.5	71.4	31.7	86.6	108.7	104.9	64.9	79.3	83.8	135.9	986.3
1915	138.4	80.1	59.1	33.2	127.4	106.8	75.8	177.6	55.4	101.8	55.8	77.8	1084.1
1916	47.3	108.8	51.8	54.5	84.6	164.9	244.6	95.7	61.5	59.0	26.9	60.5	1039.5
1917	84.0	86.2	141.3	82.7	80.6	112.7	141.2	83.3	117.8	70.7	20.5	39.6	1060.6
1918	119.2	31.9	63.8	161.6	77.3	81.8	109.6	104.9	93.1	58.4	64.4	121.5	1087.6
1919	111.7	92.5	79.1	72.2	146.6	137.2	238.5	98.3	20.8	79.2	30.3	79.7	1186.4
1920	89.9	96.4	136.6	111.0	47.6	106.0	123.0	185.0	99.5	19.3	120.9	97.7	1233.0
1921	105.0	101.9	50.4	61.7	135.7	63.9	126.7	61.9	75.1	46.0	77.3	46.7	952.3
1922	95.7	150.7	172.0	104.8	123.5	130.2	161.8	99.5	27.5	119.6	14.7	99.0	1298.9
1923	83.9	94.5	134.3	92.8	108.8	54.8	107.2	140.5	86.5	30.1	67.6	83.2	1084.1
1924	108.5	80.8	75.1	132.1	141.7	129.0	123.4	75.2	264.3	35.2	45.2	118.8	1329.4
1925	185.4	44.6	48.3	52.6	57.7	63.1	61.5	61.9	40.0	84.9	72.0	67.7	839.7
1926	127.1	98.0	100.9	53.5	38.5	73.4	157.9	96.9	56.1	46.8	81.5	96.2	1026.6
1927	28.2	101.4	77.0	77.3	48.0	102.9	150.1	111.4	48.0	122.6	44.7	167.6	1079.3
1928	37.9	95.5	80.9	149.4	110.1	143.8	116.7	251.4	271.1	38.5	18.5	40.5	1354.3
1929	77.6	174.0	169.6	113.1	139.3	145.1	121.1	87.8	113.9	214.7	94.6	86.0	1536.9
1930	94.9	28.5	70.9	47.9	68.7	105.7	89.8	49.8	84.9	44.6	85.7	91.0	862.3
1931	56.7	40.7	81.5	95.3	126.6	66.2	133.7	164.3	35.2	22.1	9.5	150.9	982.7
1932	131.1	85.7	112.2	56.3	87.9	133.1	79.8	90.1	64.3	187.4	114.2	142.0	1284.1
1933	73.9	93.7	62.3	80.5	94.1	56.2	123.9	131.4	70.4	42.9	22.8	42.0	894.0
1934	42.7	87.6	115.9	85.4	134.6	113.9	126.0	104.1	128.2	70.0	90.4	70.2	1168.9
1935	84.2	64.8	98.0	98.9	77.0	56.5	137.2	114.6	156.5	35.7	78.7	69.8	1071.7
1936	199.0	113.4	143.0	173.9	13.5	96.3	128.8	109.3	90.4	121.6	41.5	139.2	1370.0
1937	181.1	95.2	54.0	172.5	65.7	130.5	100.6	208.0	63.0	140.3	55.9	49.5	1316.3
1938	54.6	27.8	61.4	113.3	101.7	144.0	176.0	49.6	83.4	29.5	91.6	84.5	1017.3
1939	77.0	197.2	89.3	78.5	68.1	103.6	167.2	164.7	46.8	44.3	41.0	66.7	1144.6
1940	86.0	87.6	72.1	81.1	95.3	85.6	87.6	187.7	27.7	29.9	141.3	66.7	1048.7
1941	48.9	37.7	74.8	68.5	22.9	172.4	210.7	88.0	40.6	34.8	21.1	128.2	948.5
1942	59.3	79.3	161.6	34.7	135.7	123.4	138.2	177.1	108.8	110.0	58.5	105.0	1291.7
1943	113.4	42.8	126.7	88.4	84.8	119.7	140.5	64.7	64.9	23.7	40.7	85.6	995.8
1944	86.2	135.4	195.2	120.1	61.8	60.8	143.3	71.4	161.8	90.0	64.5	50.3	1240.8
1945	65.3	110.3	46.0	83.4	89.4	69.6	176.6	107.0	276.5	39.3	58.0	165.4	1286.7
1946	76.8	75.2	78.1	91.5	125.4	71.7	144.6	103.7	70.4	105.4	57.7	36.7	1037.2

Precipitation

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

SOUTHERN PIEDMONT

Area-Average Annual Precipitation Amount (continued)

Year	Precipitation (mm)												
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1947	130.3	31.4	95.9	89.7	80.7	101.5	111.5	109.1	118.9	92.3	166.0	71.1	1198.5
1948	99.6	98.8	142.3	82.4	142.0	88.1	97.5	130.2	120.1	74.8	196.9	125.5	1398.2
1949	76.3	103.4	55.0	119.9	96.0	81.0	125.3	221.7	82.4	84.1	50.6	49.5	1145.3
1950	61.9	45.9	93.2	34.3	139.1	92.5	146.9	77.3	117.2	72.4	42.8	88.9	1012.4
1951	39.9	51.2	106.0	94.4	34.3	131.1	116.2	69.0	81.9	29.1	85.9	116.5	955.5
1952	88.0	87.3	183.7	108.2	87.7	79.9	84.5	203.5	79.1	28.7	79.1	87.1	1196.9
1953	86.9	112.7	118.4	72.6	89.5	100.5	72.2	67.9	126.7	20.3	28.5	149.7	1045.9
1954	106.1	38.4	104.3	72.9	87.6	59.4	89.4	82.6	22.7	104.9	68.0	72.4	908.8
1955	75.2	86.4	79.7	107.8	98.6	74.5	135.0	182.8	62.5	71.3	58.9	13.8	1046.5
1956	39.8	139.8	95.0	101.8	56.2	70.6	139.9	82.4	147.0	78.9	38.7	72.8	1062.8
1957	69.3	88.2	90.3	76.8	129.2	103.9	52.7	92.4	158.9	62.3	166.5	81.6	1172.1
1958	100.4	97.0	106.8	158.8	102.4	105.6	158.4	116.9	33.6	60.8	27.3	95.7	1163.8
1959	66.4	86.8	116.6	110.4	86.6	81.3	223.3	109.7	168.1	165.6	40.3	67.4	1322.6
1960	133.8	157.6	120.9	84.5	87.5	71.3	130.0	112.7	100.1	55.2	28.0	48.1	1129.6
1961	70.4	153.6	115.7	136.7	91.7	143.1	96.4	159.4	35.6	44.8	54.2	127.1	1228.7
1962	139.2	100.0	124.7	94.4	63.3	136.0	96.4	77.0	121.5	35.6	130.1	73.1	1191.3
1963	92.0	78.5	127.1	69.3	80.2	106.5	87.5	53.9	114.0	4.7	135.7	70.3	1019.8
1964	142.7	125.5	129.5	118.6	51.9	90.1	170.1	166.0	84.4	178.4	49.6	111.8	1418.6
1965	48.9	104.7	159.1	81.7	46.6	157.4	151.6	89.5	68.2	64.3	44.1	15.8	1031.8
1966	130.5	109.0	69.8	67.7	116.2	75.6	77.5	94.7	130.9	74.9	40.1	78.5	1065.5
1967	62.5	86.9	67.3	55.3	127.3	73.8	115.7	176.8	64.2	40.4	68.0	123.0	1061.2
1968	111.9	19.4	79.4	68.4	107.9	125.4	138.9	69.0	34.3	92.6	107.1	69.3	1023.5
1969	64.8	84.8	103.6	112.5	84.8	107.2	120.5	123.6	105.2	37.6	37.1	114.4	1096.1
1970	58.5	79.4	121.5	66.6	75.9	67.9	136.5	140.7	50.1	125.8	63.6	75.3	1062.0
1971	100.1	116.5	133.8	73.8	153.0	87.5	147.7	137.7	108.9	171.9	69.5	43.7	1344.0
1972	107.8	108.1	75.3	58.0	145.9	181.2	117.4	86.1	84.0	89.2	125.7	140.2	1319.0
1973	97.9	114.1	144.2	126.6	109.0	172.1	85.7	101.5	72.9	60.5	27.9	146.6	1258.9
1974	122.4	90.2	78.6	66.4	126.9	91.1	91.4	139.6	121.0	14.4	61.5	132.5	1135.9
1975	137.9	108.9	185.7	66.0	141.0	90.3	213.7	71.7	182.5	58.7	71.6	94.5	1422.5
1976	84.0	36.5	98.0	24.2	146.3	144.2	85.4	66.2	116.3	184.6	77.2	107.6	1170.4
1977	68.3	31.9	145.1	52.5	60.7	84.0	54.8	114.9	111.8	134.6	103.4	89.7	1051.7
1978	199.0	22.2	111.0	101.5	116.5	95.6	140.7	116.0	54.9	28.9	75.8	76.3	1138.2
1979	148.8	157.4	84.4	134.4	116.3	131.2	95.9	93.8	208.8	77.9	109.4	35.6	1393.7
1980	120.7	42.6	211.3	68.3	86.3	80.3	82.5	53.5	128.2	88.4	72.6	29.9	1064.7
1981	17.1	98.0	58.5	45.2	75.9	102.4	146.0	123.2	72.5	82.8	24.0	139.6	985.2
1982	120.3	131.1	57.3	114.4	93.7	170.0	118.4	93.9	67.0	88.2	74.0	106.4	1234.6
1983	68.4	126.5	176.7	147.2	81.6	79.2	51.5	79.7	77.2	98.0	119.4	172.8	1278.2
1984	95.1	137.5	148.7	119.5	142.1	62.9	207.8	113.0	19.7	57.0	52.4	49.2	1203.8
1985	92.4	124.4	26.5	28.9	104.3	85.5	158.1	166.1	17.3	115.3	213.2	31.9	1165.8
1986	33.8	50.3	67.4	28.7	67.8	36.4	83.5	192.1	35.7	85.7	118.3	101.6	898.8
1987	153.5	98.3	117.9	107.2	56.3	116.3	73.7	75.8	193.0	32.1	98.2	70.5	1204.0
1988	85.7	44.5	60.7	71.7	86.7	73.2	102.7	109.1	109.3	74.1	96.7	22.2	951.7
1989	53.6	112.3	131.4	102.9	135.7	172.8	178.8	99.6	131.1	121.9	71.1	80.3	1407.1
1990	98.2	103.2	89.7	67.8	137.2	48.7	82.0	111.2	44.9	277.1	52.9	84.1	1215.6
1991	129.7	52.0	172.4	95.1	97.6	98.4	180.6	123.4	50.6	25.2	44.9	91.2	1171.6
1992	76.2	87.3	94.8	86.1	87.0	125.4	76.4	140.9	92.4				

CITE AS: Karl, T.R., D.R. Easterling, and P.Ya. Groisman. 1994. United States historical climatology network—National and regional estimates of monthly and annual precipitation. pp. 830–905. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

COASTAL NORTHEAST

Trends

The annual precipitation time series for the Coastal Northeast region shows evidence of a generally increasing trend from ca. 1915 to near the end of the record, although a major dry spell during the mid-1960s led to severe to extreme drought in much of this region (Karl and Knight 1985). The other two regions of the northeastern United States—the Northern Appalachians and the Northern Piedmont—also show similar increases. The general trend in all three series is comparable with that of the annual precipitation series produced by Groisman and Easterling (1994) for a region encompassing the northeastern United States and southeastern Canada (shown on p. 778).

Area-average annual precipitation amount for the Coastal Northeast region of the United States.

CITE AS: Karl, T.R., D.R. Easterling, and P.Ya. Groisman. 1994. United States historical climatology network—National and regional estimates of monthly and annual precipitation. pp. 830–905. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Precipitation

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

COASTAL NORTHEAST

Area-Average Annual Precipitation Amount

Year	Precipitation (mm)												Ann
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	
1900	97.1	130.1	96.0	56.9	99.1	89.9	83.0	70.9	91.8	95.4	91.9	60.9	1063.0
1901	63.4	19.3	122.0	153.6	128.9	59.6	129.8	153.0	77.2	51.7	59.9	183.8	1202.3
1902	71.9	130.3	117.5	81.6	48.6	143.3	95.7	75.3	130.2	143.7	59.5	145.7	1243.2
1903	99.6	124.6	151.1	99.1	30.0	145.5	104.1	130.0	59.3	138.7	44.0	82.7	1208.7
1904	78.3	65.8	80.5	102.2	59.5	91.2	118.4	131.7	104.6	74.3	57.1	91.7	1055.5
1905	93.8	63.1	69.1	63.7	64.5	103.5	129.7	131.2	119.9	52.1	50.4	108.0	1046.2
1906	76.5	82.1	137.6	77.3	96.2	124.7	142.7	147.9	50.9	114.9	52.4	89.3	1190.1
1907	72.6	66.8	68.3	85.9	127.0	105.2	69.8	72.7	159.4	87.8	147.5	112.1	1174.3
1908	88.0	108.1	74.0	65.3	121.4	56.9	111.1	148.0	52.4	85.5	29.3	106.7	1046.7
1909	90.8	111.8	97.1	125.8	78.3	97.8	62.4	91.7	97.8	37.7	65.7	92.1	1049.1
1910	122.0	68.4	46.3	103.3	67.7	130.8	55.2	96.3	41.3	91.9	83.2	71.7	978.0
1911	92.0	62.3	81.6	89.0	22.4	84.3	75.0	214.9	65.1	99.8	138.0	94.5	1119.0
1912	86.6	67.0	180.1	83.1	115.2	55.3	97.8	80.7	95.1	54.7	76.2	122.2	1114.1
1913	90.6	60.5	112.8	123.4	85.5	49.7	62.5	101.9	84.4	161.4	49.6	77.1	1059.5
1914	101.1	71.4	88.7	83.8	58.3	74.6	101.9	85.9	22.7	57.3	66.4	124.8	936.9
1915	174.1	109.9	20.5	53.3	81.2	86.3	106.3	180.3	43.1	94.1	40.8	96.0	1085.8
1916	41.1	99.1	76.0	77.6	100.9	119.7	161.8	49.6	71.7	52.2	58.6	106.1	1014.5
1917	74.8	54.5	135.0	70.1	87.0	118.8	129.1	91.3	67.3	157.3	17.3	58.5	1061.1
1918	99.1	48.9	79.8	121.0	79.5	82.9	99.4	76.8	118.0	33.5	47.2	93.8	980.0
1919	96.6	76.5	112.8	87.9	132.8	71.0	185.9	166.0	88.4	81.5	88.7	73.4	1261.6
1920	68.7	131.3	100.4	120.1	72.0	148.4	105.9	152.3	84.1	40.0	117.8	108.9	1249.8
1921	65.5	77.6	69.2	90.0	111.2	59.4	118.2	83.2	59.9	34.5	123.6	60.3	952.6
1922	86.3	86.1	116.6	55.4	85.7	142.1	150.7	144.7	60.8	58.7	25.2	90.4	1102.8
1923	129.9	63.6	123.9	112.9	37.4	71.3	103.9	71.0	83.2	102.1	72.8	98.6	1070.5
1924	102.0	87.6	87.4	135.9	139.1	92.6	55.2	142.2	146.2	13.2	50.5	67.2	1119.1
1925	114.5	50.2	76.5	57.1	59.1	69.4	123.9	68.5	67.2	122.4	84.4	74.8	968.0
1926	75.0	105.7	62.1	51.4	61.5	63.1	131.9	146.4	89.0	109.6	112.1	87.3	1095.2
1927	51.0	82.8	41.6	81.5	82.5	90.8	128.0	179.3	60.8	143.0	92.1	120.7	1154.1
1928	64.0	84.9	68.8	124.4	60.4	123.8	111.6	165.8	148.7	43.0	52.2	58.5	1106.3
1929	77.2	100.1	93.3	151.6	88.1	85.6	50.8	66.1	100.0	106.7	70.8	80.8	1071.1
1930	79.3	65.3	58.9	53.9	69.0	75.0	80.4	47.5	35.5	51.6	76.1	68.2	760.9
1931	62.5	49.6	115.5	78.9	111.2	114.6	102.5	185.6	59.2	80.2	24.6	64.6	1048.7
1932	130.1	62.4	139.4	61.6	91.5	87.3	76.3	76.4	101.8	155.1	139.7	80.1	1201.7
1933	74.2	86.3	99.6	130.2	108.5	69.2	105.3	224.6	136.9	65.9	47.0	84.8	1232.5
1934	66.7	99.6	109.7	88.9	126.9	77.8	89.2	84.0	198.6	64.3	86.0	72.2	1163.8
1935	135.5	78.6	70.5	94.1	62.4	120.4	108.1	73.6	194.3	55.3	126.4	47.9	1167.3
1936	173.5	91.9	137.3	80.9	57.8	102.4	75.7	102.7	113.9	82.2	32.3	174.0	1224.6
1937	174.0	61.5	70.8	137.3	83.8	119.9	80.1	169.3	75.1	137.6	118.2	45.9	1273.4
1938	81.3	64.4	64.4	65.7	106.8	151.5	191.1	71.4	200.2	63.8	84.1	74.6	1219.3
1939	89.0	131.1	118.1	119.1	26.1	97.5	79.9	159.3	66.8	125.0	45.1	54.1	1111.2
1940	62.6	81.5	100.6	141.1	119.7	56.1	78.8	115.5	104.4	56.1	136.9	64.3	1117.6
1941	84.7	50.5	68.1	63.8	54.5	120.3	148.2	94.2	13.8	54.8	56.4	87.3	896.6
1942	84.0	64.5	167.5	27.3	61.9	91.3	130.4	181.5	77.6	124.1	85.2	108.5	1203.9
1943	74.0	56.0	91.6	74.2	114.1	82.9	85.8	55.7	61.6	136.2	78.7	38.5	949.2
1944	78.9	69.4	145.8	109.7	34.5	75.8	53.2	74.4	179.4	73.3	151.3	76.9	1130.7
1945	84.5	88.9	51.7	84.9	120.5	106.7	206.1	73.8	104.9	64.2	131.5	153.0	1279.5
1946	65.3	69.5	59.2	61.2	146.6	100.3	99.2	153.5	72.7	44.4	43.9	69.7	991.2

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

COASTAL NORTHEAST

Area-Average Annual Precipitation Amount (continued)

Year	Precipitation (mm)												Ann
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	
1947	98.4	45.1	61.4	95.8	130.2	109.4	105.1	66.9	81.2	44.6	147.9	63.9	1050.0
1948	138.1	63.8	95.6	90.6	201.5	113.9	106.2	138.2	51.2	93.1	140.3	128.6	1371.5
1949	128.0	98.0	71.6	79.1	108.2	33.0	76.1	100.6	95.6	68.8	65.8	60.7	996.9
1950	67.7	83.7	97.4	60.4	92.3	78.2	122.3	102.4	99.9	51.5	117.4	90.4	1075.7
1951	72.0	89.8	94.7	82.3	94.9	108.8	90.7	86.4	56.1	81.2	165.0	125.1	1160.8
1952	132.1	80.3	113.7	132.8	111.8	83.4	74.4	193.3	74.0	33.6	113.5	90.8	1233.7
1953	123.2	87.1	176.0	120.9	121.7	59.8	97.3	116.3	63.9	100.6	90.3	110.9	1268.1
1954	73.8	55.1	91.8	102.1	107.2	46.7	62.6	156.1	118.2	75.2	106.9	107.9	1103.6
1955	20.7	87.2	111.7	73.8	51.4	108.0	64.5	300.3	81.4	138.1	83.0	18.4	1138.6
1956	81.7	102.9	112.6	74.5	68.6	82.1	152.5	70.3	83.6	107.1	111.4	103.0	1150.4
1957	63.9	75.0	83.4	79.1	47.2	67.6	45.4	88.5	81.5	79.4	107.7	155.7	974.5
1958	139.1	103.7	137.2	140.5	114.7	91.7	146.5	181.6	82.1	106.6	70.7	58.7	1373.2
1959	57.7	59.0	108.6	89.4	46.8	106.0	179.9	107.3	45.6	125.4	118.4	102.5	1146.5
1960	77.1	125.3	63.9	80.0	120.3	49.7	165.9	91.2	196.7	82.2	68.2	89.0	1209.4
1961	80.0	112.3	107.5	125.9	123.9	93.5	94.5	101.1	89.4	104.0	74.0	100.8	1206.8
1962	96.4	104.3	80.2	107.7	46.3	111.5	72.6	88.7	94.5	97.1	144.2	84.6	1128.2
1963	69.4	67.3	123.6	33.7	78.6	105.9	62.5	79.8	113.1	24.1	173.6	60.5	992.2
1964	111.3	101.6	66.1	129.3	25.5	52.0	100.9	50.7	102.0	71.2	54.2	113.2	978.1
1965	80.5	68.5	75.7	67.6	39.7	56.8	79.7	108.0	61.2	51.2	44.3	35.6	768.9
1966	92.9	94.0	49.9	69.8	110.4	50.8	56.6	47.9	169.7	106.9	71.5	83.5	1003.9
1967	44.2	75.7	104.2	64.3	135.3	78.7	120.1	208.3	68.1	52.1	72.6	161.1	1184.6
1968	69.2	27.3	138.9	45.3	116.8	124.1	52.3	72.5	53.3	68.3	128.2	106.2	1002.4
1969	51.7	86.5	81.0	86.4	67.3	70.1	159.3	149.0	106.4	48.6	101.2	202.2	1209.6
1970	29.3	91.4	106.5	112.5	78.4	100.3	95.4	91.2	47.3	78.2	115.6	90.3	1036.5
1971	71.2	145.0	77.3	66.3	131.5	41.2	106.3	177.0	90.1	138.1	119.2	58.6	1221.9
1972	72.4	139.6	109.1	99.9	130.2	231.0	86.1	55.7	105.5	119.2	180.7	150.5	1479.8
1973	88.1	88.3	88.8	166.2	108.9	112.0	102.6	106.9	82.4	86.3	52.2	178.1	1260.9
1974	98.2	56.8	119.1	72.7	100.0	97.6	46.0	125.6	135.4	46.2	42.9	124.0	1064.5
1975	130.8	80.7	123.2	83.7	97.5	125.3	184.6	81.9	205.2	96.8	111.1	101.1	1422.0
1976	144.3	59.9	69.4	49.7	98.1	48.7	94.9	132.3	81.9	177.6	27.5	80.0	1064.3
1977	71.0	50.3	106.0	81.7	60.1	107.1	69.1	105.3	115.1	141.9	131.6	164.7	1204.0
1978	207.2	36.3	112.2	64.7	159.7	67.7	109.4	131.7	55.1	60.2	76.2	119.5	1199.9
1979	235.2	137.3	92.7	105.2	147.7	81.8	95.6	169.0	164.7	115.2	102.1	51.3	1497.9
1980	64.4	29.6	168.6	137.6	63.9	73.2	97.1	55.2	58.4	113.1	87.5	33.8	982.4
1981	21.5	112.7	34.7	97.6	98.5	99.4	100.1	73.4	99.8	89.1	48.4	127.6	1002.8
1982	114.8	89.4	74.1	117.5	62.1	170.1	92.5	74.2	70.9	61.5	104.5	64.4	1096.0
1983	77.0	93.9	177.1	219.6	133.5	93.0	52.2	91.7	73.7	117.9	178.7	170.7	1479.0
1984	65.3	122.7	160.0	116.7	180.0	100.3	153.3	52.9	51.6	72.3	71.0	63.2	1215.2
1985	49.7	69.3	59.3	25.6	122.7	98.5	88.6	165.2	121.3	63.1	156.1	33.2	1052.6
1986	108.4	82.8	56.7	72.9	38.5	60.4	118.3	126.0	36.7	62.6	140.6	159.0	1062.9
1987	151.9	38.1	89.6	124.0	70.0	73.5	78.1	71.8	134.9	69.2	92.9	77.9	1071.9
1988	84.0	112.3	75.3	67.9	109.4	35.2	148.7	82.1	69.1	74.4	173.5	28.1	1060.2
1989	56.9	84.5	125.6	114.1	181.8	156.8	156.5	110.2	142.4	131.4	99.8	39.9	1399.9
1990	114.1	55.3	73.1	107.4	176.2	55.9	117.8	148.7	60.7	108.6	53.8	118.5	1190.0
1991	100.8	37.5	136.8	84.5	58.3	62.2	108.7	139.7	117.0	69.4	59.8	106.1	1083.8
1992	67.0	64.8	99.7	52.4	76.5	89.6	110.5	143.0	114.4				

CITE AS: Karl, T.R., D.R. Easterling, and P.Ya. Groisman. 1994. United States historical climatology network—National and regional estimates of monthly and annual precipitation. pp. 830–905. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Precipitation

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

COASTAL SOUTHEAST

Trends

The annual precipitation time series for the Coastal Southeast region reveals no readily apparent decadal-scale or long-term trends.

Area-average annual precipitation amount for the Coastal Southeast region of the United States.

CITE AS: Karl, T.R., D.R. Easterling, and P.Ya. Groisman. 1994. United States historical climatology network—National and regional estimates of monthly and annual precipitation. pp. 830–905. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

COASTAL SOUTHEAST

Area-Average Annual Precipitation Amount

Year	Precipitation (mm)												Ann
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	
1900	93.4	115.9	138.6	124.9	70.3	208.8	151.7	98.5	97.5	100.7	63.8	122.8	1398.4
1901	79.4	94.5	110.2	77.8	138.9	211.3	185.3	231.9	134.7	35.4	29.0	89.3	1426.3
1902	32.7	131.0	107.7	50.3	59.6	141.5	137.3	144.8	150.7	120.0	81.8	100.9	1261.0
1903	120.8	130.1	153.5	46.9	119.5	181.8	146.7	199.0	132.6	65.2	39.3	56.0	1401.0
1904	103.7	93.3	78.1	29.5	66.4	148.0	189.5	214.5	87.7	65.9	67.7	53.3	1192.8
1905	45.2	119.9	95.3	100.4	140.8	88.0	212.7	201.6	114.8	55.5	22.5	161.9	1356.2
1906	109.5	88.1	98.4	33.8	136.3	241.5	286.9	219.2	84.0	87.9	17.1	54.4	1457.2
1907	22.4	58.7	34.9	109.9	129.1	196.9	177.8	173.8	153.0	23.0	58.8	112.6	1245.7
1908	101.8	102.1	79.8	97.4	99.1	143.8	214.4	193.6	139.2	80.5	34.0	51.6	1334.9
1909	35.0	73.2	91.6	86.8	108.0	179.2	203.8	190.7	89.5	34.1	20.9	59.1	1172.4
1910	53.3	103.1	49.3	45.5	93.0	258.1	182.5	218.7	89.6	155.2	37.1	39.6	1325.2
1911	38.5	21.8	63.9	52.7	64.0	111.0	122.8	209.9	100.6	106.1	74.3	101.2	1063.5
1912	132.6	109.5	131.8	107.1	155.1	243.4	148.8	130.5	187.4	62.1	44.4	79.0	1538.2
1913	68.3	123.7	138.0	47.0	69.7	168.1	157.7	155.5	120.6	96.6	25.1	81.7	1246.4
1914	82.8	153.1	64.4	71.2	43.5	124.3	150.3	175.9	132.4	104.9	72.9	88.9	1263.7
1915	159.7	81.9	67.1	48.6	184.8	125.3	163.7	181.0	102.3	122.1	49.1	63.1	1348.1
1916	42.6	51.9	51.8	55.0	87.4	174.2	276.5	135.4	77.1	90.6	47.9	84.0	1172.4
1917	70.3	62.5	78.9	55.5	77.9	169.1	225.1	167.9	178.2	41.9	16.5	49.1	1186.1
1918	69.6	29.9	62.9	160.1	70.6	122.0	166.6	160.3	133.5	64.0	73.5	112.7	1225.1
1919	68.8	128.9	109.5	48.8	123.9	168.2	262.9	197.0	77.4	48.0	35.1	44.3	1306.5
1920	55.9	129.1	92.0	161.2	72.7	134.7	192.6	228.6	158.3	25.0	91.6	116.0	1453.7
1921	64.0	68.3	57.8	77.3	165.3	109.7	291.7	131.9	61.3	94.6	57.2	48.5	1225.9
1922	79.1	128.4	110.8	56.4	197.1	214.1	206.2	194.4	104.9	142.1	17.9	107.0	1555.1
1923	71.0	56.9	81.5	64.5	179.7	116.9	200.9	162.3	104.8	44.8	37.4	57.0	1172.1
1924	104.3	96.7	111.5	103.4	97.3	182.7	206.6	106.2	311.7	103.3	19.3	83.9	1516.9
1925	144.0	63.8	45.6	54.5	96.5	148.2	165.1	137.8	54.7	72.5	78.3	142.5	1203.5
1926	144.7	89.4	104.1	77.8	56.2	177.6	203.1	137.9	115.6	42.9	72.9	36.1	1257.4
1927	16.4	82.9	74.8	34.2	40.4	184.5	212.0	186.5	77.1	80.1	35.2	87.8	1104.7
1928	19.6	134.1	98.6	148.8	86.7	176.6	210.8	209.3	343.8	54.2	26.8	53.1	1554.1
1929	106.2	105.3	89.9	72.4	159.2	186.7	164.3	164.1	223.5	108.0	57.3	96.7	1519.5
1930	103.5	54.4	135.3	90.6	76.8	217.6	157.2	94.3	191.4	53.7	54.0	105.6	1334.7
1931	78.3	46.2	104.1	86.9	85.0	79.6	155.0	175.9	71.6	27.8	10.7	78.8	999.2
1932	61.7	54.4	81.9	32.3	129.1	210.0	100.8	210.2	139.3	115.9	110.6	50.1	1293.4
1933	68.7	124.5	68.3	125.2	77.6	120.9	212.7	176.4	173.5	69.1	33.4	13.3	1267.3
1934	37.3	96.2	78.6	85.5	167.0	175.5	170.9	155.6	122.5	61.3	54.4	48.0	1249.6
1935	60.3	57.3	43.1	83.5	74.2	101.1	285.8	196.8	239.5	31.0	37.4	70.7	1277.4
1936	105.1	133.4	119.4	74.9	61.4	188.6	176.7	154.1	107.6	157.0	50.4	106.5	1423.4
1937	94.6	123.4	88.5	155.3	57.6	161.5	221.2	191.6	122.2	98.8	95.0	41.2	1453.1
1938	42.2	26.7	37.4	95.8	117.4	156.3	207.1	108.6	187.2	93.7	46.6	50.0	1162.9
1939	58.4	131.4	58.6	97.4	99.3	201.4	206.2	212.4	108.2	70.7	35.5	47.3	1325.1
1940	82.3	113.2	80.0	63.4	61.9	140.6	157.1	238.1	110.4	14.5	41.4	95.7	1196.3
1941	62.7	73.8	105.0	97.6	22.5	241.9	229.7	154.2	103.0	95.9	54.5	146.0	1389.3
1942	78.3	93.3	162.8	36.4	93.3	220.6	161.9	163.8	116.0	53.4	28.7	91.7	1291.0
1943	76.4	24.3	128.6	65.9	112.0	141.1	238.7	184.4	102.2	31.8	36.9	76.5	1216.0
1944	85.0	99.3	195.1	106.4	70.3	103.3	205.0	175.8	133.5	134.2	43.1	32.0	1376.9
1945	65.2	66.6	28.4	81.7	61.0	176.0	288.2	233.0	296.8	64.5	36.3	144.2	1541.7
1946	72.3	67.0	83.8	64.4	164.5	161.3	265.6	189.6	150.8	92.3	69.9	26.0	1398.7

Precipitation

United States historical climatology network—National and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

COASTAL SOUTHEAST

Area-Average Annual Precipitation Amount (continued)

Year	Precipitation (mm)												Ann
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	
1947	64.2	49.7	173.3	121.6	104.2	195.0	216.7	190.3	245.0	148.9	156.8	106.2	1780.3
1948	114.6	70.1	159.4	110.1	118.2	86.5	229.1	147.2	207.2	98.2	122.9	100.9	1571.2
1949	23.8	85.9	37.9	105.3	85.1	207.0	164.1	290.4	178.3	63.0	50.5	45.2	1339.5
1950	23.5	26.4	101.7	44.3	107.6	93.6	247.0	131.7	212.7	135.5	28.2	83.5	1240.4
1951	21.4	40.8	86.1	92.9	42.3	130.7	206.2	130.6	145.1	94.8	90.5	75.6	1158.6
1952	40.5	130.1	107.5	57.8	100.8	99.3	136.8	203.2	151.4	100.7	54.7	54.5	1241.7
1953	69.6	108.9	113.0	101.4	51.9	156.6	156.9	223.1	232.7	59.7	64.8	142.1	1480.9
1954	55.6	39.3	68.5	87.5	120.3	78.9	147.0	107.9	139.9	81.9	58.5	66.9	1052.0
1955	91.9	45.8	42.9	70.8	87.3	147.4	160.7	201.1	235.2	63.8	41.8	25.7	1214.4
1956	49.3	94.8	50.1	78.3	93.6	122.6	150.3	141.7	147.3	131.2	19.5	25.5	1104.2
1957	43.2	78.5	113.3	72.8	163.8	174.2	168.0	173.3	200.0	70.8	104.1	77.8	1439.8
1958	120.4	79.2	141.5	128.1	120.1	164.4	129.8	177.7	97.6	117.6	33.2	78.9	1388.4
1959	78.1	106.2	190.7	86.3	129.5	140.4	227.8	155.9	194.6	190.3	58.0	62.9	1620.7
1960	86.1	124.4	131.0	83.9	75.0	128.9	299.9	126.9	255.8	70.4	27.1	46.6	1456.1
1961	71.5	98.1	79.4	135.8	113.9	158.8	144.4	229.0	73.9	34.6	45.4	54.3	1239.1
1962	86.1	50.1	114.6	76.2	46.4	238.0	153.8	166.0	183.5	53.0	91.5	63.8	1322.8
1963	91.0	119.2	47.4	45.3	116.1	178.9	147.1	117.5	174.3	34.5	101.0	72.2	1244.5
1964	156.4	153.4	86.6	78.4	82.5	134.2	252.9	198.7	179.6	156.2	39.0	98.9	1616.8
1965	37.0	127.1	137.3	62.3	56.1	184.7	223.7	156.1	125.6	82.8	32.8	44.5	1270.0
1966	133.5	113.6	81.6	56.8	178.4	175.1	177.2	147.4	131.2	52.4	20.0	58.4	1325.7
1967	95.7	100.8	28.9	29.6	88.7	141.2	216.8	218.0	90.4	43.2	34.0	85.5	1172.8
1968	63.1	41.0	45.6	48.0	113.4	188.7	176.8	133.1	98.0	160.3	79.6	56.6	1204.2
1969	52.1	66.4	134.4	64.8	128.0	167.4	160.9	227.8	172.7	96.7	90.3	97.8	1459.4
1970	78.6	95.0	179.7	44.3	108.6	96.0	164.7	175.5	110.2	94.6	23.0	57.9	1228.1
1971	81.5	94.4	100.8	69.7	88.4	136.1	183.2	223.9	116.0	172.1	47.5	65.3	1378.8
1972	104.7	109.1	95.0	37.4	132.8	170.3	128.2	166.4	68.5	56.1	128.1	90.1	1286.5
1973	111.5	106.6	120.3	112.9	83.0	189.1	155.8	177.5	127.3	37.9	24.3	128.3	1374.5
1974	49.1	81.5	78.2	51.6	129.3	224.7	176.1	224.4	148.7	21.8	37.2	85.7	1308.4
1975	99.1	86.5	87.7	82.6	119.0	124.0	212.6	106.5	193.0	79.2	43.6	76.9	1310.7
1976	65.7	33.2	59.1	36.7	198.6	175.4	127.8	144.6	154.6	85.8	83.8	112.8	1278.4
1977	83.1	50.6	89.8	32.3	92.8	108.8	127.1	175.3	147.5	66.7	80.5	126.3	1180.9
1978	118.3	69.9	89.6	79.3	113.4	116.7	178.5	135.1	79.7	36.9	57.3	82.1	1156.8
1979	136.5	97.3	68.6	81.6	179.4	129.7	151.0	136.6	316.5	30.0	81.7	65.2	1474.2
1980	98.2	50.9	160.6	84.8	103.2	95.3	128.7	84.3	135.0	77.6	76.1	51.1	1145.7
1981	25.5	75.0	70.6	28.8	92.9	129.4	164.4	251.3	58.0	44.1	43.1	99.4	1082.4
1982	95.7	100.3	90.7	135.0	98.4	246.7	188.2	143.1	148.0	81.9	51.2	77.8	1456.9
1983	112.5	169.9	195.3	101.9	42.9	161.8	130.8	101.1	159.1	86.7	94.3	137.5	1493.7
1984	81.6	109.9	138.6	96.1	135.7	89.1	214.5	115.8	177.2	38.4	57.1	17.0	1271.2
1985	56.0	72.0	49.6	44.6	70.5	137.6	181.6	194.9	131.0	131.2	110.3	51.7	1230.9
1986	80.0	79.5	94.6	19.0	59.2	128.4	124.7	239.4	70.8	91.5	83.0	115.1	1185.2
1987	150.7	109.9	161.8	41.4	73.1	120.9	127.0	160.8	178.7	43.0	112.0	36.0	1315.4
1988	107.9	79.8	86.4	81.6	84.5	96.1	107.7	202.7	192.5	44.9	84.7	25.6	1194.5
1989	51.1	46.3	97.6	98.3	74.7	166.8	168.6	153.8	203.9	92.9	49.1	108.1	1311.1
1990	58.9	74.5	60.8	46.6	84.8	87.7	126.4	200.4	56.4	167.4	47.1	39.5	1050.5
1991	176.7	39.1	131.0	111.9	141.8	151.9	254.2	176.6	89.8	59.8	33.8	40.5	1407.0
1992	108.2	74.7	83.4	71.6	81.9	227.9	97.3	263.0	130.1				

CITE AS: Karl, T.R., D.R. Easterling, and P.Ya. Groisman. 1994. United States historical climatology network—national and regional estimates of monthly and annual precipitation. pp. 830–905. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

United States historical climatology network—national and regional estimates of monthly and annual precipitation

T.R. Karl, D.R. Easterling, and P.Ya. Groisman (continued)

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Precipitation

Area-average precipitation over the main part of the former USSR

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Period of Record

1891–1993

Methods

Groisman, Koknaeva, Belokrylova, and Karl have produced an area-average time series of precipitation amount from 500 stations within a region of the former USSR extending from 37° to 70° N and from 25° to 140° E. These stations were selected from the 600-station precipitation archive of the former USSR (Vinnikov et al. 1990). Their first step in producing an unbiased series (i.e., one which reflects only changes in precipitation amount and not changes in how precipitation was measured) was to constrain the period of record to 1891–1993, because most gauges before 1891 were not uniform in design and because adequate descriptions of the gauges have not survived (Groisman et al. 1991). During the

The main part of the former USSR (37°–70° N and 25°–140° E), for which the precipitation data were analyzed.

CITE AS: Groisman, P.Ya., V.V. Koknaeva, T.A. Belokrylova, and T.R. Karl. 1994. Area-average precipitation over the main part of the former USSR. pp. 906–910. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Area-average precipitation over the main part of the former USSR

P.Ya. Groisman, V.V. Koknaeva, T.A. Belokrylova, and T.R. Karl (continued)

selected 103-year period, however, there still were a number of important changes in the operation of the USSR precipitation gauge network.

These changes include the following. (1) Gauges began to be standardized in 1891 (the process took many years to complete for the entire network): the gauge orifice was positioned 2 m above ground level and the Nipher wind shield was installed around the gauge orifice to prevent undercatch of solid precipitation as a result of the aerodynamic effects of the wind around the gauge. (2) New observing stations were established at airports, and some stations were moved to airports; as a result, gauges were more in the open and thereby exposed more to the effects of wind. (3) Over time, the stations changed the number of times per day that precipitation was measured; in turn, gauge-wall wetting corrections were altered, thus affecting the magnitude of the evaporation losses between measurements. (4) Stations switched from the Nipher-shielded gauge to the Tretiyakov gauge in the late 1940s and early 1950s to further increase the accuracy of measuring solid precipitation. Groisman et al. (1991) give full details on these and other changes in the operation of the network and describe methods by which the measurements were homogenized to compensate for the changes and thus allow the construction of an effectively unbiased time series.

CITE AS: Groisman, P.Ya., V.V. Koknaeva, T.A. Belokrylova, and T.R. Karl. 1994. Area-average precipitation over the main part of the former USSR. pp. 906–910. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Precipitation

Area-average precipitation over the main part of the former USSR

P.Ya. Groisman, V.V. Koknaeva, T.A. Belokrylova, and T.R. Karl (continued)

MAIN PART OF THE FORMER USSR

(37°–70° N and 25°–140° E)

Trends

The area-average precipitation time series for the former USSR exhibits a linear increase of 9% per 100 years; this increase is significantly different from zero at the 5% level (Vinnikov et al. 1990). The direction of this trend is consistent with climate-modeling experiments using increased concentrations of greenhouse gases; however, the magnitude of the precipitation trend is considerably greater than the models would suggest (Groisman 1991).

Annual precipitation amount for the main part of the former USSR.

CITE AS: Groisman, P.Ya., V.V. Koknaeva, T.A. Belokrylova, and T.R. Karl. 1994. Area-average precipitation over the main part of the former USSR. pp. 906–910. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Area-average precipitation over the main part of the former USSR

P.Ya. Groisman, V.V. Koknaeva, T.A. Belokrylova, and T.R. Karl (continued)

MAIN PART OF THE FORMER USSR (37°–70° N and 25°–140° E)

Area-Average Annual Precipitation Amount (mm), 1891–1993

Year	Precipitation amount	Year	Precipitation amount	Year	Precipitation amount
1891	437.1	1926	506.6	1961	550.3
1892	440.5	1927	533.3	1962	537.6
1893	468.0	1928	525.8	1963	528.9
1894	469.6	1929	485.7	1964	507.4
1895	504.0	1930	518.4	1965	535.4
1896	474.4	1931	494.4	1966	562.4
1897	476.8	1932	514.9	1967	502.5
1898	440.6	1933	490.3	1968	509.2
1899	484.8	1934	469.0	1969	521.9
1900	501.9	1935	519.5	1970	525.9
1901	477.1	1936	507.1	1971	519.8
1902	504.5	1937	503.2	1972	502.5
1903	491.9	1938	517.6	1973	523.3
1904	460.2	1939	505.0	1974	485.2
1905	500.8	1940	520.3	1975	500.4
1906	514.6	1941	533.9	1976	483.8
1907	481.3	1942	522.6	1977	534.8
1908	499.3	1943	518.5	1978	546.0
1909	464.1	1944	501.2	1979	530.5
1910	462.3	1945	516.5	1980	519.2
1911	473.2	1946	517.3	1981	532.1
1912	507.0	1947	524.0	1982	543.0
1913	502.7	1948	551.8	1983	546.6
1914	510.7	1949	528.6	1984	475.4
1915	519.8	1950	522.2	1985	511.9
1916	492.7	1951	515.4	1986	492.8
1917	454.6	1952	539.4	1987	517.3
1918	471.6	1953	552.9	1988	529.3
1919	497.1	1954	520.3	1989	526.7
1920	455.5	1955	521.2	1990	553.7
1921	477.4	1956	542.8	1991	527.6
1922	524.7	1957	556.2	1992 ^a	552.9
1923	512.3	1958	570.1	1993 ^a	541.6
1924	498.4	1959	525.2		
1925	509.6	1960	532.7		

^aPreliminary data.

CITE AS: Groisman, P.Ya., V.V. Koknaeva, T.A. Belokrylova, and T.R. Karl. 1994. Area-average precipitation over the main part of the former USSR, pp. 906–910. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

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Century-scale series of annual and seasonal precipitation anomalies for East Asia (15°–60° N; 70°–140° E)

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Period of Record

1880–1992

Methods

These time series of annual and seasonal precipitation anomalies for East Asia have been derived mainly from the global monthly precipitation dataset held in the Climatic Research Unit at the University of East Anglia. They are supplemented by a 160-station monthly dataset for China covering the period 1951–90, which was obtained from the Long Range Forecast Division of the Chinese State Meteorological Administration (Hulme et al. 1994). East Asia, as defined here, includes the whole of the Peoples Republic of China and the surrounding territories within the region between the parallels 15° and 60° N and between the meridians 70° and 140° E. Monitoring of precipitation trends over this region has particular significance because it contains ~20% of the earth's land area (~30 million km²) and ~50% of the world's population. Time series of annual, winter (December–February), and summer (June–August) precipitation anomalies are expressed as percent departures from the 1951–80 mean.

East Asia (15°–60° N; 70°–140° E) and the locations of the precipitation stations used in the analysis.

CITE AS: Hulme, M., and Z. Zhao. 1994. Century-scale series of annual and seasonal precipitation anomalies for East Asia (15°–60° N; 70°–140° E). pp. 911–917. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Precipitation

Century-scale series of annual and seasonal precipitation anomalies for East Asia (15°–60° N; 70°–140° E)

M. Hulme and Z. Zhao (continued)

EAST ASIA

(15°–60° N; 70°–140° E)

Trends

The annual time series of East Asian precipitation anomalies shows a weak tendency for increasing precipitation over the last 100 years. The annual series bears a great resemblance to that for the summer season (June–August), because, in general, for this region of the world most rainfall is received in the summer months (owing to the Indian and East Asian monsoon). The winter (December–February) series shows no obvious century-scale trend, but many relatively dry years are apparent over the period 1960–90, when interannual variability was seemingly smaller than that for the first 80 years of the series.

Hulme et al. (1994) note that the series show a much greater relative variability of winter precipitation as compared with summer (mean interannual variability of 25.7% in the winter and 6.3% in the summer), although in absolute terms summer precipitation variability is larger (20.1 mm, as compared with 10.2 mm for winter).

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Century-scale series of annual and seasonal precipitation anomalies
for East Asia (15°–60° N; 70°–140° E)

M. Hulme and Z. Zhao (continued)

EAST ASIA
(15°–60° N; 70°–140° E)

Annual, winter (December–February), and summer (June–August) precipitation anomalies for East Asia. Values are percent anomalies from the 1951–80 reference period. The smooth curves represent the effect of a 10-point Gaussian filter, which suppresses variations on time scales of less than a decade.

CITE AS: Hulme, M., and Z. Zhao. 1994. Century-scale series of annual and seasonal precipitation anomalies for East Asia (15°–60° N; 70°–140° E). pp. 911–917. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Precipitation

Century-scale series of annual and seasonal precipitation anomalies for East Asia (15°–60° N; 70°–140° E)

M. Hulme and Z. Zhao (continued)

EAST ASIA

(15°–60° N; 70°–140° E)

Precipitation Anomalies^a

Year	Winter ^b		Summer		Annual	
	Number of stations	Percent anomaly	Number of stations	Percent anomaly	Number of stations	Percent anomaly
1880			38	–9.81	35	–11.36
1881	37	–44.22	45	–0.63	42	–6.34
1882	46	1.38	45	–0.27	41	–0.37
1883	48	–6.64	51	–10.30	48	–7.89
1884	50	–5.23	49	–13.23	46	–7.42
1885	48	24.94	48	3.37	45	0.96
1886	46	52.19	55	0.47	48	4.40
1887	59	25.56	61	–1.93	58	–5.08
1888	61	31.38	63	–13.63	60	–10.45
1889	64	6.53	65	7.86	62	1.39
1890	66	–29.63	66	0.07	62	1.15
1891	66	29.72	70	–6.28	66	–4.25
1892	70	–0.97	74	3.56	68	4.03
1893	74	15.89	75	–12.22	71	0.69
1894	76	–10.74	75	–7.05	70	–0.71
1895	74	3.07	76	–6.12	71	–10.90
1896	76	–24.72	78	0.80	72	–7.41
1897	79	–5.59	82	–2.56	76	–0.74
1898	80	12.33	83	–5.23	75	–5.63
1899	85	–1.44	86	–17.77	80	–21.11
1900	86	–22.31	86	–12.31	81	–10.41
1901	87	35.27	91	–1.88	82	–9.74
1902	93	–39.73	93	–16.35	86	–10.18
1903	95	60.78	94	5.50	89	2.03
1904	93	–22.66	92	–16.77	88	–13.11
1905	89	7.03	94	–0.07	83	–5.85
1906	93	82.61	94	1.39	88	1.01
1907	94	36.50	96	–6.56	88	–4.21
1908	100	10.74	100	7.79	94	4.93
1909	96	–15.88	100	1.37	95	0.27
1910	103	16.88	110	3.77	103	–1.90
1911	110	–9.36	116	–2.36	107	0.65
1912	111	13.09	113	–1.03	105	–4.22
1913	111	–6.16	113	–13.31	106	–11.70
1914	112	30.01	119	–1.29	108	7.33
1915	115	55.20	118	–4.01	110	3.50
1916	118	–8.53	122	0.21	114	1.47
1917	122	–6.77	124	5.41	115	5.19
1918	120	–36.72	124	–8.45	113	–10.20
1919	123	38.57	125	0.11	111	–4.41
1920	119	18.38	123	–7.11	112	–6.91
1921	120	–4.39	131	–2.80	121	–3.60
1922	128	4.90	134	–2.63	127	–3.90
1923	136	6.42	137	–1.15	131	–1.36
1924	136	–1.53	142	–2.37	136	–3.51
1925	140	–24.24	146	–7.05	137	–7.20

Century-scale series of annual and seasonal precipitation anomalies
for East Asia (15°–60° N; 70°–140° E)

M. Hulme and Z. Zhao (continued)

EAST ASIA
(15°–60° N; 70°–140° E)

Precipitation Anomalies (continued)^a

Year	Winter ^b		Summer		Annual	
	Number of stations	Percent anomaly	Number of stations	Percent anomaly	Number of stations	Percent anomaly
1926	145	14.33	146	-1.60	136	-2.23
1927	143	12.60	140	-8.30	130	-4.41
1928	138	44.01	144	-2.36	134	-1.96
1929	137	8.37	140	-5.46	128	-8.98
1930	133	40.66	142	-9.69	127	-5.12
1931	142	-8.78	153	2.84	135	1.59
1932	159	-2.65	165	0.79	149	-4.16
1933	158	-12.19	172	0.89	160	-0.29
1934	171	8.07	176	0.93	163	-1.11
1935	170	21.44	174	-0.08	166	-1.82
1936	173	2.41	205	-4.27	193	-4.69
1937	215	25.63	230	3.76	195	2.37
1938	207	5.70	214	3.66	182	1.28
1939	200	-20.18	206	-9.82	190	-9.27
1940	207	-5.43	227	-3.74	211	-5.29
1941	223	5.61	231	-5.00	213	-6.54
1942	222	-6.76	228	-4.35	210	-2.24
1943	202	-9.23	207	-0.31	190	-4.83
1944	200	-3.42	200	-11.06	178	-8.33
1945	189	23.93	193	-1.79	177	-2.22
1946	197	-13.48	208	5.45	191	-0.71
1947	198	-2.92	202	4.06	186	-0.04
1948	208	43.90	206	1.57	190	3.07
1949	195	-4.81	202	4.33	178	2.51
1950	188	2.30	209	-4.62	190	-2.53
1951	211	-15.80	355	-5.40	343	-2.68
1952	358	-12.38	368	-0.49	355	-1.46
1953	370	-2.03	413	0.99	398	2.34
1954	414	40.86	438	15.33	424	9.93
1955	435	-1.53	443	1.77	428	-0.89
1956	443	-0.77	451	6.01	438	5.06
1957	445	26.64	452	-3.13	440	-3.13
1958	443	15.09	453	2.21	439	2.90
1959	444	44.70	452	11.34	440	13.34
1960	444	-15.47	454	-0.85	438	-1.40
1961	436	-9.86	447	0.25	426	5.41
1962	435	-7.07	449	-0.53	426	-3.66
1963	443	-30.02	453	-2.46	435	-4.18
1964	442	7.10	454	3.67	436	9.20
1965	440	-24.43	449	-9.06	436	-10.56
1966	443	3.33	454	-1.97	436	-4.68
1967	443	-12.30	450	-2.62	438	-0.22
1968	439	1.07	451	-4.46	436	-6.64
1969	439	2.37	448	3.85	434	1.45
1970	442	-14.56	450	-0.08	435	2.55
1971	443	3.01	450	0.73	435	-1.91

Precipitation

Century-scale series of annual and seasonal precipitation anomalies for East Asia (15°–60° N; 70°–140° E)

M. Hulme and Z. Zhao (continued)

EAST ASIA

(15°–60° N; 70°–140° E)

Precipitation Anomalies (continued)^a

Year	Winter ^b		Summer		Annual	
	Number of stations	Percent anomaly	Number of stations	Percent anomaly	Number of stations	Percent anomaly
1972	442	12.67	452	–8.51	435	–5.33
1973	445	3.58	450	6.26	435	7.72
1974	443	–29.07	452	–2.10	436	–2.60
1975	443	1.82	449	–3.29	436	2.02
1976	434	1.86	449	1.49	428	–0.74
1977	432	–25.74	448	–1.89	429	–0.67
1978	437	4.37	452	–7.61	411	–6.02
1979	444	17.60	448	1.68	429	–1.40
1980	439	5.47	449	–1.83	434	–4.64
1981	413	–8.38	413	5.69	403	0.32
1982	406	–16.12	420	–1.73	402	–3.12
1983	406	7.97	419	1.00	393	7.77
1984	297	–19.59	298	0.62	289	–0.96
1985	297	12.16	303	–1.65	277	1.43
1986	295	–22.81	294	–6.98	280	–11.29
1987	270	9.03	263	–2.58	238	0.46
1988	258	–9.43	249	2.37	227	0.37
1989	270	17.48	258	–5.98	238	–3.05
1990	257	63.07	253	0.57	232	8.54
1991	120	–5.81	118	0.59	76	–2.32
1992	88	1.99	92	–0.26	58	5.46

^aAnnual, Winter (December–February), and Summer (June–August) percent anomalies from the mean for the 1951–80 reference period.

^bWinters are dated by January; e.g., the 1881 winter extends from December, 1880 through February, 1881.

CITE AS: Hulme, M., and Z. Zhao. 1994. Century-scale series of annual and seasonal precipitation anomalies for East Asia (15°–60° N; 70°–140° E). pp. 911–917. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Century-scale series of annual and seasonal precipitation anomalies
for East Asia (15°–60° N; 70°–140° E)

M. Hulme and Z. Zhao (continued)

References

- Hulme, M., Z.-C. Zhao, and T. Jiang. 1994. Recent and future climate change in East Asia.
International Journal of Climatology (in press).

Precipitation

Australian precipitation records from ten regionally representative stations

B. Lavery, N. Nicholls

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Leura Post Office (Eastern New South Wales) • Dowerin (Western Australia) • Gatton-Lawes (Southeastern Queensland) • Brownlow Post Office (South Australia) • Carrick (Tasmania) • Winton Post Office (Northeastern Australia) • Mount Barker (SW Western Australia) • Albany (South Coast of Western Australia) • Canary Island (Victoria) • Peak Hill Post Office (Inland New South Wales)

Period of Record

1910–90

Methods

Ten stations have been selected to assess and monitor trends in Australian regional precipitation (Nicholls and Lavery 1992). These stations are a carefully chosen subset of a high-quality, 191-station set compiled through an extensive search of station documentation pertaining to instrumentation, observational practices, site relocations, and exposure (Lavery et al. 1992). Nicholls and Lavery (1992) cite three basic reasons for using individual stations to examine precipitation changes on a regional scale: (1) area-averaging of data from a group of stations may reduce interannual variability, making trends appear stronger in relation to interannual variations than they would for an individual station; (2) it is simpler to continuously monitor precipitation amount from a representative station than to form averages from many stations; and (3) designating representative stations may help to ensure the maintenance of high-quality stations that are not moved or closed, and thus may facilitate continued monitoring of climatic change.

The selection of representative stations began by using cluster analysis to group together stations that exhibited highly correlated annual precipitation variations over the period 1910–88 (the period for which data were available when the method was devised). The clustering method identified ten clusters of stations with discrete geographical patterns and essentially no spatial overlap [see Nicholls and Lavery (1992) for a geographical depiction of the clusters]. The station from each cluster showing the highest correlation between its annual precipitation variations and those of the whole cluster was chosen as the cluster's "representative" station. (See table and map on the facing page for descriptions and locations of stations.) The data from these ten stations consist of monthly precipitation totals, which are used to examine variations in seasonal ["winter" (April–September) and "summer" (October–March)] and annual precipitation amounts.

As noted by Nicholls (1988) and Nicholls and Wong (1990), the effects of the El Niño–Southern Oscillation add to the high interannual variability often observed in Australian precipitation amount. This variability makes it difficult to discern any decadal- to century-scale trends in the data. To facilitate the identification of such trends, Nicholls and Lavery (1992) computed and plotted 11-point running mean series from their annual series.

CITE AS: Lavery, B., and N. Nicholls. 1994. Australian precipitation records from ten regionally representative stations. pp. 918–950. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Australian precipitation records from ten regionally representative stations

B. Lavery and N. Nicholls (continued)

Descriptions of Clusters and Representative Stations

Cluster number and name	Number of stations	Representative station			
		Station name	Lat. (South)	Long. (East)	Elev. (m)
1 Eastern New South Wales	10	Leura Post Office	33°42'	150°21'	975
2 Western Australia	29	Dowerin (Doodarding Well)	31°01'	117°12'	295
3 Southeastern Queensland	18	Gatton-Lawes	27°33'	152°20'	94
4 South Australia	40	Brownlow Post Office	34°15'	139°16'	210
5 Tasmania	17	Carrick	41°33'	147°00'	150
6 Northeastern Australia	19	Winton Post Office	22°23'	143°02'	185
7 South Western Australia	12	Mount Barker (Kendenup Post Office)	34°29'	117°38'	262
8 South Coast W. Australia	4	Albany (Cape Riche)	34°36'	118°44'	40
9 Victoria	27	Canary Island	35°58'	143°51'	88
10 Inland New South Wales	15	Peak Hill Post Office	32°43'	148°11'	267

Locations of the ten representative stations in Australia. The numerals 1–10 indicate the clusters that the stations represent (see table).

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Precipitation

Australian precipitation records from ten regionally representative stations

B. Lavery and N. Nicholls (continued)

LEURA POST OFFICE (Eastern New South Wales)

Trends

Nicholls and Lavery (1992) describe the data from the Leura Post Office station as showing a rather abrupt increase in 12-month (April–March) precipitation ca. 1950. This increase resulted primarily from increased summer (October–March) precipitation and is indicated on the graph below by the larger spread between the thick lines representing 11-point running means for the winter (April–September) and 12-month precipitation over the period 1950–90. The increase in summer precipitation resulted in a pronounced summer precipitation maximum, whereas before 1950 the data exhibited a weaker annual cycle. However, many of the years with the highest 12-month precipitation totals since 1950 (e.g., 1950, 1952, 1974, and 1988) received one-half or more of this precipitation in the winter months.

Winter (Apr.-Sept., thin solid line) and 12-month (Apr.-Mar., dashed line) precipitation amounts at Leura Post Office. The summer (Oct.-Mar.) precipitation amount is represented by the spacing between the thin solid and dashed lines. The spacing between the two thick solid lines (the winter and 12-month, 11-point running means) indicates long-term changes in summer precipitation.

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Australian precipitation records from ten regionally representative stations

B. Lavery and N. Nicholls (continued)

LEURA POST OFFICE

(Eastern New South Wales)

Precipitation Amount, 1910–90

Precipitation (mm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	April– Sept	April– Mar ^a	Jan– Dec
1910	273.3	34.5	232.3	44.4	29.9	72.4	214.9	4.6	30.5	100.4	45.4	221.2	396.7	1613.1	1303.8
1911	496.8	276.4	76.2	40.1	31.3	19.3	118.2	115.9	49.5	48.9	65.5	61.0	374.3	1015.0	1399.1
1912	41.2	277.0	147.1	57.5	78.4	136.3	307.8	60.0	19.1	47.3	79.4	54.0	659.1	1190.4	1305.1
1913	118.2	71.4	161.0	354.5	414.4	236.7	73.1	12.3	63.4	45.5	43.7	49.2	1154.4	1635.1	1643.4
1914	55.2	103.9	183.2	75.5	86.8	100.6	175.2	24.3	171.4	229.2	181.3	254.7	633.8	1473.9	1641.3
1915	18.4	35.2	121.3	56.1	172.2	42.2	47.4	81.2	16.2	29.4	0.5	87.7	415.3	735.9	707.8
1916	46.8	90.8	65.4	96.5	16.0	28.6	51.9	49.4	80.3	334.1	68.2	156.4	322.7	1246.7	1084.4
1917	179.8	164.9	20.6	163.5	31.8	54.1	8.9	33.1	112.6	92.0	165.2	142.1	404.0	1227.9	1170.6
1918	320.4	79.7	24.5	110.0	12.3	7.4	88.8	53.4	54.5	26.4	30.2	20.6	326.4	641.0	828.2
1919	50.0	126.9	60.5	43.7	353.9	25.9	44.7	20.0	36.6	38.1	130.3	187.0	524.8	1242.0	1117.6
1920	242.6	65.6	53.6	40.7	8.3	47.0	146.9	55.8	79.6	45.9	105.8	324.1	378.3	1397.4	1215.9
1921	254.8	67.6	220.9	206.3	245.8	80.2	230.0	35.0	71.3	58.4	90.7	205.7	868.6	1604.3	1766.7
1922	165.2	160.5	55.2	59.0	60.9	67.8	371.0	24.6	137.7	41.2	2.1	42.6	721.0	948.5	1187.8
1923	68.4	15.8	57.4	208.8	10.1	95.6	159.3	128.9	90.9	39.5	29.7	58.6	693.6	1181.3	963.0
1924	87.4	156.6	115.9	189.3	47.3	83.1	44.6	50.9	105.7	54.6	174.4	81.2	520.9	1195.2	1191.0
1925	193.5	61.3	109.3	72.9	270.3	332.5	23.7	61.9	27.2	35.4	116.2	90.8	788.5	1488.6	1395.0
1926	72.2	5.1	380.4	106.9	170.9	64.8	120.3	37.9	53.4	11.5	13.2	262.2	554.2	1061.1	1298.8
1927	136.8	30.5	52.7	632.2	18.1	38.7	2.3	11.3	71.9	73.1	206.4	133.2	774.5	1909.8	1407.2
1928	131.1	398.8	192.7	148.4	68.6	257.8	94.4	13.2	5.3	64.5	34.8	24.5	587.7	1568.2	1434.1
1929	30.3	739.9	86.5	127.0	60.7	42.2	76.7	79.2	125.4	356.8	89.9	41.1	511.2	1370.3	1855.7
1930	131.6	80.0	159.7	67.6	148.1	370.1	72.1	51.1	6.6	98.8	35.1	134.0	715.6	1371.0	1354.8
1931	39.7	135.1	212.7	445.7	140.5	27.5	105.6	5.5	54.6	19.1	131.6	194.0	779.4	1430.6	1511.6
1932	16.5	152.4	137.6	80.2	23.4	8.5	26.1	78.4	392.6	42.3	73.3	58.2	609.2	1163.9	1089.5
1933	260.7	4.3	115.9	186.5	80.5	99.9	188.4	1.6	195.1	85.9	213.0	147.5	752.0	1973.9	1579.3
1934	119.9	511.6	144.0	131.1	131.3	94.0	265.6	74.8	107.2	59.0	149.1	151.0	804.0	1549.7	1938.6
1935	146.2	143.5	96.9	97.3	20.2	16.2	73.0	14.4	136.1	82.3	46.0	170.6	357.2	1177.7	1042.7
1936	157.7	157.1	206.8	78.6	59.1	53.6	30.1	27.7	40.5	12.8	10.1	210.4	289.6	1019.5	1044.5
1937	66.2	149.7	280.7	54.3	11.5	182.0	65.1	76.0	32.5	57.6	199.8	102.8	421.4	1160.0	1278.2
1938	243.5	89.6	45.3	120.8	105.6	11.7	34.3	202.2	27.3	144.8	76.8	19.1	501.9	1238.8	1121.0
1939	151.7	12.6	331.9	133.1	42.9	20.1	18.5	65.4	107.3	126.3	56.2	15.9	387.3	696.4	1081.9
1940	84.8	23.4	2.5	141.1	49.0	17.9	25.0	26.0	61.0	26.0	142.5	324.0	320.0	1152.8	923.2
1941	128.0	151.2	61.1	35.4	27.8	50.6	11.2	31.1	53.0	80.5	64.8	43.0	209.1	997.8	737.7
1942	52.0	85.2	463.2	52.2	29.9	72.9	83.0	40.5	31.8	553.9	198.0	153.4	310.3	1548.7	1816.0
1943	137.5	95.0	100.6	63.3	576.0	30.0	18.2	155.8	170.6	64.2	244.6	123.8	1013.9	1583.7	1779.6
1944	49.4	29.6	58.2	42.5	146.8	28.7	75.9	140.7	98.9	21.0	23.2	28.3	533.5	878.2	743.2
1945	127.7	85.5	59.0	211.3	61.6	535.5	61.4	52.5	5.3	25.2	70.1	60.9	927.6	1337.6	1356.0
1946	45.7	146.7	61.4	372.3	16.8	73.9	31.0	3.1	23.9	80.8	101.6	74.4	521.0	1525.9	1031.6
1947	68.6	564.0	115.5	154.5	54.7	23.9	26.2	33.4	42.7	53.0	148.1	454.4	335.4	1411.9	1739.0
1948	199.9	105.9	115.2	68.9	268.2	253.4	9.4	13.2	94.9	26.4	40.9	66.6	708.0	1618.3	1262.9
1949	307.2	205.4	263.8	60.5	144.8	477.9	29.4	104.7	110.6	52.3	117.2	65.8	927.9	1989.3	1939.6

Precipitation

Australian precipitation records from ten regionally representative stations

B. Lavery and N. Nicholls (continued)

LEURA POST OFFICE (Eastern New South Wales)

Precipitation Amount, 1910–90 (continued)

	Precipitation (mm)														
Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	April– Sept	April– Mar ^a	Jan– Dec
1950	188.1	331.3	306.7	189.2	132.6	695.9	287.8	68.8	61.8	184.3	251.0	65.8	1436.1	2915.9	2763.3
1951	638.9	162.7	177.1	9.4	77.4	432.3	44.0	61.2	83.9	48.8	15.7	29.4	708.2	1090.4	1780.8
1952	65.8	76.2	146.3	307.2	65.8	185.6	299.2	463.6	27.8	135.4	65.5	115.5	1349.2	2089.8	1953.9
1953	144.1	208.2	71.9	20.1	365.1	5.6	11.2	21.8	55.8	77.5	61.0	21.3	479.6	1309.2	1063.6
1954	257.1	392.3	20.4	69.0	31.0	18.1	214.4	46.5	37.0	197.2	105.4	77.5	416.0	1564.6	1465.9
1955	81.8	409.6	277.1	166.4	177.2	33.6	17.4	81.4	53.8	100.1	153.4	159.1	529.8	2421.6	1710.9
1956	183.8	833.4	462.0	89.1	152.4	147.2	41.8	70.0	32.8	115.8	3.8	78.2	533.3	1086.7	2210.3
1957	83.4	208.1	64.1	26.8	2.5	54.2	100.9	188.0	1.0	4.3	17.0	79.7	373.4	1116.6	830.0
1958	263.3	179.0	199.9	94.0	20.8	217.6	46.4	74.6	37.8	56.7	16.0	220.2	491.2	1577.4	1426.3
1959	325.3	278.8	189.2	149.2	13.2	166.4	137.7	19.3	38.3	208.3	177.5	68.6	524.1	1369.8	1771.8
1960	119.1	153.6	118.6	53.1	92.7	64.0	108.5	50.4	72.4	114.2	69.4	160.2	441.1	1222.1	1176.2
1961	125.3	131.2	180.7	99.8	19.6	132.5	45.5	180.5	37.8	134.3	437.0	232.3	515.7	1774.9	1756.5
1962	201.0	201.1	53.5	116.1	296.6	0.0	110.6	120.6	162.2	54.9	35.7	314.4	806.1	1952.7	1666.7
1963	155.0	132.1	454.5	271.4	254.6	181.0	25.4	154.5	128.8	71.7	71.4	330.4	1015.7	1654.2	2230.8
1964	40.4	32.7	91.9	207.3	32.6	464.6	35.3	38.5	26.8	91.0	126.4	14.2	805.1	1133.7	1201.7
1965	51.6	29.2	16.2	133.0	14.8	65.9	105.1	11.7	86.7	236.8	53.6	163.1	417.2	1132.8	967.7
1966	48.8	132.0	81.3	67.0	29.0	65.5	11.8	52.0	46.9	109.9	165.3	167.6	272.2	1353.5	977.1
1967	308.9	181.3	148.3	67.2	31.7	345.6	44.6	269.7	98.8	136.9	23.4	19.0	857.6	1476.6	1675.4
1968	283.7	43.2	112.8	28.5	152.7	28.6	23.4	63.2	5.4	30.0	19.9	123.9	301.8	1003.8	915.3
1969	48.9	324.7	154.6	188.8	54.4	152.4	18.0	212.2	65.5	110.5	288.0	54.3	691.3	1701.3	1672.3
1970	391.2	77.8	88.2	28.0	41.3	50.8	0.8	18.7	206.0	57.6	122.9	264.2	345.6	1331.5	1347.5
1971	20.5	258.0	262.7	45.0	28.7	0.0	13.5	50.9	100.8	6.4	78.4	270.2	238.9	1578.3	1135.1
1972	650.2	151.1	183.1	112.8	76.0	35.8	1.3	56.7	44.6	273.1	7.4	50.4	327.2	1443.9	1642.5
1973	136.4	523.6	125.8	45.0	37.7	50.7	178.5	60.8	57.7	163.9	218.9	100.8	430.4	1687.6	1699.8
1974	304.9	207.9	260.8	671.3	367.1	201.4	25.2	84.2	25.5	78.2	100.9	3.0	1374.7	1949.8	2330.4
1975	80.9	292.8	19.3	16.9	27.6	332.9	94.4	58.4	70.4	199.8	87.0	115.0	600.6	2005.8	1195.4
1976	349.0	298.6	355.8	12.6	19.4	136.0	51.0	33.2	77.3	178.7	53.4	17.8	329.5	1254.4	1582.8
1977	69.6	229.4	376.0	13.8	148.6	27.8	13.2	28.8	81.1	20.0	35.1	40.8	313.3	1392.9	1084.2
1978	517.0	52.2	414.5	50.0	140.2	319.0	21.2	38.1	80.2	103.1	171.4	82.1	648.7	1337.1	1989.0
1979	98.8	30.6	202.4	24.4	174.6	97.2	20.0	10.0	31.7	64.6	87.9	11.9	357.9	796.1	854.1
1980	120.8	64.4	88.6	9.2	261.2	67.0	44.6	9.8	9.6	67.8	57.6	91.4	401.4	1291.2	892.0
1981	216.4	423.2	33.4	294.0	173.0	51.6	76.8	15.0	10.4	207.2	245.4	136.6	620.8	1697.7	1883.0
1982	137.4	95.9	254.4	36.2	6.8	30.6	3.4	8.2	191.4	63.4	13.2	50.6	276.6	851.2	891.5
1983	59.2	113.0	275.2	90.4	257.7	122.2	25.4	22.0	86.0	106.4	43.6	158.8	603.7	1664.7	1359.9
1984	188.0	425.8	138.4	199.7	95.4	38.0	169.4	22.4	53.4	58.0	337.2	38.4	578.3	1383.5	1764.1
1985	115.6	81.2	174.8	220.6	171.4	54.0	108.8	38.0	110.6	387.0	90.3	39.0	703.4	1509.5	1591.3
1986	197.4	71.8	20.6	106.9	46.3	11.5	48.0	531.6	149.2	89.5	258.4	29.2	893.5	1692.4	1560.4
1987	54.0	64.4	303.4	33.0	95.4	53.9	50.0	343.2	12.8	158.6	109.2	176.1	588.3	1394.8	1454.0
1988	134.2	116.4	112.0	567.7	142.6	51.1	271.0	52.6	116.8	11.4	156.1	168.7	1201.8	2187.2	1900.6
1989	258.0	104.4	286.8	400.0	127.6	183.8	37.4	45.3	15.1	22.8	80.4	108.3	809.2	1689.1	1669.9
1990	182.4	338.5	147.5	358.9	134.3	44.8	72.4	350.2	93.8	96.8	29.0	46.7	1054.4		1895.3

^aThe total in this column is calculated for April of the listed year through March of the following year.

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Australian precipitation records from ten regionally representative stations

B. Lavery and N. Nicholls (continued)

DOWERIN
(Western Australia)**Trends**

According to Nicholls and Lavery (1992), the data from Dowerin show no clear long-term precipitation trends. Annual precipitation is dominated by winter (April–September) precipitation, which shows marked interannual variability over the period of record. In contrast, summer precipitation is less variable, as evidenced on the graph below by consistent spacing between the lines representing the 11-point running means for 12-month (April–March) and winter precipitation.

Winter (Apr.-Sept., thin solid line) and 12-month (Apr.-Mar., dashed line) precipitation amount at Dowerin. The summer (Oct.-Mar.) precipitation amount is represented by the spacing between the thin solid and dashed lines. The spacing between the two thick solid lines (the winter and 12-month, 11-point running means) indicates long-term changes in summer precipitation.

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Precipitation

Australian precipitation records from ten regionally representative stations

B. Lavery and N. Nicholls (continued)

DOWERIN (Western Australia)

Precipitation Amount, 1910–90

Precipitation (mm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	April– Sept	April– Mar ^a	Jan– Dec
1910	0.8	37.9	0.0	14.6	73.4	108.7	78.2	28.2	19.8	14.7	8.1	2.5	322.9	384.3	386.9
1911	27.7	2.0	6.4	9.6	14.4	21.8	28.2	9.7	13.5	2.0	0.0	0.0	97.2	146.4	135.3
1912	38.4	0.8	8.0	10.5	27.9	11.4	89.5	9.9	30.2	14.8	9.2	9.2	179.4	218.5	259.8
1913	0.0	3.1	2.8	7.2	4.1	70.6	32.7	80.3	44.5	23.2	3.6	31.5	239.4	312.9	303.6
1914	15.2	0.0	0.0	7.8	2.8	23.3	30.1	12.4	0.3	16.1	6.2	13.0	76.7	357.8	127.2
1915	95.0	140.6	10.2	14.0	28.4	58.3	84.6	63.3	34.8	22.7	0.5	1.0	283.4	380.6	553.4
1916	49.5	9.1	14.4	1.0	28.3	50.0	66.9	41.8	4.6	29.7	11.5	0.0	192.6	392.3	306.8
1917	0.0	1.3	157.2	15.8	47.1	90.6	104.3	59.3	47.3	25.9	8.1	8.5	364.4	517.5	565.4
1918	20.6	65.6	24.4	33.3	33.8	104.7	32.9	45.7	40.1	42.7	25.7	0.3	290.5	369.6	469.8
1919	8.1	0.0	2.3	69.0	15.0	43.5	66.1	45.0	11.6	27.2	15.8	3.6	250.2	342.5	307.2
1920	3.3	0.0	42.4	6.4	34.5	67.3	37.1	94.4	32.0	4.3	7.9	0.0	271.7	296.3	329.6
1921	2.8	0.0	9.6	0.8	103.2	57.9	29.9	54.1	31.0	23.7	1.3	13.2	276.9	389.0	327.5
1922	0.0	18.3	55.6	21.7	43.9	14.8	66.1	15.6	11.8	5.0	0.0	2.5	173.9	192.9	255.3
1923	6.9	2.0	2.6	51.0	32.1	133.3	38.3	17.0	47.7	11.2	0.0	97.5	319.4	435.2	439.6
1924	0.0	0.0	7.1	3.8	48.3	48.7	32.8	56.7	23.3	52.7	4.6	0.0	213.6	382.8	278.0
1925	59.0	23.6	29.3	2.8	41.3	66.8	49.4	10.0	34.8	19.5	7.6	11.2	205.1	306.8	355.3
1926	1.5	23.4	38.5	35.1	37.6	44.2	89.6	24.4	25.2	26.3	19.9	6.6	256.1	432.5	372.3
1927	0.0	1.5	122.1	4.7	8.7	46.2	48.9	25.2	40.3	30.5	4.6	1.5	174.0	240.5	334.2
1928	17.0	0.0	12.9	3.4	20.4	22.6	79.9	41.4	21.2	4.6	1.0	9.9	188.9	266.0	234.3
1929	5.1	45.5	11.0	0.3	69.3	74.7	31.7	27.4	4.4	13.0	24.4	0.8	207.8	265.5	307.6
1930	0.0	0.6	18.9	30.3	11.7	62.1	48.4	39.8	13.1	3.6	1.8	23.4	205.4	235.2	253.7
1931	0.0	0.0	1.0	25.1	51.3	32.0	57.1	56.7	38.5	15.2	3.3	9.4	260.7	326.0	289.6
1932	16.8	1.0	19.6	14.4	52.7	23.4	74.7	102.8	21.2	30.5	0.6	0.0	289.2	352.8	357.7
1933	3.3	5.8	23.4	0.0	39.6	61.6	39.5	40.5	15.1	25.6	30.5	4.3	196.3	302.5	289.2
1934	11.7	9.1	25.0	108.1	13.0	41.0	45.5	38.1	24.1	4.4	14.5	1.3	269.8	355.0	335.8
1935	21.8	38.1	5.1	24.6	14.6	15.0	41.4	49.0	21.1	4.1	0.8	2.8	165.7	207.4	238.4
1936	9.6	0.0	24.4	0.0	22.4	48.2	20.7	49.2	21.4	7.9	1.0	72.9	161.9	248.8	277.7
1937	0.0	5.1	0.0	9.7	62.7	46.3	6.6	44.5	14.7	4.3	12.0	0.0	184.5	247.0	205.9
1938	12.4	0.0	33.8	25.9	14.0	42.4	48.3	19.6	10.2	3.5	13.3	0.0	160.4	276.1	223.4
1939	20.9	78.0	0.0	17.5	77.5	60.5	64.4	48.3	1.3	39.7	22.7	1.8	269.5	339.5	432.6
1940	5.8	0.0	0.0	0.0	14.7	33.7	48.3	5.1	19.8	26.1	2.0	36.0	121.6	209.8	191.5
1941	2.0	22.1	0.0	47.0	50.0	79.9	32.8	25.9	24.0	8.9	20.9	16.3	259.6	336.9	329.8
1942	0.0	0.0	31.2	11.0	80.0	31.3	44.5	53.5	14.9	9.8	1.8	30.0	235.2	427.6	308.0
1943	18.3	62.8	69.7	38.8	21.0	64.1	26.9	32.4	25.1	13.8	0.0	11.1	208.3	251.2	384.0
1944	4.6	5.8	7.6	2.1	64.3	22.6	71.7	50.6	8.9	2.5	3.3	4.8	220.2	256.3	248.8
1945	0.0	5.6	19.9	17.8	41.3	137.5	32.9	104.4	23.9	3.6	9.2	1.3	357.8	379.1	397.4
1946	0.8	6.4	0.0	26.2	41.6	76.7	91.0	37.3	5.1	1.3	20.1	6.6	277.9	322.1	313.1
1947	3.3	7.6	5.3	23.1	48.1	67.5	45.4	11.7	11.1	42.2	9.7	0.0	206.9	309.1	275.0
1948	0.0	2.0	48.3	46.0	0.3	34.2	51.8	65.5	18.9	5.9	9.1	8.6	216.7	259.5	290.6
1949	6.4	8.7	4.1	2.8	2.3	34.0	68.7	48.9	27.5	10.4	30.0	0.0	184.2	228.2	243.8

Australian precipitation records from ten regionally representative stations

B. Lavery and N. Nicholls (continued)

DOWERIN
(Western Australia)

Precipitation Amount, 1910–90 (continued)

	Precipitation (mm)														
Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	April– Sept	April– Mar ^a	Jan– Dec
1950	3.6	0.0	0.0	0.0	44.6	30.3	40.9	30.0	28.7	17.9	4.4	0.5	174.5	290.5	200.9
1951	38.9	38.6	15.7	71.8	21.0	72.5	45.2	31.0	10.6	4.5	12.8	14.2	252.1	301.2	376.8
1952	13.0	0.0	4.6	4.4	42.3	16.6	59.2	24.0	25.3	22.5	4.6	17.8	171.8	298.9	234.3
1953	0.0	26.7	55.5	39.4	69.1	56.7	35.5	37.6	10.1	17.7	7.2	0.0	248.4	284.1	355.5
1954	10.8	0.0	0.0	2.3	63.5	23.9	48.4	36.6	16.9	6.3	6.9	22.9	191.6	345.4	238.5
1955	15.2	99.7	2.8	26.3	33.9	16.8	26.6	77.1	41.7	19.9	0.3	2.8	222.4	253.0	363.1
1956	7.6	0.0	0.0	5.9	80.1	71.8	69.4	2.4	11.0	21.0	38.1	3.0	240.6	320.0	310.3
1957	8.4	1.0	7.9	10.9	50.6	139.5	14.5	33.6	5.1	6.6	0.0	0.0	254.2	272.7	278.1
1958	0.5	11.4	0.0	2.3	86.3	36.8	129.2	40.4	45.2	8.8	3.4	16.3	340.2	393.8	380.6
1959	8.4	4.8	11.9	2.6	7.1	77.7	23.7	67.2	14.0	17.6	18.8	3.6	192.3	275.1	257.4
1960	16.7	8.1	18.0	10.5	83.6	20.5	96.6	10.7	42.9	1.8	4.3	0.0	264.8	361.6	313.7
1961	61.2	6.7	22.8	59.8	15.5	79.6	38.8	24.8	7.6	6.0	0.0	4.3	226.1	279.3	327.1
1962	11.3	21.6	10.0	3.8	78.4	56.2	52.6	18.2	22.0	21.1	8.3	12.2	231.2	362.9	315.7
1963	30.3	43.0	16.8	13.2	115.1	113.8	76.6	99.9	15.1	3.1	0.0	7.4	433.7	476.2	534.3
1964	1.3	20.0	10.7	10.7	3.1	91.6	79.5	40.7	7.2	20.8	5.4	6.7	232.8	281.7	297.7
1965	6.1	4.6	5.3	17.6	68.2	91.1	85.0	52.7	19.3	28.4	79.6	13.6	333.9	482.9	471.5
1966	12.4	15.0	0.0	72.3	6.1	82.9	60.8	27.3	25.9	36.6	9.9	1.3	275.3	335.5	350.5
1967	11.4	1.0	0.0	11.2	58.2	56.1	66.4	27.7	6.6	10.7	10.2	5.0	226.2	381.0	264.5
1968	79.8	6.3	42.8	23.8	15.7	153.7	41.0	29.3	27.9	9.4	1.5	0.5	291.4	325.1	431.7
1969	2.0	4.3	16.0	26.6	18.2	39.5	28.6	17.0	14.2	2.3	6.3	0.9	144.1	260.2	175.9
1970	0.0	95.1	11.5	23.1	18.4	67.0	21.0	18.1	39.9	16.5	15.1	10.9	187.5	372.2	336.6
1971	6.9	9.8	125.5	3.0	13.5	31.5	37.9	39.8	38.4	26.1	16.1	1.6	164.1	227.5	350.1
1972	2.0	13.8	3.8	9.4	18.5	62.0	43.7	54.0	14.4	10.3	1.3	0.8	202.0	239.1	234.0
1973	5.6	18.3	0.8	10.4	23.2	69.5	67.5	62.2	76.8	22.6	10.2	0.0	309.6	377.3	367.1
1974	0.0	0.6	34.3	61.5	94.0	46.4	56.6	50.5	11.7	23.2	8.8	0.0	320.7	368.7	387.6
1975	3.0	7.0	6.0	51.6	24.1	35.1	67.6	26.3	26.8	46.5	4.6	16.6	231.5	356.6	315.2
1976	13.4	44.0	0.0	23.2	38.0	21.4	5.3	62.6	19.2	16.6	35.8	0.0	169.7	227.5	279.5
1977	1.4	4.0	0.0	15.0	29.0	53.0	12.5	34.6	5.1	24.8	4.0	10.4	149.2	235.2	193.8
1978	22.8	18.0	6.0	23.4	21.6	30.1	45.4	12.4	28.0	20.0	19.0	116.0	160.9	398.7	362.7
1979	2.0	66.0	14.8	15.2	32.6	51.2	21.8	46.4	19.2	1.6	17.6	3.2	186.4	213.2	291.6
1980	0.0	3.4	1.0	26.8	17.6	22.6	40.2	19.8	6.6	11.2	7.0	0.2	133.6	188.4	156.4
1981	4.2	31.0	1.2	0.0	81.2	34.6	29.6	35.6	15.0	14.0	15.4	38.0	196.0	340.2	299.8
1982	74.2	0.0	2.6	0.8	23.8	52.0	22.2	49.0	31.2	12.4	1.6	2.0	179.0	231.0	271.8
1983	0.0	1.0	35.0	12.0	14.6	87.6	64.8	32.2	16.9	0.0	68.4	28.7	228.1	399.8	361.2
1984	0.0	9.8	64.8	32.6	114.6	18.2	41.7	22.0	23.2	9.8	11.4	5.6	252.3	309.6	353.7
1985	0.0	6.3	24.2	2.4	44.8	16.8	72.0	29.4	25.8	2.8	7.4	3.4	191.2	262.4	235.3
1986	8.6	43.2	5.8	6.0	60.0	55.4	43.2	41.4	27.6	8.0	30.0	0.0	233.6	276.2	329.2
1987	0.0	0.0	4.6	25.8	35.8	48.4	47.8	30.2	9.2	19.2	19.0	19.2	197.2	280.2	259.2
1988	0.0	0.0	25.6	29.4	55.8	65.2	45.4	57.8	18.4	8.4	5.6	66.8	272.0	403.7	378.4
1989	8.2	23.7	19.0	28.0	44.4	66.6	41.0	13.6	4.2	15.0	3.6	0.0	197.8	373.8	267.3
1990	113.0	13.4	31.0	12.8	6.6	39.2	57.6	29.4	28.8	40.2	2.2	0.0	174.4		374.2

^aThe total in this column is calculated for April of the listed year through March of the following year.

CITE AS: Lavery, B., and N. Nicholls. 1994. Australian precipitation records from ten regionally representative stations. pp. 918–950. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Precipitation

Australian precipitation records from ten regionally representative stations

B. Lavery and N. Nicholls (continued)

GATTON-LAWES (Southeastern Queensland)

Trends

The data from Gatton-Lawes exhibit increasing 12-month (April–March) precipitation from ca. 1920 through 1970, primarily as a result of increased summer (October–March) precipitation. The summer increase is indicated on the graph below by the widening gap between the lines representing the 11-point running means for 12-month and winter (April–September) precipitation. After 1970, the 12-month and summer precipitation amounts show no clear trend, whereas there is some indication of increasing winter precipitation over the period 1975–90.

Winter (Apr.–Sept., thin solid line) and 12-month (Apr.–Mar., dashed line) precipitation amount at Gatton-Lawes. The summer (Oct.–Mar.) precipitation amount is represented by the spacing between the thin solid and dashed lines. The spacing between the two thick solid lines (the winter and 12-month, 11-point running means) indicates long-term changes in summer precipitation.

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Australian precipitation records from ten regionally representative stations

B. Lavery and N. Nicholls (continued)

GATTON-LAWES

(Southeastern Queensland)

Precipitation Amount, 1910–90

Precipitation (mm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	April– Sept	April– Mar ^a	Jan– Dec
1910	299.6	43.3	93.1	17.5	15.5	112.3	48.3	15.3	47.0	91.3	72.4	173.7	255.9	1071.2	1029.3
1911	305.7	101.1	71.1	35.0	14.7	0.0	18.3	23.0	24.4	95.9	12.5	48.3	115.4	646.1	750.0
1912	90.3	84.0	199.7	7.8	0.0	168.5	46.9	26.4	13.5	126.8	65.7	100.9	263.1	775.1	930.5
1913	119.7	58.6	40.3	15.9	88.8	119.1	11.2	0.0	35.5	47.5	10.7	71.9	270.5	701.4	619.2
1914	138.0	64.2	98.6	38.9	57.2	76.3	25.6	6.4	12.2	100.7	22.4	194.7	216.6	713.3	835.2
1915	61.6	101.0	16.3	34.9	49.8	1.3	31.8	41.2	28.4	1.3	19.3	34.8	187.4	406.0	421.7
1916	51.8	57.5	53.9	122.8	7.6	49.5	39.9	45.6	46.8	74.4	126.0	66.8	312.2	879.3	742.6
1917	122.3	102.1	75.5	13.5	3.8	4.1	10.2	20.9	190.5	30.7	193.0	181.3	243.0	889.0	947.9
1918	186.9	40.4	13.7	41.4	25.8	5.6	4.0	38.9	13.2	19.1	46.5	39.9	128.9	412.8	475.4
1919	28.6	14.0	135.8	6.7	75.4	12.6	1.1	10.6	3.1	16.7	16.6	46.3	109.5	380.7	367.5
1920	139.2	4.6	47.8	13.7	82.8	55.3	64.8	33.4	64.5	93.5	84.5	54.5	314.5	726.3	738.6
1921	59.5	27.2	92.6	46.6	29.7	154.5	104.7	5.6	46.9	17.0	12.2	193.1	388.0	751.5	789.6
1922	60.7	79.7	0.8	0.5	0.5	26.1	53.8	5.3	24.3	42.2	68.9	78.2	110.5	416.1	441.0
1923	60.6	0.0	55.7	19.0	3.1	60.2	15.4	9.9	17.5	5.3	46.6	98.5	125.1	688.8	391.8
1924	60.3	281.0	72.0	40.1	7.7	73.1	66.6	44.6	67.4	43.3	99.8	49.2	299.5	828.5	905.1
1925	106.1	150.6	80.0	2.6	39.4	76.0	15.0	80.4	6.6	3.6	151.0	75.5	220.0	605.1	786.8
1926	81.7	14.0	59.3	32.5	11.2	59.4	9.2	12.5	34.5	20.8	54.1	184.0	159.3	785.1	573.2
1927	231.9	61.8	73.2	41.6	0.8	68.1	3.6	7.1	32.2	72.0	115.1	184.9	153.4	958.8	892.3
1928	89.5	307.3	36.6	176.3	34.5	49.5	20.1	16.0	3.6	35.4	44.9	89.5	300.0	789.6	903.2
1929	62.5	151.8	105.5	111.0	1.8	37.4	16.5	26.0	5.1	69.4	43.2	60.7	197.8	677.7	690.9
1930	151.1	90.5	65.0	68.8	82.5	150.4	24.3	23.4	29.2	35.8	36.4	36.1	378.6	854.1	793.5
1931	89.1	168.8	109.3	37.4	27.2	11.9	56.2	11.7	21.0	25.3	110.3	228.4	165.4	616.7	896.6
1932	58.1	28.2	1.0	115.8	13.2	26.4	16.2	15.3	79.1	65.9	122.3	37.2	266.0	827.6	578.7
1933	260.7	73.5	2.0	48.5	11.4	26.2	74.0	18.6	48.2	39.6	129.2	114.0	226.9	799.9	845.9
1934	115.4	166.7	8.1	115.8	33.2	20.1	72.5	25.6	19.7	49.5	72.0	142.7	286.9	823.1	841.3
1935	94.9	151.9	25.2	41.8	53.9	2.0	49.0	12.9	76.0	71.5	7.9	134.4	235.6	731.1	721.4
1936	157.8	51.6	72.3	8.6	15.7	49.9	37.5	0.0	32.4	3.8	76.1	112.2	144.1	565.7	617.9
1937	15.7	33.0	180.8	30.8	8.1	21.0	24.9	39.4	5.1	136.5	85.0	85.5	129.3	620.4	665.8
1938	104.5	21.2	58.4	35.7	162.4	13.2	33.5	31.9	21.9	62.3	151.6	1.3	298.6	1012.2	697.9
1939	166.6	8.4	323.4	62.4	18.1	46.0	59.1	39.7	3.5	43.4	90.0	77.5	228.8	771.5	938.1
1940	93.9	129.6	108.3	13.0	21.8	27.7	2.8	5.3	15.0	14.8	84.8	256.1	85.6	848.2	773.1
1941	218.6	44.9	143.4	19.9	23.7	28.4	12.2	5.9	2.8	17.4	61.8	11.2	92.9	558.3	590.2
1942	46.5	263.7	64.8	72.1	22.1	21.1	33.2	39.4	20.1	137.1	33.2	278.7	208.0	810.6	1032.0
1943	51.2	57.5	44.9	25.0	17.5	25.4	0.0	41.8	51.9	269.0	82.8	237.4	161.6	919.5	904.4
1944	103.2	59.5	6.0	6.6	39.9	15.8	94.1	45.6	34.5	19.3	78.3	74.9	236.5	694.5	577.7
1945	91.9	181.9	11.7	32.7	41.7	112.4	51.7	27.4	48.3	139.5	91.3	132.2	314.2	1180.8	962.7
1946	235.4	161.1	107.1	28.8	5.4	2.3	6.6	10.7	132.2	45.2	32.3	71.5	186.0	716.6	838.6
1947	131.4	123.7	126.5	43.1	44.2	16.0	11.7	16.2	67.3	50.6	53.5	172.2	198.5	731.1	956.4
1948	26.9	49.8	79.6	41.7	106.2	212.7	20.9	6.7	38.4	0.0	58.1	64.1	426.6	869.1	705.1
1949	33.3	157.2	129.8	5.3	8.3	54.0	24.4	20.8	52.4	172.8	37.4	80.1	165.2	985.0	775.8

Precipitation

Australian precipitation records from ten regionally representative stations

B. Lavery and N. Nicholls (continued)

GATTON-LAWES

(Southeastern Queensland)

Precipitation Amount, 1910–90 (continued)

Precipitation (mm)													
Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	April– Sept
													April– Mar ^a
													Jan– Dec
1950	198.6	274.4	56.5	62.4	10.9	152.7	151.8	14.0	2.9	157.8	115.7	43.7	394.7
1951	282.0	44.4	78.2	62.4	36.1	32.8	0.0	8.6	20.3	38.9	5.6	45.8	160.2
1952	39.6	83.0	101.4	122.2	64.5	57.2	17.1	40.6	24.1	106.1	37.5	48.4	325.7
1953	119.9	176.5	102.1	36.1	35.9	0.0	3.0	70.1	3.6	32.3	42.2	56.9	148.7
1954	100.1	272.5	20.7	19.2	37.2	19.5	137.0	68.3	50.0	127.3	79.3	57.8	331.2
1955	122.4	54.0	248.7	142.8	103.7	23.2	40.6	12.2	60.7	80.3	30.7	116.3	383.2
1956	99.1	237.7	114.4	125.8	101.3	67.3	26.9	0.0	7.4	16.5	20.9	205.3	328.7
1957	38.9	70.5	83.5	35.3	0.0	22.9	63.7	13.6	8.6	60.9	3.3	33.5	144.1
1958	52.5	191.3	98.5	90.1	7.7	125.6	5.4	31.6	33.5	62.5	23.7	122.3	293.9
1959	191.0	174.0	54.9	37.2	27.3	6.5	50.4	0.0	46.3	136.9	218.2	168.2	167.7
1960	77.5	133.8	25.2	10.5	10.7	33.8	32.2	16.0	4.4	67.2	122.1	59.7	107.6
1961	84.1	131.6	14.4	44.8	20.1	34.6	54.7	25.4	8.6	70.4	216.6	75.7	188.2
1962	138.3	47.8	151.6	63.2	6.4	10.9	74.9	32.0	55.9	42.7	58.7	128.2	243.3
1963	108.6	49.2	219.4	18.8	131.3	8.4	2.8	49.9	17.8	39.1	95.9	162.2	229.0
1964	64.8	114.0	121.3	60.3	46.2	52.7	40.9	17.0	87.7	69.7	125.3	119.4	304.8
1965	26.1	28.8	3.8	24.6	4.6	47.3	225.1	31.8	23.6	45.2	27.7	144.8	357.0
1966	15.5	126.1	127.7	70.9	1.8	89.5	11.4	81.1	54.6	26.2	53.6	91.3	309.3
1967	134.3	92.4	166.1	16.7	72.7	319.6	27.8	17.1	11.7	140.5	47.0	22.2	465.6
1968	371.1	41.9	75.0	54.3	37.3	1.8	48.4	52.2	26.6	8.9	25.4	91.5	220.6
1969	145.4	19.3	73.4	4.1	162.9	28.4	17.0	91.1	22.0	193.3	87.8	65.3	325.5
1970	109.1	95.1	137.4	20.6	7.9	15.7	7.4	3.6	48.2	129.2	52.1	265.4	103.4
1971	226.3	256.6	24.0	5.4	19.5	3.4	20.6	36.8	57.2	60.0	130.7	144.8	142.9
1972	134.0	104.9	49.7	53.1	27.1	13.0	0.0	13.2	3.0	237.4	60.8	94.1	109.4
1973	117.3	122.6	28.4	3.6	18.4	19.2	306.4	40.0	30.4	59.4	88.1	93.1	418.0
1974	452.9	16.6	119.9	46.0	45.1	18.1	5.3	51.2	37.5	47.1	180.7	41.3	203.2
1975	92.7	160.3	96.8	40.4	0.5	45.5	28.8	25.7	68.6	126.2	113.0	134.9	209.5
1976	86.7	175.3	79.3	13.7	26.8	19.4	31.4	1.6	88.2	38.2	182.1	36.4	181.1
1977	24.1	79.6	127.1	73.9	60.9	16.0	0.9	3.2	1.5	17.4	116.6	38.3	156.4
1978	193.2	98.8	117.4	130.1	38.0	38.1	43.2	50.4	72.4	23.0	105.0	112.0	372.2
1979	118.1	66.0	66.4	51.2	20.3	109.2	30.0	4.8	11.2	41.0	92.5	82.9	226.7
1980	29.4	87.5	5.0	7.2	86.4	2.9	35.2	14.6	0.1	100.2	42.6	78.2	146.4
1981	51.6	240.4	36.1	100.8	42.9	61.3	45.9	16.0	5.3	19.6	172.5	131.1	272.2
1982	161.9	126.7	142.5	16.1	34.7	5.2	6.0	11.6	80.9	85.5	5.7	158.3	154.5
1983	91.4	25.5	83.8	90.4	193.6	180.3	64.7	25.1	18.6	107.1	129.5	76.6	572.7
1984	113.3	29.7	54.3	130.8	20.9	25.7	121.8	24.1	33.3	43.1	71.4	49.1	356.6
1985	121.2	15.9	63.6	93.5	34.0	42.4	35.8	44.4	34.4	85.4	57.4	133.8	284.5
1986	30.8	59.6	8.0	0.7	102.3	0.0	35.0	59.1	13.5	78.4	87.5	65.7	210.6
1987	121.5	13.7	63.0	7.7	130.0	33.4	18.1	27.8	0.3	148.2	25.4	150.3	217.3
1988	121.0	139.0	50.0	324.1	20.8	85.7	81.6	56.2	50.1	10.1	37.5	102.7	618.5
1989	86.2	63.6	97.4	225.4	119.3	15.7	19.3	21.3	18.0	81.9	162.1	86.9	419.0
1990	87.0	139.4	91.0	127.3	136.1	24.2	32.0	9.6	21.8	21.2	37.2	32.5	351.0

^aThe total in this column is calculated for April of the listed year through March of the following year.

CITE AS: Lavery, B., and N. Nicholls. 1994. Australian precipitation records from ten regionally representative stations. pp. 918–950. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Australian precipitation records from ten regionally representative stations

B. Lavery and N. Nicholls (continued)

BROWNLOW POST OFFICE
(South Australia)**Trends**

According to Nicholls and Lavery (1992), the data from the Brownlow Post Office show no clear long-term precipitation trends. The line representing the 11-point running mean for 12-month (April–March) precipitation hints at an increase over the period 1930–75, primarily as a result of increasing summer (October–March) precipitation, but the increase was followed by a rather abrupt return to amounts received ca. 1930.

Winter (Apr.–Sept., thin solid line) and 12-month (Apr.–Mar., dashed line) precipitation amount at Brownlow Post Office. The summer (Oct.–Mar.) precipitation amount is represented by the spacing between the thin solid and dashed lines. The spacing between the two thick solid lines (the winter and 12-month, 11-point running means) indicates long-term changes in summer precipitation.

CITE AS: Lavery, B., and N. Nicholls. 1994. Australian precipitation records from ten regionally representative stations. pp. 918–950. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Precipitation

Australian precipitation records from ten regionally representative stations

B. Lavery and N. Nicholls (continued)

BROWNLOW POST OFFICE (South Australia)

Precipitation Amount, 1910–90

Precipitation (mm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	April– Sept	April– Mar ^a	Jan– Dec
1910	19.8	0.0	115.9	0.0	65.7	63.6	57.3	23.3	60.4	34.3	1.8	21.4	270.3	374.6	463.5
1911	7.4	32.8	6.6	1.3	53.1	19.4	37.0	13.0	17.1	6.1	6.8	36.6	140.9	242.4	237.2
1912	1.3	15.0	35.7	4.4	2.0	54.9	30.8	51.4	44.7	11.5	16.2	11.7	188.2	346.1	279.6
1913	3.0	31.3	84.2	2.8	11.4	1.5	12.3	23.5	54.8	39.3	19.7	14.5	106.3	217.3	298.3
1914	12.1	11.4	14.0	14.1	16.7	6.9	13.1	1.5	9.2	0.0	29.4	23.8	61.5	121.3	152.2
1915	6.1	0.0	0.5	30.0	43.4	69.1	22.8	75.4	50.8	15.7	8.4	10.2	291.5	352.7	332.4
1916	10.4	2.5	14.0	15.8	18.1	73.4	66.3	82.2	47.5	64.2	53.5	19.5	303.3	492.1	467.4
1917	11.2	23.4	17.0	2.3	31.3	25.3	42.8	35.1	47.7	74.2	30.2	45.7	184.5	369.9	386.2
1918	2.3	9.4	23.6	53.4	29.0	7.4	30.7	43.6	8.7	24.4	3.0	0.5	172.8	280.8	236.0
1919	6.6	71.7	1.8	4.8	31.9	13.0	14.3	14.9	25.3	16.3	11.4	28.6	104.2	170.6	240.6
1920	2.0	0.8	7.3	8.6	17.4	55.9	11.6	49.1	51.3	43.8	74.4	36.2	193.9	512.2	358.4
1921	33.8	51.1	79.0	0.5	75.0	48.4	19.7	17.9	38.1	24.2	30.8	4.8	199.6	263.8	423.3
1922	3.9	0.5	0.0	37.1	81.5	22.6	41.0	33.5	15.2	20.4	1.3	41.8	230.9	302.8	298.8
1923	7.9	0.5	0.0	3.6	58.5	56.5	35.7	35.9	42.9	32.6	7.9	37.8	233.1	366.1	319.8
1924	26.2	8.1	20.4	11.4	26.9	42.4	7.6	21.9	54.9	50.6	34.3	20.6	165.1	307.2	325.3
1925	9.9	21.6	5.1	24.4	42.4	4.0	20.9	22.4	41.9	3.8	13.1	0.0	156.0	177.4	209.5
1926	1.3	1.6	1.6	11.5	61.6	27.9	23.0	42.4	53.7	18.3	5.3	1.8	220.1	276.3	250.0
1927	17.0	4.1	9.7	0.8	18.3	16.0	18.3	39.9	14.3	5.7	23.3	12.7	107.6	235.9	180.1
1928	13.4	47.8	25.4	8.4	21.9	24.3	40.9	17.2	36.1	34.4	1.0	5.6	148.8	223.4	276.4
1929	8.9	14.5	10.2	5.9	17.3	23.7	11.4	11.3	15.9	6.4	23.0	67.4	85.5	190.2	215.9
1930	0.0	7.1	0.8	13.0	8.6	13.4	47.9	69.2	18.8	75.3	16.6	10.5	170.9	291.4	281.2
1931	7.2	2.0	8.9	41.9	43.1	50.4	30.2	33.2	44.5	11.7	13.8	0.5	243.3	318.0	287.4
1932	1.8	30.6	16.3	46.9	44.5	38.8	28.9	55.0	37.4	18.8	2.8	28.0	251.5	360.6	349.8
1933	37.4	0.0	22.1	5.3	42.6	4.4	8.2	47.0	42.4	3.8	13.5	12.2	149.9	203.8	238.9
1934	13.2	6.4	4.8	41.0	7.4	28.0	19.7	18.9	24.9	53.2	46.0	4.6	139.9	283.4	268.1
1935	11.8	0.0	27.9	22.5	25.7	17.8	30.0	33.5	15.1	31.0	9.9	14.3	144.6	320.5	239.5
1936	75.7	28.7	16.3	8.0	21.4	15.1	49.2	27.4	7.2	28.1	8.2	48.1	128.3	285.1	333.4
1937	34.1	33.5	4.8	9.4	32.2	59.1	15.2	60.6	43.7	9.4	33.1	75.9	220.2	401.1	411.0
1938	39.7	22.3	0.5	32.5	1.0	13.4	33.2	55.9	4.1	14.0	5.3	0.0	140.1	240.0	221.9
1939	15.0	64.0	1.6	20.8	11.2	17.6	18.6	65.0	9.6	8.1	53.5	2.4	142.8	244.2	287.4
1940	16.6	10.4	10.4	34.4	12.7	4.6	12.6	9.9	16.3	10.9	6.2	15.5	90.5	307.7	160.5
1941	138.3	1.6	44.7	11.1	4.4	42.8	39.3	23.3	30.7	67.4	12.0	4.9	151.6	260.3	420.5
1942	20.3	4.1	0.0	44.6	56.1	42.7	43.4	48.9	63.0	17.3	21.2	9.4	298.7	404.2	371.0
1943	8.6	44.4	4.6	20.0	5.7	22.6	11.3	29.8	17.2	23.1	13.8	22.4	106.6	179.7	223.5
1944	1.1	8.3	4.4	12.6	28.6	7.3	12.2	14.3	5.3	8.5	22.9	20.5	80.3	147.4	146.0
1945	4.8	10.4	0.0	2.6	20.1	26.7	18.2	26.2	14.6	49.9	42.4	23.6	108.4	384.1	239.5
1946	26.2	111.2	22.4	12.2	26.2	27.9	26.8	10.8	7.4	9.4	37.9	110.7	111.3	398.0	429.1
1947	3.8	70.9	54.0	22.9	1.8	25.9	74.6	30.4	42.2	29.4	19.8	27.0	197.8	287.6	402.7
1948	1.1	4.9	7.6	59.0	14.8	25.5	19.4	33.2	9.4	37.8	27.6	24.2	161.3	279.7	264.5
1949	2.4	26.4	0.0	0.5	39.0	23.5	24.7	8.0	18.6	49.7	18.5	2.6	114.3	302.6	213.9

Australian precipitation records from ten regionally representative stations

B. Lavery and N. Nicholls (continued)

BROWNLOW POST OFFICE

(South Australia)

Precipitation Amount, 1910-90 (continued)

	Precipitation (mm)														
Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	April-Sept	April-Mar ^a	Jan-Dec
1950	0.6	65.6	51.3	6.7	70.9	27.9	30.5	26.9	13.6	25.7	19.3	5.6	176.5	241.6	344.6
1951	6.1	6.4	2.0	19.0	26.6	85.26	58.4	51.7	20.8	69.4	3.1	20.4	261.7	389.1	369.1
1952	23.3	3.8	7.4	24.8	98.6	43.7	18.6	11.7	39.5	63.8	19.1	11.5	236.9	343.7	365.8
1953	11.1	0.0	1.3	5.1	14.6	19.2	22.5	18.2	31.8	44.9	11.2	34.6	111.4	226.3	214.5
1954	21.4	0.0	2.8	55.4	2.3	35.9	22.8	16.2	7.2	41.7	14.6	30.3	139.8	311.0	250.6
1955	0.8	60.2	23.6	27.8	120.2	73.4	12.4	57.5	14.2	10.5	22.9	9.4	305.5	421.8	432.9
1956	9.2	8.4	55.9	27.5	55.0	40.7	73.4	28.9	34.9	23.4	8.1	2.8	260.4	302.6	368.2
1957	0.0	0.8	7.1	3.8	12.2	48.1	14.5	14.6	21.0	26.0	8.9	8.4	114.2	191.6	165.4
1958	2.8	4.4	26.9	17.8	40.4	4.4	38.5	63.1	51.2	33.1	14.0	5.1	215.4	296.9	301.7
1959	6.6	20.1	2.6	1.0	11.4	5.6	6.5	17.1	14.2	77.6	6.6	9.9	55.8	221.9	179.2
1960	8.7	52.7	10.6	32.0	81.7	9.5	45.1	26.2	46.5	2.1	23.1	6.9	241.0	293.1	345.1
1961	3.8	12.4	3.8	79.6	8.1	13.8	33.9	20.3	44.6	5.1	112.6	12.0	200.3	411.2	350.0
1962	35.3	7.1	38.8	0.5	42.4	14.9	17.5	32.6	12.1	67.2	6.4	57.6	120.0	280.7	332.4
1963	22.1	6.9	0.5	92.0	86.9	53.0	51.2	40.7	21.0	21.6	5.3	1.8	344.8	417.2	403.0
1964	24.2	17.7	1.8	41.2	20.3	11.7	50.9	24.5	66.9	43.8	20.9	31.2	215.5	312.4	355.1
1965	0.0	0.0	1.0	5.9	34.7	32.7	16.3	32.6	37.8	2.6	19.7	12.8	160.0	241.2	196.1
1966	10.5	25.7	9.9	5.8	21.1	25.9	43.1	8.8	24.7	17.7	5.5	86.6	129.4	259.2	285.3
1967	11.4	5.6	3.0	0.5	13.2	11.2	19.4	28.6	6.6	3.8	0.0	2.1	79.5	176.1	105.4
1968	18.6	43.2	28.9	35.2	32.6	59.2	48.3	27.6	7.8	27.7	16.5	21.8	210.7	401.7	367.4
1969	5.1	76.7	43.2	15.2	52.9	19.8	38.6	21.6	36.3	2.5	11.2	22.8	184.4	238.2	345.9
1970	9.2	0.0	8.1	24.3	24.3	26.2	15.2	33.9	59.1	8.6	49.3	20.2	183.0	319.5	278.4
1971	0.0	29.7	28.7	31.0	19.3	44.9	29.8	49.0	34.0	15.3	24.3	6.7	208.0	335.2	312.7
1972	37.9	42.2	0.8	14.3	9.2	9.7	24.6	46.8	11.9	14.5	64.3	2.8	116.5	358.8	279.0
1973	7.9	99.6	53.2	27.9	8.5	47.2	54.1	57.4	31.7	101.4	32.2	15.5	226.8	594.1	536.6
1974	136.8	44.8	36.6	72.6	96.8	28.0	58.4	26.6	42.4	78.0	14.0	1.0	324.8	448.2	636.0
1975	4.0	5.4	21.0	8.4	9.8	4.0	13.2	30.0	68.0	77.6	9.4	10.8	133.4	276.6	261.6
1976	13.0	28.0	4.4	7.8	3.8	14.2	18.4	15.0	35.8	78.4	20.6	2.8	95.0	225.8	242.2
1977	12.8	4.0	12.2	2.6	17.2	14.8	13.0	11.0	26.6	16.6	77.6	21.8	85.2	220.8	230.2
1978	8.0	0.0	11.6	47.6	20.4	50.4	49.0	51.6	63.4	4.6	22.4	7.2	282.4	407.6	336.2
1979	47.2	42.0	1.8	13.8	40.9	3.2	7.2	38.0	93.8	38.8	31.0	32.8	196.9	303.7	390.5
1980	1.4	0.6	2.2	56.8	21.4	57.2	42.0	7.2	22.4	75.0	5.2	6.0	207.0	352.0	297.4
1981	36.2	8.2	14.4	5.6	34.2	29.4	39.6	46.8	14.1	10.4	23.4	0.0	169.7	220.3	262.3
1982	8.0	1.8	7.0	27.0	11.0	18.7	5.7	8.4	18.2	6.2	0.0	2.6	89.0	130.2	114.6
1983	2.2	0.8	29.4	37.1	26.0	7.3	44.6	40.0	34.0	51.6	24.0	26.2	189.0	340.0	323.2
1984	36.4	5.6	7.2	23.6	11.6	16.1	63.3	44.2	14.8	20.6	11.3	6.6	173.6	260.3	261.3
1985	5.2	0.0	43.0	18.2	25.4	14.0	5.0	61.4	13.8	19.2	5.4	22.0	137.8	187.2	232.6
1986	2.2	0.6	0.0	9.2	11.2	10.4	55.2	65.8	38.6	37.6	22.4	14.2	190.4	326.7	267.4
1987	30.5	23.4	8.2	13.6	53.4	30.6	17.8	31.8	14.0	34.4	6.6	40.2	161.2	272.6	304.5
1988	15.8	3.6	10.8	22.6	46.4	48.4	26.4	17.8	26.6	7.0	46.6	26.8	188.2	307.8	298.8
1989	1.8	2.0	35.4	3.4	57.2	22.4	55.6	28.4	26.2	19.4	20.0	36.8	193.2	314.6	308.6
1990	19.0	24.6	1.6	4.9	32.4	29.6	59.6	36.6	17.4	24.3	9.2	18.0	180.5		277.2

^aThe total in this column is calculated for April of the listed year through March of the following year.

CITE AS: Lavery, B., and N. Nicholls. 1994. Australian precipitation records from ten regionally representative stations. pp. 918-950. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

CARRICK (Tasmania)

Trends

According to Nicholls and Lavery (1992), the data from Carrick show no clear long-term precipitation trends. Interannual variations are large, because of the high variability of both winter (April–September) and summer (October–March) precipitation.

Winter (Apr.–Sept., thin solid line) and 12-month (Apr.–Mar., dashed line) precipitation amount at Carrick. The summer (Oct.–Mar.) precipitation amount is represented by the spacing between the thin solid and dashed lines. The spacing between the two thick solid lines (the winter and 12-month, 11-point running means) indicates long-term changes in summer precipitation.

Australian precipitation records from ten regionally-representative stations

B. Lavery and N. Nicholls (continued)

CARRICK
(Tasmania)

Precipitation Amount, 1910–90

Precipitation (mm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	April– Sept	April– Mar ^a	Jan– Dec
1910	60.5	1.8	31.6	60.1	96.1	98.3	73.1	82.5	114.5	52.3	53.7	73.2	524.6	924.8	797.7
1911	9.9	49.7	161.4	33.6	76.9	71.6	109.0	34.1	51.9	22.2	4.2	83.9	377.1	584.7	708.4
1912	16.0	4.6	76.7	68.4	40.3	54.4	100.8	60.3	90.4	54.6	74.8	72.1	414.6	727.4	713.4
1913	8.9	11.0	91.4	41.3	9.1	27.8	56.8	102.1	56.3	55.6	38.7	47.9	293.4	478.7	546.9
1914	16.5	2.5	24.1	97.0	60.6	46.2	35.8	12.7	11.2	4.2	32.6	37.3	263.5	415.3	380.7
1915	11.9	26.1	39.7	104.3	88.7	92.7	67.8	82.6	122.3	80.8	69.3	5.5	558.4	872.0	791.7
1916	77.7	64.3	16.0	83.5	36.2	110.3	80.8	134.1	67.4	114.2	84.4	139.0	512.3	958.9	1007.9
1917	31.1	38.8	39.1	21.1	101.1	119.9	121.1	61.1	156.9	127.0	79.6	32.3	581.2	943.7	929.1
1918	46.2	54.4	23.0	32.2	166.9	116.2	65.1	24.2	31.0	83.1	18.0	42.3	435.6	642.7	702.6
1919	11.4	32.2	20.1	14.5	76.6	72.6	48.4	36.6	29.7	45.9	25.4	54.9	278.4	482.2	468.3
1920	34.0	6.1	37.5	29.7	53.7	135.0	122.3	88.4	83.2	42.3	35.1	19.5	512.3	737.0	686.8
1921	71.6	40.9	15.3	30.0	47.5	83.3	115.0	66.5	98.0	54.2	66.7	2.2	440.3	691.2	691.2
1922	22.2	84.0	21.6	47.7	47.7	26.4	47.3	48.0	61.3	96.6	12.2	95.2	278.4	588.5	610.2
1923	67.5	16.8	21.8	7.1	216.1	69.8	66.0	46.0	158.5	81.9	83.5	57.0	563.5	1019.6	892.0
1924	56.2	96.8	80.7	57.9	55.6	60.6	67.2	95.0	100.6	68.4	87.6	3.8	436.9	668.9	830.4
1925	25.2	14.2	32.8	38.0	50.8	55.4	53.3	80.5	43.8	71.9	10.4	9.6	321.8	462.1	485.9
1926	9.7	21.6	17.1	50.9	52.2	82.0	131.7	114.7	29.1	111.8	31.4	43.5	460.6	784.2	695.7
1927	48.8	51.0	37.1	3.6	52.6	66.3	72.0	107.5	41.8	44.1	10.1	118.8	343.8	661.7	653.7
1928	70.3	45.6	29.0	79.8	29.5	64.4	92.3	41.4	95.2	143.2	52.7	28.4	402.6	755.1	771.8
1929	66.9	23.8	37.5	114.0	48.6	137.2	88.9	73.9	33.6	67.0	57.7	63.0	496.2	738.8	812.1
1930	7.4	31.7	15.8	60.8	62.7	8.3	104.8	114.3	49.3	59.4	61.6	121.0	400.2	803.1	697.1
1931	6.9	25.3	128.7	38.9	189.8	194.1	113.3	73.9	118.9	27.0	43.8	0.0	728.9	956.9	960.6
1932	22.7	32.4	102.1	93.5	6.1	83.9	45.0	80.5	59.9	69.7	40.2	63.3	368.9	632.9	699.3
1933	18.3	6.9	65.6	48.3	56.1	29.2	43.0	41.2	99.2	69.4	41.7	20.4	317.0	510.5	539.3
1934	28.0	21.1	12.9	82.0	12.2	14.8	117.2	45.7	79.9	89.9	90.7	61.1	351.8	748.0	655.5
1935	21.5	75.9	57.1	99.1	79.0	65.7	87.8	65.9	36.8	27.0	37.9	29.0	434.3	601.4	682.7
1936	20.3	11.4	41.5	42.9	26.2	43.2	44.6	219.6	39.9	66.5	30.5	50.0	416.4	751.8	636.6
1937	86.0	40.7	61.7	14.7	55.5	19.0	66.3	57.4	47.6	59.8	24.5	109.2	260.5	640.7	642.4
1938	55.7	108.3	22.7	60.0	38.0	160.9	23.1	73.7	44.8	57.8	52.1	44.0	400.5	704.3	741.1
1939	3.8	79.5	66.6	82.0	84.4	93.9	40.2	200.0	50.5	71.7	75.6	35.5	551.0	857.1	883.7
1940	86.1	18.6	18.6	37.8	34.2	64.5	130.4	25.9	20.5	17.0	35.6	84.9	313.3	570.9	574.1
1941	29.6	15.0	75.5	13.8	30.4	70.5	67.3	38.9	59.2	65.4	51.8	29.2	280.1	526.4	546.6
1942	45.5	32.8	21.6	19.9	100.2	132.8	146.0	93.5	82.8	55.7	12.0	60.2	575.2	799.2	803.0
1943	37.9	53.9	4.3	65.6	25.7	46.3	126.8	37.5	80.6	48.7	30.3	17.7	382.5	622.4	575.3
1944	77.3	47.1	18.8	29.4	68.4	26.7	168.4	30.0	44.1	57.2	39.1	79.5	367.0	769.0	686.0
1945	75.2	140.3	10.7	9.1	39.6	79.2	77.0	141.7	54.2	15.5	21.4	30.0	400.8	765.6	693.9
1946	62.4	103.7	131.8	18.0	59.0	18.5	168.2	79.6	43.0	18.6	51.6	72.6	386.3	635.1	827.0
1947	26.0	24.7	55.3	33.6	88.2	135.2	137.6	97.3	52.0	144.8	45.8	88.4	543.9	939.0	928.9
1948	49.0	50.6	16.5	44.7	54.2	27.8	71.7	49.6	61.2	76.2	53.0	50.3	309.2	618.0	604.8
1949	28.2	54.4	46.7	16.7	76.2	31.5	41.2	39.0	37.7	133.5	106.8	12.8	242.3	581.3	624.7

Precipitation

Australian precipitation records from ten regionally-representative stations

B. Lavery and N. Nicholls (continued)

CARRICK (Tasmania)

Precipitation Amount, 1910–90 (continued)

	Precipitation (mm)														
Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	April– Sept	April– Mar ^a	Jan– Dec
1950	34.2	22.5	29.2	18.8	62.2	24.3	80.2	94.8	62.7	114.3	74.0	71.7	343.0	680.6	688.9
1951	18.5	20.9	38.2	126.4	76.6	37.5	98.5	54.6	27.5	52.9	64.5	82.6	421.1	676.7	698.7
1952	36.3	14.7	4.6	111.0	87.7	71.7	94.8	52.4	123.0	116.3	156.8	26.4	540.6	903.0	895.7
1953	39.8	1.1	22.0	40.7	48.2	118.5	99.5	74.6	93.8	76.4	89.5	96.0	475.3	877.3	800.1
1954	22.0	97.8	20.3	75.4	45.6	48.9	64.9	84.8	40.4	25.0	42.1	56.8	360.0	563.2	624.0
1955	20.5	42.7	16.1	88.0	99.1	80.8	101.6	159.9	66.2	154.5	63.9	73.9	595.6	1099.3	967.2
1956	61.2	77.0	73.2	143.9	100.9	143.8	89.0	99.6	80.9	64.7	50.8	59.6	658.1	926.9	1044.6
1957	14.9	41.2	37.6	115.2	92.6	60.6	16.8	47.8	51.7	38.4	59.8	47.0	384.7	635.6	623.6
1958	4.6	72.3	28.8	54.6	161.4	35.6	88.0	73.7	33.1	119.8	65.9	64.3	446.4	802.4	802.1
1959	19.7	68.1	18.2	49.8	11.4	67.1	36.6	80.5	35.4	31.3	25.6	103.4	280.8	519.0	547.1
1960	21.8	41.0	15.1	169.6	105.2	69.9	112.9	45.6	74.1	54.5	47.7	2.6	577.3	716.3	760.0
1961	2.9	20.4	10.9	94.5	24.4	57.9	59.2	73.0	29.3	49.0	30.8	69.3	338.3	613.4	521.6
1962	37.9	27.9	60.2	30.8	94.7	74.8	47.6	90.7	37.3	89.3	36.6	26.6	375.9	668.6	654.4
1963	69.6	30.4	40.2	3.0	32.3	37.3	116.5	77.9	95.2	52.0	32.1	21.5	362.2	661.0	608.0
1964	15.8	105.7	71.7	35.9	75.5	113.5	144.0	53.6	91.1	86.9	56.0	44.6	513.6	756.5	894.3
1965	29.8	1.5	24.1	97.3	112.6	37.3	39.4	32.6	79.3	23.7	48.3	57.2	398.5	605.7	583.1
1966	7.5	23.2	47.3	33.0	55.1	27.4	190.0	36.3	107.2	56.9	24.1	68.7	449.0	679.2	676.7
1967	39.4	21.6	19.5	10.7	20.6	32.9	103.1	101.4	39.0	33.6	17.0	49.4	307.7	542.1	488.2
1968	18.5	58.0	57.9	70.4	101.0	62.6	90.2	122.8	48.3	97.2	92.1	21.1	495.3	917.8	840.1
1969	41.2	123.7	47.2	36.8	113.6	21.5	68.9	89.3	46.3	25.7	34.7	37.4	376.4	629.1	686.3
1970	68.3	36.6	50.0	55.3	41.6	74.5	106.4	109.4	47.6	47.0	61.2	137.2	434.8	781.8	835.1
1971	50.1	19.2	32.3	100.6	85.5	108.5	31.8	111.0	93.3	101.6	88.4	92.1	530.7	908.0	914.4
1972	54.9	36.5	3.8	38.2	20.9	47.3	78.2	90.6	31.0	22.3	38.1	5.2	306.2	533.0	467.0
1973	55.8	59.3	46.1	82.9	112.6	86.8	47.2	96.0	95.9	98.6	40.4	109.6	521.4	889.0	931.2
1974	48.2	23.4	47.4	110.6	58.8	88.6	145.2	89.4	112.8	66.0	48.8	119.4	605.4	1035.4	958.6
1975	46.6	7.6	141.6	28.8	97.6	96.6	230.2	92.4	68.2	72.8	109.0	34.2	613.8	980.3	1025.6
1976	68.0	17.5	65.0	21.6	53.2	58.6	42.8	97.6	46.0	37.0	88.2	88.6	319.8	773.0	684.1
1977	53.6	56.6	129.2	6.3	133.5	72.4	43.4	91.4	10.4	43.2	45.6	12.0	357.4	596.0	697.6
1978	25.0	81.2	31.6	58.4	78.2	33.0	64.4	77.6	70.6	57.8	83.2	60.2	382.2	756.4	721.2
1979	90.2	41.2	41.6	52.8	53.4	54.4	62.6	66.8	102.4	125.8	30.2	21.0	392.4	653.4	742.4
1980	24.0	18.2	41.8	88.6	37.2	64.2	93.0	108.6	85.2	55.4	38.0	52.0	476.8	715.3	706.2
1981	18.8	14.2	60.1	34.1	41.3	77.2	115.4	156.0	30.8	69.4	36.6	32.3	454.8	694.3	686.2
1982	23.3	19.3	58.6	67.8	54.0	65.6	47.6	15.6	69.0	24.7	16.2	62.2	319.6	536.3	523.9
1983	27.6	1.0	85.0	63.7	46.6	46.5	40.4	60.4	92.4	42.0	67.8	12.8	350.0	605.7	586.2
1984	17.5	15.0	100.6	56.5	77.0	46.6	59.0	157.3	163.5	21.2	64.4	60.6	559.9	792.0	839.2
1985	37.0	3.9	45.0	31.8	168.0	65.0	48.0	78.8	35.2	63.9	68.1	153.6	426.8	779.6	798.3
1986	44.0	14.8	8.4	95.6	98.0	44.4	130.0	65.4	73.8	109.6	20.0	51.6	507.2	772.0	755.6
1987	44.4	9.4	29.8	18.8	95.0	49.0	68.8	21.8	17.0	47.4	68.0	60.4	270.4	482.0	529.8
1988	18.8	12.8	4.2	33.0	86.2	89.0	101.0	77.4	63.6	70.6	73.2	60.4	450.2	798.6	690.2
1989	66.0	8.2	70.0	147.0	86.4	90.6	95.0	58.0	81.6	101.0	22.2	52.8	558.6	823.4	878.8
1990	11.4	55.8	21.6	49.2	36.0	77.6	84.6	107.0	46.8	66.6	72.8	40.4	401.2		669.8

^aThe total in this column is calculated for April of the listed year through March of the following year.

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Australian precipitation records from ten regionally-representative stations

B. Lavery and N. Nicholls (continued)

WINTON POST OFFICE

(Northeastern Australia)

Trends

According to Nicholls and Lavery (1992), the data from the Winton Post Office station show no clear long-term precipitation trends. Shorter time scale, quasi-decadal variations in 12-month (April–March) and summer (October–March) precipitation are clearly evident. Winter (April–September) precipitation, while often varying greatly from year to year, shows no obvious decadal-scale variation.

Winter (Apr.-Sept., thin solid line) and 12-month (Apr.-Mar., dashed line) precipitation amount at Winton Post Office. The summer (Oct.-Mar.) precipitation amount is represented by the spacing between the thin solid and dashed lines. The spacing between the two thick solid lines (the winter and 12-month, 11-point running means) indicates long-term changes in summer precipitation.

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Precipitation

Australian precipitation records from ten regionally-representative stations

B. Lavery and N. Nicholls (continued)

WINTON POST OFFICE (Northeastern Australia)

Precipitation Amount, 1910–90

Precipitation (mm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	April– Sept	April– Mar ^a	Jan– Dec
1910	94.1	159.0	16.7	2.8	0.0	35.8	31.7	0.0	43.8	1.8	93.3	3.8	114.1	433.1	482.8
1911	128.4	90.2	1.5	36.0	6.1	0.0	6.6	1.0	4.8	5.6	99.6	50.3	54.5	373.5	430.1
1912	38.7	62.1	62.7	0.0	0.5	158.1	34.2	0.5	4.6	0.0	19.4	40.5	197.9	624.8	421.3
1913	25.8	294.0	47.2	25.4	0.0	13.7	0.0	0.0	3.8	10.1	1.8	54.6	42.9	339.4	476.4
1914	102.9	124.0	3.1	3.8	3.6	62.3	0.0	0.0	0.0	34.8	25.9	53.2	69.7	224.7	413.6
1915	22.8	16.0	2.3	1.0	56.2	0.0	0.0	17.8	48.5	3.8	0.0	90.0	123.5	498.4	258.4
1916	175.8	102.7	2.6	5.9	0.0	9.9	113.5	7.8	8.4	23.8	113.8	128.5	145.5	869.5	692.7
1917	71.2	136.9	249.8	0.0	0.0	1.8	1.0	34.3	27.7	31.3	126.5	91.2	64.8	793.2	771.7
1918	362.6	40.4	76.4	8.6	0.0	0.0	0.0	0.8	5.3	0.5	0.0	28.7	14.7	277.1	523.3
1919	56.1	109.5	67.6	10.2	15.1	0.0	0.0	3.0	0.0	0.0	0.0	7.4	28.3	262.0	268.9
1920	212.3	0.0	14.0	67.0	67.4	24.2	102.6	6.4	8.1	44.0	114.0	85.6	275.7	644.1	745.6
1921	7.9	57.4	59.5	32.5	15.0	47.7	30.5	8.5	0.0	119.0	0.0	175.2	134.2	702.9	553.2
1922	214.1	60.4	0.0	0.0	0.0	11.4	0.0	0.0	0.0	8.4	11.1	110.1	11.4	233.0	415.5
1923	54.7	31.2	6.1	1.5	6.9	54.3	0.0	0.0	0.0	25.2	4.8	40.7	62.7	529.1	225.4
1924	94.7	208.6	92.4	49.5	0.5	4.1	0.0	10.2	4.3	24.4	91.3	67.6	68.6	502.9	647.6
1925	32.7	97.7	120.6	0.0	0.0	0.0	0.3	0.0	10.4	0.0	50.0	13.0	10.7	91.1	324.7
1926	16.9	0.5	0.0	2.0	13.5	0.0	1.8	0.0	58.0	5.8	3.3	32.8	75.3	229.6	134.6
1927	62.5	30.9	19.0	0.5	0.0	16.5	0.0	0.0	7.6	6.4	1.0	42.9	24.6	120.5	187.3
1928	0.0	38.7	6.9	10.2	0.0	19.3	9.1	0.0	0.0	1.8	22.8	89.3	38.6	355.3	198.1
1929	136.2	16.3	50.3	63.7	0.0	2.1	0.0	0.0	0.0	0.0	19.8	10.5	65.8	410.2	298.9
1930	142.3	153.0	18.8	0.0	66.6	18.8	0.5	0.0	0.0	171.8	26.3	27.5	85.9	434.8	625.6
1931	29.4	0.0	93.9	7.1	23.9	7.1	0.0	0.0	13.5	16.8	36.8	58.2	51.6	215.6	286.7
1932	16.8	24.2	11.2	2.8	72.4	17.3	0.0	0.0	0.0	13.0	21.7	4.0	92.5	327.6	183.4
1933	37.1	154.0	5.3	0.0	0.8	17.5	56.6	1.6	2.5	5.3	49.1	20.3	79.0	349.6	350.1
1934	79.7	111.1	5.1	42.9	0.8	29.2	44.5	0.0	0.0	20.1	4.1	1.3	117.4	179.3	338.8
1935	35.6	0.8	0.0	0.0	2.5	155.5	0.0	3.5	21.4	10.4	37.0	6.1	182.9	513.8	272.8
1936	63.0	71.8	142.6	3.1	86.4	6.7	11.4	3.6	5.3	0.0	21.6	28.2	116.5	519.1	443.7
1937	57.9	54.6	240.3	0.0	0.0	52.7	0.0	3.3	2.5	3.0	63.4	5.4	58.5	403.2	483.1
1938	47.6	224.0	1.3	0.0	8.1	19.9	40.9	0.5	0.0	0.0	41.2	0.0	69.4	281.2	383.5
1939	27.2	138.6	4.8	42.0	0.0	37.1	11.4	14.0	3.6	140.1	39.5	30.2	108.1	738.1	488.5
1940	76.7	328.1	15.4	4.0	0.5	43.5	0.0	0.0	0.0	0.0	18.6	47.6	48.0	600.2	534.4
1941	235.5	11.4	239.1	120.9	16.3	63.4	0.0	0.0	0.0	8.7	32.3	57.6	200.6	389.0	785.2
1942	23.1	66.7	0.0	31.6	42.2	0.5	0.0	0.0	17.5	17.8	3.3	61.7	91.8	258.4	264.4
1943	21.6	58.1	4.1	14.2	8.7	0.8	0.0	0.3	39.4	3.8	9.3	25.5	63.4	418.0	185.8
1944	28.7	277.4	9.9	0.0	43.4	0.5	54.8	2.3	0.5	6.3	1.5	48.1	101.5	260.6	473.4
1945	24.1	64.8	14.3	2.6	37.6	19.7	41.1	0.0	0.5	2.8	0.3	55.3	101.5	349.2	263.1
1946	147.1	42.2	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	27.7	17.6	0.8	258.3	235.4
1947	22.3	165.0	24.9	0.0	0.0	1.5	0.0	49.6	62.8	12.8	28.7	39.8	113.9	260.7	407.4
1948	38.1	12.9	14.5	0.0	2.0	11.5	16.5	0.0	0.0	12.9	3.5	60.6	30.0	420.7	172.5
1949	55.4	56.5	201.8	1.5	0.0	0.0	0.0	0.0	1.9	131.3	0.0	146.1	3.4	847.7	594.5

Australian precipitation records from ten regionally-representative stations

B. Lavery and N. Nicholls (continued)

WINTON POST OFFICE

(Northeastern Australia)

Precipitation Amount, 1910–90 (continued)

	Precipitation (mm)														
Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	April– Sept	April– Mar ^a	Jan– Dec
1950	222.8	98.3	245.8	78.6	63.3	63.5	99.3	0.0	24.2	29.3	100.8	35.4	328.9	754.9	1061.3
1951	225.0	18.5	17.0	0.0	1.8	26.2	0.0	3.8	0.8	6.4	16.3	6.6	32.6	127.4	322.4
1952	6.1	59.4	0.0	32.8	49.1	0.0	0.5	15.5	0.3	20.5	57.6	9.4	98.2	415.8	251.2
1953	120.7	105.8	3.6	0.0	17.5	0.0	0.0	17.5	0.3	7.4	1.6	7.1	35.3	447.5	281.5
1954	231.0	141.8	23.3	45.5	0.0	33.0	2.8	18.8	0.8	7.4	3.6	23.4	100.9	632.0	531.4
1955	130.3	175.4	191.0	29.7	214.9	16.8	12.7	0.8	0.0	39.7	2.8	13.0	274.9	620.0	827.1
1956	107.0	66.9	115.7	16.2	38.1	35.6	90.6	0.8	7.4	4.8	40.6	147.9	188.7	763.9	671.6
1957	212.9	100.4	68.6	3.5	2.3	14.7	16.5	0.0	0.0	19.8	0.5	23.1	37.0	202.5	462.3
1958	35.0	9.9	77.2	138.4	9.1	87.7	4.2	0.0	0.0	4.1	26.2	16.5	239.4	374.1	408.3
1959	46.5	6.1	35.3	14.5	83.3	0.0	2.8	16.0	3.5	4.8	8.1	23.4	120.1	334.5	244.3
1960	11.1	160.4	6.6	9.1	35.4	3.8	6.6	17.3	20.6	1.0	11.2	173.5	92.8	348.1	456.6
1961	11.4	43.5	14.7	30.4	0.3	0.0	19.8	0.0	0.0	0.5	17.2	121.7	50.5	310.3	259.5
1962	63.6	23.7	33.1	15.5	23.4	14.5	6.3	0.0	34.6	11.4	34.3	103.2	94.3	506.7	363.6
1963	16.2	29.0	218.3	90.7	4.8	0.0	0.0	6.6	0.0	1.5	0.3	27.2	102.1	315.8	394.6
1964	44.4	60.7	79.6	11.2	0.8	5.6	1.6	0.0	24.4	44.4	7.1	28.7	43.6	202.8	308.5
1965	5.3	6.3	67.4	43.7	0.0	0.0	0.0	0.0	1.0	1.3	0.0	45.3	44.7	206.8	170.3
1966	100.0	11.9	3.6	0.0	1.5	0.8	0.0	31.3	0.0	0.0	41.4	4.1	33.6	223.1	194.6
1967	2.3	64.5	77.2	0.0	0.5	54.3	0.0	0.0	0.0	4.6	5.7	13.0	54.8	243.0	222.1
1968	1.0	163.9	0.0	63.3	97.8	0.0	5.1	0.0	1.0	0.0	7.6	24.4	167.2	231.5	364.1
1969	4.3	13.2	14.8	6.6	39.7	0.0	2.0	0.0	0.0	6.4	3.8	66.3	48.3	245.0	157.1
1970	2.8	100.9	16.5	19.6	0.0	0.0	0.0	0.0	18.6	6.9	86.9	48.2	38.2	344.5	300.4
1971	46.6	18.1	99.6	95.5	0.0	10.9	32.0	28.5	4.3	78.5	27.2	115.8	171.2	613.7	557.0
1972	91.9	14.2	114.9	0.0	22.9	1.8	0.0	1.8	0.0	0.0	19.9	24.7	26.5	656.5	292.1
1973	51.9	288.3	245.2	16.5	14.7	2.0	7.4	1.3	28.3	13.5	44.3	53.2	70.2	890.0	766.6
1974	562.8	108.6	37.4	186.2	44.6	1.4	0.0	26.2	13.0	11.2	16.2	78.5	271.4	677.1	1086.1
1975	160.6	77.8	61.4	0.0	0.0	1.6	0.0	10.3	13.0	49.6	0.8	78.4	24.9	668.2	453.5
1976	126.4	349.5	38.6	4.6	1.0	0.0	2.4	5.2	4.6	17.0	32.1	113.0	17.8	507.0	694.4
1977	124.2	163.5	39.4	8.6	73.5	0.0	0.0	0.0	0.0	1.2	0.0	85.2	82.1	307.8	495.6
1978	100.4	31.5	7.4	0.6	35.9	4.9	112.8	1.3	28.9	70.2	25.8	47.6	184.4	597.0	467.3
1979	67.4	183.5	18.1	0.2	5.6	31.4	0.0	0.2	1.5	24.0	6.5	47.5	38.9	292.4	385.9
1980	126.6	29.6	19.3	2.6	2.5	0.0	1.0	11.7	0.0	7.7	0.0	26.0	17.8	352.8	227.0
1981	234.2	44.3	22.8	3.2	40.3	69.3	88.7	1.2	0.4	5.2	13.9	19.7	203.1	387.9	543.2
1982	89.0	3.6	53.4	3.6	0.0	0.0	0.0	0.0	6.2	0.0	31.8	11.9	9.8	95.1	199.5
1983	15.6	5.2	20.8	58.0	30.8	0.0	0.0	5.5	0.0	1.8	40.8	10.6	94.3	451.1	189.1
1984	166.8	110.8	26.0	0.0	0.0	0.4	82.9	0.4	18.0	4.0	0.0	145.7	101.7	286.9	555.0
1985	0.0	20.4	15.1	9.0	1.4	59.6	8.8	6.6	0.0	30.3	150.5	76.4	85.4	526.6	378.1
1986	0.2	183.8	0.0	0.5	24.0	0.0	34.2	13.5	1.0	53.6	23.0	18.7	73.2	356.8	352.5
1987	83.2	83.6	21.5	16.4	3.8	12.0	2.6	6.4	8.0	5.4	27.9	38.8	49.2	147.5	309.6
1988	17.2	7.8	1.2	104.2	40.4	0.0	75.8	20.6	4.0	0.0	1.6	36.0	245.0	491.2	308.8
1989	11.0	119.8	77.8	23.4	87.2	20.4	24.0	0.0	0.0	16.6	185.6	29.4	155.0	525.2	595.2
1990	26.0	26.8	85.8	181.0	81.3	43.2	0.0	0.2	0.0	3.4	1.0	1.0	305.7		449.7

^aThe total in this column is calculated for April of the listed year through March of the following year.

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MOUNT BARKER (SW Western Australia)

Trends

According to Nicholls and Lavery (1992), the data from Mount Barker (Kendenup Post Office) show a relatively smooth and marked downward trend in 12-month (April–March) precipitation amount after about 1950. This 12-month trend results mainly from decreasing winter (April–September) precipitation; on the graph below, the spacing between the two lines representing the 11-point running means [indicative of variations in summer (October–March) precipitation] remains fairly uniform during the post-1950 period. Nicholls and Lavery (1992) emphasize that other stations in the SW Western Australia cluster show similar downward trends in winter precipitation amount, while data from stations in the South Coast Western Australia cluster (described in the following pages) reveal increasing precipitation amount after 1950, although these stations are close to Mount Barker.

Winter (Apr.-Sept., thin solid line) and 12-month (Apr.-Mar., dashed line) precipitation amount at Mount Barker. The summer (Oct.-Mar.) precipitation amount is represented by the spacing between the thin solid and dashed lines. The spacing between the two thick solid lines (the winter and 12-month, 11-point running means) indicates long-term changes in summer precipitation.

Australian precipitation records from ten regionally-representative stations

B. Lavery and N. Nicholls (continued)

MOUNT BARKER

(SW Western Australia)

Precipitation Amount, 1910–90

Precipitation (mm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	April– Sept	April– Mar ^a	Jan– Dec
1910	21.1	1.8	16.5	44.6	98.8	120.4	211.3	75.9	47.6	90.1	51.2	11.4	598.6	820.9	790.7
1911	3.1	3.0	63.5	28.2	69.2	49.4	108.7	68.7	59.3	83.5	2.3	15.2	383.5	508.7	554.1
1912	3.8	4.9	15.5	18.8	61.9	39.2	217.0	37.6	97.6	27.4	43.5	10.2	472.1	604.5	577.4
1913	13.2	0.0	38.1	150.0	24.7	67.6	66.2	121.8	78.5	50.3	16.5	39.1	508.8	685.5	666.0
1914	0.0	39.0	31.8	19.3	51.3	30.5	77.7	21.8	17.3	37.1	57.9	50.0	217.9	437.6	433.7
1915	14.4	29.2	31.1	28.4	65.7	73.9	101.8	122.5	99.3	30.1	12.2	2.5	491.6	619.3	611.1
1916	22.3	38.0	22.6	8.9	26.2	67.0	145.5	99.6	2.8	88.7	59.5	5.4	350.0	599.1	586.5
1917	5.6	34.6	55.3	93.9	167.2	154.1	97.8	121.8	136.3	54.0	0.0	14.2	771.1	988.3	934.8
1918	90.8	34.6	23.6	77.6	110.5	96.3	20.0	80.5	39.1	51.8	16.0	0.5	424.0	511.8	641.3
1919	2.8	12.1	4.6	105.2	31.0	30.9	149.6	94.8	38.4	57.2	5.9	9.4	449.9	578.8	541.9
1920	4.3	44.5	7.6	19.1	82.2	85.8	79.4	159.5	55.2	31.2	13.0	0.0	481.2	570.6	581.8
1921	12.7	29.2	3.3	24.7	131.5	52.6	63.2	69.4	72.9	85.3	25.1	81.2	414.3	677.3	651.1
1922	5.8	23.1	42.5	65.6	112.5	60.6	100.2	74.6	44.3	28.7	29.5	29.6	457.8	617.3	617.0
1923	20.3	2.3	49.1	29.8	141.3	180.9	83.1	66.1	130.4	37.9	8.1	7.6	631.6	694.7	756.9
1924	3.3	4.1	2.1	12.5	88.7	41.1	64.8	78.2	97.0	131.1	38.7	2.3	382.3	640.7	563.9
1925	25.1	24.9	36.3	31.4	67.8	53.3	70.5	26.7	44.3	81.7	4.3	97.0	294.0	572.3	563.3
1926	2.5	31.5	61.3	96.0	46.6	43.8	163.0	54.4	96.1	64.2	41.8	19.3	499.9	721.0	720.5
1927	23.7	10.7	61.4	15.0	69.6	89.3	80.1	62.1	85.5	63.2	15.2	17.9	401.6	564.0	593.7
1928	57.2	0.5	8.4	41.8	52.9	45.0	112.6	104.8	93.0	49.0	11.4	12.3	450.1	606.8	588.9
1929	4.2	68.9	10.9	37.3	78.1	112.7	59.1	49.6	52.5	35.5	110.8	26.8	389.3	600.9	646.4
1930	1.3	6.1	31.1	30.8	96.0	93.3	87.9	38.2	48.6	23.3	19.5	22.5	394.8	504.9	498.6
1931	2.3	4.6	37.9	38.5	55.5	76.5	50.1	103.7	83.2	30.9	16.4	38.4	407.5	535.6	538.0
1932	21.9	8.5	12.0	48.5	80.4	118.6	92.8	94.8	34.2	51.1	27.1	15.5	469.3	658.6	605.4
1933	43.4	3.8	48.4	37.9	73.6	176.3	62.5	63.5	62.0	101.7	41.3	31.8	475.8	783.9	746.2
1934	22.8	7.6	102.9	36.9	50.1	86.0	104.6	73.0	63.2	54.7	39.0	23.0	413.8	562.1	663.8
1935	16.3	12.4	2.9	69.9	38.1	97.2	104.1	62.7	75.3	66.9	13.0	18.4	447.3	569.8	577.2
1936	18.0	4.6	1.6	25.5	75.8	102.3	69.0	74.0	34.2	38.1	8.7	23.0	380.8	527.6	474.8
1937	12.0	3.6	61.4	49.5	117.5	43.7	56.2	98.1	54.6	45.2	32.5	4.4	419.6	558.7	578.7
1938	9.0	3.6	44.4	25.4	90.7	78.9	113.6	75.8	46.2	47.5	23.8	13.4	430.6	667.9	572.3
1939	115.5	34.8	2.3	27.8	68.5	103.0	87.9	106.5	20.9	156.1	57.2	1.6	414.6	640.5	782.1
1940	7.9	1.0	2.1	15.9	37.7	47.3	75.1	35.5	36.4	20.2	20.8	62.1	247.9	472.7	362.0
1941	7.3	2.3	112.1	54.7	53.5	93.3	85.2	65.8	107.9	63.2	25.4	8.7	460.4	626.7	679.4
1942	5.2	9.0	54.8	56.6	149.2	88.4	85.2	115.7	79.2	46.3	23.4	62.0	574.3	876.5	775.0
1943	50.5	28.7	91.3	60.8	34.9	57.3	111.2	77.0	59.1	22.1	10.6	19.3	400.3	469.6	622.8
1944	0.6	5.6	11.1	25.4	73.4	46.3	97.0	76.3	34.2	5.4	20.7	33.6	352.6	467.6	429.6
1945	2.6	8.2	44.5	20.4	74.7	158.8	121.9	183.5	92.4	19.7	21.4	21.6	651.7	735.6	769.7
1946	8.9	2.1	10.2	24.4	95.5	92.4	114.7	69.0	42.7	25.3	60.3	38.8	438.7	595.4	584.3
1947	1.3	24.6	6.4	148.2	134.8	171.2	107.2	40.6	68.9	104.8	31.8	19.0	670.9	837.6	858.8
1948	0.0	3.3	7.8	26.8	17.7	50.1	110.7	84.1	86.8	31.6	56.1	29.8	376.2	551.1	504.8
1949	11.4	11.7	34.3	24.9	27.4	65.2	115.2	107.8	48.2	101.4	59.2	3.4	388.7	568.0	610.1

Precipitation

Australian precipitation records from ten regionally-representative stations

B. Lavery and N. Nicholls (continued)

MOUNT BARKER

(SW Western Australia)

Precipitation Amount, 1910–90 (continued)

	Precipitation (mm)														
Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	April– Sept	April– Mar ^a	Jan– Dec
1950	9.2	3.8	2.3	0.5	207.3	82.0	109.7	50.5	56.4	48.3	35.8	12.4	506.4	682.9	618.2
1951	38.4	35.3	6.3	67.2	57.1	143.0	54.1	91.0	82.4	54.3	52.7	78.7	494.8	747.0	760.5
1952	31.5	7.1	27.9	23.7	96.8	118.3	52.3	45.1	51.3	85.1	34.1	25.1	387.5	574.4	598.3
1953	3.3	35.1	4.2	11.3	73.4	80.9	67.1	51.3	60.5	64.0	46.1	5.6	344.5	483.2	502.8
1954	11.0	3.6	8.4	29.7	58.5	35.5	55.9	33.8	22.7	31.8	22.7	9.1	236.1	486.5	322.7
1955	5.1	175.5	6.2	93.2	57.4	77.4	82.6	139.4	60.4	77.2	9.7	23.0	510.4	680.1	807.1
1956	0.0	1.1	58.7	22.6	93.0	86.3	116.3	31.0	39.6	47.6	25.9	14.3	388.8	496.1	536.4
1957	6.6	4.7	8.2	50.0	69.0	163.5	31.3	63.6	32.9	33.6	1.0	13.8	410.3	492.8	478.2
1958	11.8	12.2	10.1	30.7	79.2	44.2	131.7	70.0	88.3	40.4	20.1	39.9	444.1	598.7	578.6
1959	6.1	34.9	13.2	61.9	31.5	96.3	41.1	71.8	87.1	56.9	89.9	53.8	389.7	688.7	644.5
1960	30.8	4.6	63.0	44.5	73.2	51.4	126.9	44.4	48.5	15.6	14.6	10.6	388.9	526.9	528.1
1961	37.1	32.3	27.8	127.4	23.1	105.2	122.5	73.5	51.4	32.0	6.4	71.9	503.1	644.2	710.6
1962	0.0	15.0	15.8	4.1	62.5	102.8	61.6	107.0	33.7	76.1	23.1	38.0	371.7	611.5	539.7
1963	22.8	17.9	61.9	26.9	143.3	73.8	96.8	93.8	74.9	42.3	13.5	7.4	509.5	589.1	675.3
1964	8.7	3.6	4.1	38.4	16.1	116.6	158.1	90.4	54.0	79.4	13.0	22.6	473.6	699.9	605.0
1965	27.4	9.0	74.9	16.9	72.6	80.9	38.6	99.1	58.3	101.3	59.0	56.5	366.4	617.5	694.5
1966	8.2	22.6	3.5	37.2	34.4	118.8	53.9	41.8	66.4	70.2	15.1	21.5	352.5	530.1	493.6
1967	4.4	37.1	29.3	38.1	82.2	79.0	110.1	87.8	29.7	27.9	10.7	18.4	426.9	585.2	554.7
1968	20.7	3.3	77.3	42.3	41.1	109.8	74.7	55.2	90.6	39.6	5.3	2.1	413.7	493.8	562.0
1969	2.6	15.0	15.5	34.2	29.9	90.0	88.5	50.7	27.4	14.6	33.7	13.6	320.7	421.5	415.7
1970	0.8	33.3	4.8	67.6	41.5	110.4	56.9	34.4	73.8	39.7	18.4	16.8	384.6	575.5	498.4
1971	40.3	14.1	61.6	25.8	92.7	36.9	44.0	57.4	82.0	69.3	83.7	17.5	338.8	541.2	625.3
1972	11.3	11.7	8.9	28.8	59.3	38.1	81.5	63.9	20.9	44.8	2.1	20.3	292.5	369.9	391.6
1973	5.3	2.8	2.1	48.4	73.9	61.5	101.0	75.0	80.1	79.7	55.7	17.6	439.9	636.7	603.1
1974	7.4	24.0	12.4	40.0	97.8	49.4	122.5	40.2	27.1	36.7	59.8	1.2	377.0	497.1	518.5
1975	5.4	3.6	13.4	74.6	108.8	50.3	105.3	47.1	43.0	57.7	25.0	4.7	429.1	610.7	538.9
1976	57.8	11.6	24.8	80.7	73.2	45.3	57.4	77.6	44.4	92.4	50.1	5.7	378.6	546.1	621.0
1977	13.8	2.4	3.1	29.2	128.3	58.0	60.4	72.3	40.0	100.0	22.6	20.5	388.2	649.0	550.6
1978	29.5	77.1	11.1	7.2	66.2	113.8	94.7	36.9	58.3	42.2	23.8	25.4	377.1	547.1	586.2
1979	17.6	38.1	22.9	8.6	82.3	62.4	84.6	41.6	66.2	35.0	64.8	3.2	345.7	504.9	527.3
1980	7.0	48.0	1.2	60.2	31.8	66.6	77.4	75.0	39.8	94.4	30.6	11.4	350.8	513.4	543.4
1981	8.0	8.6	9.6	71.0	52.6	92.2	79.8	65.6	31.6	26.6	30.4	11.4	392.8	694.2	487.4
1982	187.6	15.4	30.0	4.4	31.2	54.0	60.4	45.6	24.6	28.8	33.0	10.6	220.2	338.8	525.6
1983	1.0	27.6	17.6	15.6	35.4	87.2	78.2	57.6	60.8	30.6	40.6	54.2	334.8	488.2	506.4
1984	0.6	14.0	13.4	22.8	74.0	91.0	60.3	91.8	82.6	28.4	96.4	8.8	422.5	608.7	584.1
1985	37.6	6.2	8.8	69.6	29.2	41.4	70.8	102.6	33.2	36.8	20.8	11.4	346.8	481.2	468.4
1986	0.0	50.6	14.8	4.6	43.8	75.4	84.0	61.8	61.4	33.8	13.6	4.0	331.0	406.4	447.8
1987	3.8	0.6	19.6	47.2	50.4	29.0	59.0	40.6	25.4	24.8	52.8	24.0	251.6	398.0	377.2
1988	14.2	0.6	30.0	15.2	187.8	128.8	81.0	69.8	68.0	27.0	19.0	42.6	550.6	744.6	684.0
1989	64.0	35.0	6.4	51.0	40.4	49.8	92.0	64.6	30.0	68.6	32.4	14.0	327.8	545.8	548.2
1990	42.6	25.6	34.8	52.4	53.8	63.6	123.8	36.4	46.2	69.8	21.6	6.4	376.2		577.0

^aThe total in this column is calculated for April of the listed year through March of the following year.

CITE AS: Lavery, B., and N. Nicholls. 1994. Australian precipitation records from ten regionally-representative stations. pp. 918–950. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Australian precipitation records from ten regionally-representative stations

B. Lavery and N. Nicholls (continued)

ALBANY
(South Coast of Western Australia)**Trends**

According to Nicholls and Lavery (1992), the data from Albany (Cape Riche) show increased 12-month (April–March) precipitation during most of the post-1950 period (the upward trend actually began in the late 1930s). They emphasize that the nearby Mount Barker station and other stations in the SW Western Australia cluster recorded decreased precipitation during roughly the same period. They attribute the opposing trends from the two nearby stations (clusters) to a probable subtle shift in atmospheric circulation in the region, a shift which perhaps caused a decrease in the frequency or strength of northwest winds, as hypothesized by Wright (1974a,b). The upward trend in the Albany 12-month precipitation amount was mainly the result of increasing winter (April–September) precipitation from the late 1930s until the early 1960s (as evidenced by uniform spacing between the 11-point running mean lines on the graph below). In contrast, from the early 1960s to ca. 1980 the 11-point running mean lines indicate an increase in summer (October–March) precipitation and no obvious trend in winter precipitation. The peak in the 12-month precipitation amount ca. 1980 represents a return to levels not seen at Albany since the first decade of the record.

Winter (Apr.-Sept., thin solid line) and 12-month (Apr.-Mar., dashed line) precipitation amount at Albany. The summer (Oct.-Mar.) precipitation amount is represented by the spacing between the thin solid and dashed lines. The spacing between the two thick solid lines (the winter and 12-month, 11-point running means) indicates long-term changes in summer precipitation.

CITE AS: Lavery, B., and N. Nicholls. 1994. Australian precipitation records from ten regionally-representative stations. pp. 918-950. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Precipitation

Australian Precipitation records from ten regionally-representative stations

B. Lavery and N. Nicholls (continued)

ALBANY

(South Coast of Western Australia)

Precipitation Amount, 1910–90

Precipitation (mm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Apr– Sep	Apr– Mar ^a	Jan– Dec
1910	13.7	11.4	25.4	48.1	58.2	73.1	113.5	29.9	41.8	224.8	86.1	6.4	364.6	722.6	732.4
1911	0.0	0.0	40.7	22.9	78.3	45.7	108.4	112.7	46.4	49.4	14.2	44.7	414.4	563.7	563.4
1912	4.8	27.8	8.4	23.1	19.3	44.4	135.8	54.3	35.2	23.4	49.2	21.1	312.1	458.5	446.8
1913	17.9	0.8	34.0	326.0	54.1	57.0	47.7	58.7	110.7	62.7	13.5	60.3	654.2	875.3	843.4
1914	0.0	48.0	36.6	36.3	69.3	23.8	61.3	27.7	21.1	91.0	68.1	45.4	239.5	580.6	528.6
1915	46.0	67.0	23.6	31.5	61.6	86.9	112.4	78.1	50.0	27.1	13.9	0.4	420.5	503.7	472.6
1916	11.7	4.8	25.3	20.1	57.7	154.7	108.1	57.8	47.8	71.3	67.6	3.3	446.2	823.1	630.2
1917	23.7	25.0	186.0	82.3	160.4	197.1	37.3	112.2	70.4	55.3	2.6	5.6	659.7	930.0	957.9
1918	69.1	97.0	40.7	45.8	65.5	31.5	19.3	67.8	32.2	40.3	54.6	12.6	262.1	411.5	576.4
1919	1.0	33.3	7.6	126.0	30.9	28.5	58.9	47.0	37.6	62.5	37.7	11.0	328.9	575.8	482.0
1920	0.0	52.9	82.8	9.2	24.2	139.0	62.1	96.2	64.1	21.1	1.8	2.3	394.8	442.9	555.7
1921	10.7	4.6	7.6	41.9	188.3	29.2	21.5	65.7	107.3	56.8	51.1	37.2	453.9	655.8	621.9
1922	10.1	20.1	26.6	151.2	45.7	68.5	96.8	53.0	52.6	20.6	9.6	21.6	467.8	572.5	576.4
1923	3.8	16.8	32.3	17.0	54.0	162.8	38.3	55.5	55.3	29.2	4.6	3.0	382.9	434.1	472.6
1924	1.0	10.1	3.3	6.3	59.5	43.9	16.3	68.3	99.8	147.5	20.1	10.6	294.1	555.0	486.7
1925	21.0	26.7	35.0	73.6	72.7	55.8	63.8	19.8	46.2	86.0	3.3	37.6	331.9	632.7	541.5
1926	10.0	31.7	132.2	85.7	30.7	32.0	110.6	57.4	47.5	21.7	18.4	26.4	363.9	566.2	604.3
1927	92.7	3.0	40.1	9.7	59.6	79.1	52.1	42.9	74.1	70.5	2.5	13.2	317.5	505.9	539.5
1928	67.1	0.8	34.3	64.2	33.8	21.3	48.7	50.3	60.5	41.1	15.0	8.4	278.8	395.0	445.5
1929	4.9	27.2	19.6	19.5	46.3	139.4	59.3	36.2	127.4	27.5	121.4	18.2	428.1	668.2	646.9
1930	1.8	6.0	65.2	48.7	85.1	26.8	51.8	16.5	31.9	18.2	11.9	16.0	260.8	366.8	379.9
1931	4.9	21.2	33.8	29.0	50.9	74.8	56.6	69.9	72.1	18.2	8.2	15.7	353.3	459.0	455.3
1932	14.7	12.4	36.5	53.1	46.1	107.1	43.3	112.1	41.1	101.0	21.2	8.4	402.8	604.5	597.0
1933	28.8	0.0	42.3	33.5	42.6	64.0	28.8	36.9	22.2	40.7	34.7	7.7	228.0	486.9	382.2
1934	12.5	2.0	161.3	62.3	34.0	67.9	68.6	44.7	31.8	44.2	19.6	9.7	309.3	440.2	558.6
1935	7.9	43.7	5.8	33.2	11.9	64.3	70.8	112.0	39.7	35.3	1.8	12.2	331.9	389.7	438.6
1936	5.6	2.9	0.0	13.0	66.3	60.4	29.0	23.8	19.6	23.3	10.7	18.0	212.1	453.1	272.6
1937	15.7	0.8	172.5	38.9	83.1	94.7	41.9	86.2	77.2	17.3	28.2	5.9	422.0	530.6	662.4
1938	27.0	3.5	26.7	30.4	15.2	69.1	72.8	57.3	16.6	27.5	11.5	21.7	261.4	540.1	379.3
1939	170.1	37.8	10.1	61.7	72.7	64.0	101.0	55.6	10.3	129.2	73.5	8.4	365.3	586.8	794.4
1940	6.8	1.3	2.3	26.1	36.4	31.4	66.1	28.0	37.9	5.1	31.6	77.5	225.9	437.5	350.5
1941	28.2	6.4	62.8	16.5	45.5	51.2	34.2	23.2	40.8	46.2	33.0	6.8	211.4	367.7	394.8
1942	6.6	17.2	46.5	46.9	119.9	68.3	63.8	50.9	32.8	33.8	12.2	99.8	382.6	684.0	598.7
1943	67.3	30.4	57.9	55.7	50.8	50.1	95.6	36.1	27.9	14.0	19.6	16.3	316.2	378.6	521.7
1944	3.3	0.0	9.2	24.3	52.4	40.2	79.5	107.4	65.0	13.2	2.5	16.5	368.8	461.1	413.5
1945	5.5	13.0	41.6	11.2	71.4	142.1	107.0	103.0	64.8	23.9	9.9	60.4	499.5	612.5	653.8
1946	7.9	2.3	8.6	10.9	44.1	105.3	41.1	34.8	37.2	47.2	51.0	24.1	273.4	426.2	414.5
1947	3.3	20.2	7.0	84.4	77.3	90.5	48.8	35.7	44.5	119.4	70.9	10.5	381.2	616.0	612.5
1948	3.8	9.6	20.6	44.7	16.5	56.2	64.8	34.1	53.9	21.5	51.1	15.3	270.2	393.5	392.1
1949	3.6	5.6	26.2	22.1	53.1	25.5	112.7	72.6	43.5	88.0	39.6	3.3	329.5	470.9	495.8

Australian precipitation records from ten regionally-representative stations

B. Lavery and N. Nicholls (continued)

ALBANY

(South Coast of Western Australia)

Precipitation Amount, 1910–90 (continued)

Precipitation (mm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Apr– Sep	Apr– Mar ^a	Jan– Dec
1950	9.4	0.3	0.8	3.0	243.0	71.4	45.8	35.4	75.7	39.3	31.8	64.8	474.3	751.1	620.7
1951	85.4	49.4	6.1	73.6	71.0	91.9	47.5	74.8	163.1	38.0	9.4	27.0	521.9	660.5	737.2
1952	28.0	0.0	36.2	28.5	47.4	76.2	70.0	23.5	49.7	54.7	39.4	24.5	295.3	493.9	478.1
1953	11.7	58.9	9.4	25.4	58.8	85.3	42.4	60.5	53.8	57.5	30.7	8.6	326.2	479.6	503.0
1954	47.4	5.9	3.3	25.1	20.9	41.0	39.7	64.5	24.5	82.8	30.0	19.0	215.7	601.6	404.1
1955	7.4	242.9	3.8	160.9	74.3	114.1	55.0	80.0	59.7	69.8	8.8	25.0	544.0	667.9	901.7
1956	0.8	8.0	11.5	45.4	66.3	118.7	60.4	41.3	21.2	50.8	25.5	6.4	353.3	479.5	456.3
1957	3.5	8.7	31.3	36.3	19.9	74.5	58.6	70.9	21.4	39.4	2.0	26.6	281.6	415.1	393.1
1958	9.8	42.4	13.3	19.8	24.2	19.3	106.8	82.0	105.1	52.9	18.8	54.8	357.2	507.7	549.2
1959	5.6	11.1	7.3	12.2	35.2	97.7	40.9	71.8	197.5	50.9	93.9	36.4	455.3	771.1	660.5
1960	35.6	57.2	41.8	77.6	99.6	48.9	127.1	53.0	92.1	12.8	24.5	10.4	498.3	585.3	680.6
1961	20.7	5.6	13.0	132.8	70.4	87.4	119.7	45.0	58.4	24.0	9.8	20.6	513.7	613.8	607.4
1962	3.5	25.4	16.8	9.0	42.4	54.5	66.5	68.6	26.9	69.6	13.6	29.2	267.9	436.8	426.0
1963	5.4	15.7	35.4	64.3	130.0	56.7	77.1	43.3	115.1	52.6	62.4	5.8	486.5	678.7	663.8
1964	43.9	23.6	3.9	94.3	27.4	94.7	76.4	76.7	31.2	93.8	14.1	45.8	400.7	586.8	625.8
1965	8.5	5.1	18.8	22.1	58.9	48.3	36.2	99.8	39.2	97.1	70.9	49.5	304.5	558.7	554.4
1966	18.0	14.1	4.6	82.3	45.9	169.7	45.1	41.3	110.3	85.1	16.0	26.1	494.6	737.2	658.5
1967	3.6	23.2	88.6	30.7	93.3	60.6	129.0	100.3	60.3	42.5	10.9	16.1	474.2	697.9	659.1
1968	73.4	22.4	58.4	47.1	60.6	79.3	56.4	88.3	107.1	47.3	13.5	24.0	438.8	543.0	677.8
1969	3.4	2.5	13.5	30.4	36.8	41.3	90.4	67.3	53.6	20.6	29.8	14.5	319.8	426.7	404.1
1970	3.8	26.3	11.9	77.8	29.9	55.2	47.4	58.3	78.3	29.1	42.6	25.2	346.9	582.8	485.8
1971	59.5	13.5	66.0	53.2	104.1	12.2	39.7	85.5	52.1	75.1	198.0	41.6	346.8	710.6	800.5
1972	14.5	6.1	28.5	38.9	46.4	90.5	92.8	70.1	31.3	67.9	2.8	8.1	370.0	486.3	497.9
1973	16.8	12.5	8.2	48.8	23.7	54.3	40.8	108.3	70.9	78.4	33.9	28.6	346.8	528.5	525.2
1974	8.8	19.6	12.4	113.8	70.4	54.2	64.0	33.5	48.8	45.2	69.8	2.4	384.7	521.7	542.9
1975	7.2	3.2	9.2	123.5	80.2	11.4	83.0	121.0	57.9	72.7	35.4	3.8	477.0	728.1	608.5
1976	84.6	37.0	17.6	54.0	67.8	76.8	87.4	91.0	68.4	120.1	71.9	1.2	445.4	682.6	777.8
1977	6.0	23.4	14.6	14.0	111.8	26.8	31.6	64.8	82.4	127.8	15.0	47.4	331.4	594.0	565.6
1978	18.6	53.8	0.0	47.8	65.8	195.2	201.8	71.0	97.2	46.8	27.6	27.8	678.8	846.1	853.4
1979	6.0	39.3	19.8	25.8	103.0	68.0	87.3	191.1	80.0	25.4	50.6	4.2	555.2	744.8	700.5
1980	18.8	88.8	1.8	53.6	36.3	60.8	58.8	51.4	23.0	96.8	23.2	38.7	283.9	472.8	552.0
1981	7.8	21.4	1.0	34.5	89.9	105.9	83.4	48.2	25.4	32.8	41.6	9.8	387.3	777.4	501.7
1982	240.9	25.4	39.6	14.0	47.0	37.8	54.6	64.8	28.4	17.6	17.2	31.4	246.6	366.2	618.7
1983	11.2	32.0	10.2	39.8	43.8	141.6	71.0	26.6	63.0	75.8	55.2	77.0	385.8	649.2	647.2
1984	0.0	19.8	35.6	25.6	43.0	61.3	133.0	81.8	80.6	31.2	33.4	7.2	425.3	708.7	552.5
1985	67.6	8.6	135.4	39.4	26.0	50.2	92.6	85.8	84.8	59.0	52.2	12.8	378.8	587.0	714.4
1986	0.0	65.6	18.6	6.4	76.2	72.0	98.8	70.8	65.8	43.8	23.0	5.4	390.0	500.8	546.4
1987	5.6	0.0	33.0	34.0	72.0	34.0	46.6	50.8	57.0	41.4	77.6	20.8	294.4	476.1	472.8
1988	13.8	1.1	27.0	20.4	184.4	112.6	103.2	38.4	41.2	15.8	14.6	7.2	500.2	607.4	579.7
1989	36.8	20.8	12.0	75.4	47.8	140.4	89.4	51.4	33.2	60.4	18.0	7.0	437.6	657.8	592.6
1990	94.4	22.0	18.4	28.4	87.0	82.8	90.0	26.6	39.2	90.0	35.8	14.4	354.0		629.0

^aThe total in this column is calculated for April of the listed year through March of the following year.

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Precipitation

Australian precipitation records from ten regionally-representative stations

B. Lavery and N. Nicholls (continued)

CANARY ISLAND (Victoria)

Trends

According to Nicholls and Lavery (1992), the data from Canary Island show an abrupt increase in precipitation amount after ca. 1950. The increase resulted mainly from an increase in summer (October–March) precipitation, as illustrated in the graph below by the generally larger spread between the two lines representing the 11-point running means between ca. 1950 and 1980. This period is marked by numerous years in which summer precipitation exceeded that of winter (April–September), a theretofore rare occurrence for Canary Island. The record after 1980 hints at a return to conditions more reminiscent of the earliest decades of the record: winter precipitation has averaged slightly higher than that of summer.

Winter (Apr.-Sept., thin solid line) and 12-month (Apr.-Mar., dashed line) precipitation amount at Canary Island. The summer (Oct.-Mar.) precipitation amount is represented by the spacing between the thin solid and dashed lines. The spacing between the two thick solid lines (the winter and 12-month, 11-point running means) indicates long-term changes in summer precipitation.

CITE AS: Lavery, B., and N. Nicholls. 1994. Australian precipitation records from ten regionally-representative stations. pp. 918–950. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Australian precipitation records from ten regionally-representative stations

B. Lavery and N. Nicholls (continued)

CANARY ISLAND
(Victoria)

Precipitation Amount, 1910–90

Precipitation (mm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Apr– Sep	Apr– Mar ^a	Jan– Dec
1910	30.7	5.8	60.7	0.0	40.8	29.9	50.8	50.8	59.2	16.5	35.3	13.2	231.5	492.7	393.7
1911	2.3	158.8	35.1	2.6	51.5	46.3	17.8	10.0	38.6	4.6	0.8	15.7	166.8	245.3	384.1
1912	2.0	52.1	3.3	3.3	0.8	52.9	27.5	39.3	51.3	2.6	50.5	52.6	175.1	372.2	338.2
1913	3.6	4.1	83.7	12.0	54.6	30.3	10.1	15.7	38.0	80.4	6.8	14.0	160.7	272.1	353.3
1914	0.8	0.0	9.4	41.4	20.8	4.6	11.2	5.8	0.0	0.0	25.1	18.2	83.8	146.2	137.3
1915	15.0	2.3	1.8	19.4	35.8	46.5	31.5	46.4	67.4	22.8	4.3	7.9	247.0	365.4	301.1
1916	75.5	7.9	0.0	8.6	24.1	64.8	45.5	51.3	98.6	47.2	47.9	11.9	292.9	494.6	483.3
1917	11.2	70.3	13.2	3.6	29.3	59.4	53.0	87.7	64.7	62.0	47.4	4.6	297.7	546.7	506.4
1918	16.4	35.3	83.3	29.0	79.5	28.2	12.2	53.8	6.4	19.1	0.0	6.9	209.1	352.1	370.1
1919	2.8	76.7	37.5	12.5	56.2	25.0	20.4	25.3	33.3	10.4	20.1	45.5	172.7	253.0	365.7
1920	0.5	0.0	3.8	7.9	27.0	35.0	31.3	102.5	62.1	63.3	38.6	9.9	265.8	513.3	381.9
1921	26.9	37.1	71.7	4.1	54.3	61.8	33.1	43.0	57.8	33.0	20.8	23.6	254.1	354.9	467.2
1922	5.3	18.1	0.0	8.2	50.0	35.9	20.5	21.9	56.4	32.8	0.0	20.0	192.9	251.6	269.1
1923	5.9	0.0	0.0	0.0	44.3	119.2	74.6	12.6	28.2	19.8	14.5	17.1	278.9	484.7	336.2
1924	29.2	84.4	40.8	17.8	13.2	42.1	2.6	43.2	47.3	56.6	87.0	51.3	166.2	416.5	515.5
1925	20.6	24.4	10.4	4.8	60.0	41.7	21.9	18.4	27.2	2.3	12.7	0.3	174.0	232.0	244.7
1926	2.1	0.0	40.6	39.9	49.0	15.6	24.8	31.3	32.0	32.2	0.6	11.2	192.6	253.1	279.3
1927	8.6	3.6	4.3	1.3	25.3	15.3	46.2	33.8	9.7	16.9	11.2	9.0	131.6	478.5	185.2
1928	174.3	78.7	56.8	7.9	25.7	50.6	23.6	4.5	31.6	50.6	1.8	2.5	143.9	243.6	508.6
1929	7.4	31.5	5.9	38.9	6.3	30.3	5.6	31.2	16.8	26.2	16.3	40.2	129.1	226.0	256.6
1930	0.0	3.0	11.2	5.7	47.8	6.9	26.8	36.0	25.3	84.8	14.6	151.4	148.5	456.3	413.5
1931	12.0	0.5	44.5	55.4	73.8	75.0	27.9	11.0	21.6	20.1	13.7	0.0	264.7	407.3	355.5
1932	0.0	54.6	54.2	95.8	24.4	52.2	32.8	49.7	18.8	28.1	20.7	15.7	273.7	366.2	447.0
1933	13.0	0.0	15.0	3.5	42.3	44.8	47.9	47.9	45.7	23.1	37.3	77.0	232.1	469.6	397.5
1934	16.5	73.7	9.9	39.4	0.0	10.3	27.3	29.4	13.1	75.2	58.2	8.9	119.5	317.8	361.9
1935	24.7	17.1	14.2	31.0	19.5	20.5	54.0	20.2	55.5	68.0	2.6	16.3	200.7	338.7	343.6
1936	41.2	5.8	4.1	12.7	32.7	36.6	109.5	42.4	7.6	46.1	1.3	68.7	241.5	391.5	408.7
1937	24.0	8.1	1.8	9.9	19.4	15.3	12.7	32.9	18.5	76.1	0.5	16.4	108.7	234.8	235.6
1938	15.5	17.6	0.0	8.2	6.4	30.3	39.0	8.4	2.1	1.5	5.3	0.3	94.4	220.8	134.6
1939	5.6	96.2	17.5	46.3	53.6	35.4	29.5	40.3	11.0	23.7	53.9	3.0	216.1	310.9	416.0
1940	8.1	4.8	1.3	46.0	0.8	6.6	30.5	7.1	47.2	4.0	18.8	7.8	138.2	261.8	183.0
1941	65.3	3.0	24.7	4.3	12.5	26.4	50.7	9.7	45.7	29.7	21.7	3.1	149.3	251.5	296.8
1942	10.7	16.2	20.8	11.2	52.6	59.2	37.2	61.5	22.4	22.2	49.5	6.6	244.1	341.5	370.1
1943	13.2	5.6	0.3	16.1	8.9	15.3	29.4	27.7	16.7	28.2	22.7	11.2	114.1	199.4	195.3
1944	19.1	3.3	0.8	32.2	31.5	4.0	25.1	2.0	4.1	16.0	16.1	19.2	98.9	185.1	173.4
1945	15.4	14.2	5.3	0.0	12.6	56.5	31.5	53.3	14.0	34.8	46.9	10.2	167.9	422.8	294.7
1946	58.9	85.7	18.4	8.1	35.3	25.2	25.3	17.9	4.1	14.0	28.0	22.4	115.9	235.5	343.3
1947	0.0	12.5	42.7	18.6	4.0	23.0	55.7	24.5	32.1	77.1	39.0	53.1	157.9	358.8	382.3
1948	3.3	28.4	0.0	30.0	34.6	33.2	16.3	4.7	16.3	79.0	23.0	17.0	135.1	336.5	285.8
1949	0.6	46.7	35.1	5.8	35.7	14.4	45.4	9.4	22.1	85.6	27.3	2.5	132.8	407.9	330.6

Precipitation

Australian precipitation records from ten regionally-representative stations

B. Lavery and N. Nicholls (continued)

CANARY ISLAND

(Victoria)

Precipitation Amount, 1910–90 (continued)

	Precipitation (mm)														
Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Apr– Sep	Apr– Mar ^a	Jan– Dec
1950	0.0	60.1	99.6	58.0	58.5	23.6	39.1	20.2	40.9	48.8	26.3	17.5	240.3	431.8	492.6
1951	34.1	64.8	0.0	12.6	60.8	80.5	41.2	49.2	4.2	17.6	6.1	9.2	248.5	325.9	380.3
1952	17.8	5.8	20.9	53.7	77.5	60.7	15.8	17.9	23.0	54.2	73.1	17.7	248.6	445.3	438.1
1953	40.8	10.9	0.0	26.9	9.8	53.4	29.4	56.8	41.2	44.4	35.3	10.9	217.5	357.4	359.8
1954	35.1	9.9	4.3	49.2	19.8	15.7	28.3	42.0	24.9	47.2	51.3	53.3	179.9	456.6	381.0
1955	1.8	89.3	33.8	4.3	56.4	67.9	44.5	74.5	76.1	62.0	29.4	8.9	323.7	522.1	548.9
1956	23.9	5.6	68.6	52.1	128.5	45.9	81.9	28.4	41.5	119.3	36.4	2.5	378.3	637.6	634.6
1957	2.5	77.3	21.3	15.0	7.4	63.6	21.6	25.5	11.9	20.8	13.4	8.4	145.0	265.6	288.7
1958	51.9	23.6	2.5	7.6	54.5	5.3	63.4	93.4	22.6	88.0	66.6	2.0	246.8	472.8	481.4
1959	21.4	8.9	39.1	4.3	7.6	25.7	8.9	22.9	27.0	77.5	14.7	24.6	96.4	336.3	282.6
1960	89.2	20.4	13.5	32.6	92.0	26.4	63.0	57.1	79.9	2.5	64.7	27.0	351.0	565.7	568.3
1961	0.0	12.0	108.5	53.7	11.7	23.6	33.6	29.5	38.6	17.8	32.3	19.6	190.7	336.9	380.9
1962	57.7	2.8	16.0	0.0	51.7	30.7	44.4	40.9	59.1	40.9	12.3	26.9	226.8	428.8	383.4
1963	81.5	3.8	36.6	15.5	82.0	47.7	39.6	45.9	34.7	26.6	3.0	14.0	265.4	325.2	430.9
1964	5.8	10.4	0.0	105.9	32.0	29.4	77.3	23.7	65.0	82.3	27.4	5.6	333.3	450.6	464.8
1965	0.0	0.0	2.0	9.5	37.3	17.3	52.0	45.7	25.9	17.5	97.0	30.5	187.7	411.0	334.7
1966	27.1	25.1	26.1	6.6	18.1	8.9	31.2	35.8	78.3	53.1	15.5	73.8	178.9	329.4	399.6
1967	4.3	2.3	1.5	6.6	28.2	29.1	12.7	43.4	14.5	5.1	0.8	7.4	134.5	202.4	155.9
1968	16.5	0.0	38.1	47.1	74.9	55.3	39.0	75.8	15.4	33.7	12.6	21.9	307.5	573.2	430.3
1969	26.0	57.6	113.9	14.9	42.4	7.2	42.9	43.2	22.4	23.7	20.5	28.4	173.0	358.4	443.1
1970	56.2	16.8	39.8	55.8	23.1	27.9	9.6	48.9	58.8	3.8	45.8	19.0	224.1	497.6	405.5
1971	79.3	58.2	67.4	55.6	26.7	19.6	18.2	28.3	28.5	18.6	99.5	35.1	176.9	443.7	535.0
1972	54.9	55.7	3.0	19.0	10.7	7.6	14.6	40.9	15.2	9.7	34.7	2.0	108.0	399.1	268.0
1973	46.7	156.4	41.6	41.5	48.3	58.2	58.7	95.5	56.1	147.5	39.7	21.5	358.3	757.1	811.7
1974	111.4	27.3	51.4	59.4	93.5	9.4	39.8	49.6	65.4	78.2	12.2	0.0	317.1	449.1	597.6
1975	5.0	2.8	33.8	0.8	42.0	2.0	34.3	41.8	88.4	128.6	4.2	57.0	209.3	439.1	440.7
1976	26.6	9.2	4.2	0.4	5.3	9.8	19.0	28.8	30.2	62.7	57.2	15.4	93.5	268.8	268.8
1977	0.0	29.8	10.2	29.6	35.8	23.4	15.8	10.4	32.6	12.6	25.6	5.4	147.6	263.0	231.2
1978	29.6	4.6	37.6	21.2	47.4	38.6	78.2	37.0	77.2	15.8	60.8	23.0	299.6	473.5	471.0
1979	49.4	12.5	12.4	27.2	41.0	15.8	4.0	70.0	86.6	32.6	16.6	1.0	244.6	312.6	369.1
1980	1.4	0.0	16.4	48.0	29.6	34.8	32.2	39.0	18.0	69.4	7.0	32.2	201.6	392.8	328.0
1981	24.0	22.8	35.8	0.0	50.4	55.8	82.4	61.2	22.4	18.8	18.0	8.5	272.2	346.2	400.1
1982	2.9	0.0	25.8	14.0	18.2	18.0	1.4	5.4	7.2	4.2	6.8	18.8	64.2	198.5	122.7
1983	1.0	1.0	102.5	25.6	41.9	31.2	73.3	51.4	72.7	19.4	37.0	70.4	296.1	541.3	527.4
1984	91.0	7.4	20.0	8.0	7.0	1.8	44.4	80.1	27.8	16.9	30.8	1.2	169.1	243.4	336.4
1985	18.8	3.6	3.0	10.6	53.7	15.0	8.4	117.6	21.8	26.0	33.3	83.3	227.1	381.2	395.1
1986	0.7	10.8	0.0	35.2	51.2	13.1	67.2	35.5	59.5	66.3	13.2	26.7	261.7	415.7	379.4
1987	10.8	27.1	9.9	15.7	35.8	45.3	36.5	53.1	15.1	21.8	12.5	82.5	201.5	340.1	366.1
1988	3.2	9.2	9.4	10.2	97.0	52.4	55.1	6.6	69.9	11.2	53.8	67.2	291.2	522.5	445.2
1989	3.6	0.0	95.5	109.4	58.8	57.4	28.9	42.4	16.8	33.6	10.0	32.1	313.7	432.2	488.5
1990	0.0	32.8	10.0	28.8	24.1	42.7	65.8	40.0	15.4	22.5	10.1	16.2	216.8		308.4

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Australian precipitation records from ten regionally-representative stations

B. Lavery and N. Nicholls (continued)

PEAK HILL POST OFFICE

(Inland New South Wales)

Trends

According to Nicholls and Lavery (1992), the data from Peak Hill Post Office show an abrupt increase in 12-month (April–March) precipitation ca. 1950. This increase resulted primarily from increased summer (October–March) precipitation, as indicated on the graph below by the greater spread between the lines representing the 11-point running means over the period 1950–90. The increase in summer precipitation resulted in a pronounced summer precipitation maximum, whereas before ca. 1950 the data exhibited a weaker annual cycle.

Winter (Apr.–Sept., thin solid line) and 12-month (Apr.–Mar., dashed line) precipitation amount at Peak Hill Post Office. The summer (Oct.–Mar.) precipitation amount is represented by the spacing between the thin solid and dashed lines. The spacing between the two thick solid lines (the winter and 12-month, 11-point running means) indicates long-term changes in summer precipitation.

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Precipitation

Australian precipitation records from ten regionally-representative stations

B. Lavery and N. Nicholls (continued)

PEAK HILL POST OFFICE (Inland New South Wales)

Precipitation Amount, 1910–90

Precipitation (mm)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	April– Sept	April– Mar ^a	Jan– Dec
1910	218.8	0.0	71.9	0.0	33.5	55.9	32.7	6.6	35.4	20.5	30.8	85.1	164.1	577.1	591.2
1911	189.4	57.2	30.0	0.0	45.5	30.5	45.4	13.2	49.6	10.9	90.5	114.6	184.2	435.8	676.8
1912	17.0	13.0	5.6	1.0	0.0	45.0	142.2	94.2	21.3	23.4	4.6	18.5	303.7	513.2	385.8
1913	31.2	43.7	88.1	40.6	59.4	64.8	7.7	15.8	11.6	34.0	1.0	17.3	199.9	472.0	415.2
1914	52.8	68.1	98.9	13.8	77.5	29.2	46.5	0.0	27.4	21.5	36.2	86.9	194.4	374.6	558.8
1915	14.8	5.3	15.5	40.6	80.8	62.2	57.6	35.3	23.6	57.4	1.0	22.6	300.1	451.6	416.7
1916	52.0	9.4	9.1	188.0	12.0	186.5	120.5	76.9	64.8	91.0	67.9	103.9	648.7	1061.6	982.0
1917	93.2	27.2	29.7	2.0	11.9	59.7	67.9	85.6	36.6	71.7	116.3	28.0	263.7	598.3	629.8
1918	85.8	17.0	15.8	17.1	31.0	34.2	39.8	96.2	6.6	22.0	3.0	5.6	224.9	323.6	374.1
1919	6.6	61.5	0.0	9.1	88.3	11.5	3.6	27.2	22.9	2.1	3.1	92.1	162.6	366.0	328.0
1920	20.2	29.2	56.7	4.1	1.3	123.7	70.3	50.6	47.6	32.9	25.6	125.8	297.6	591.5	588.0
1921	45.0	17.1	47.5	64.5	50.2	35.0	50.4	37.5	24.9	20.7	75.4	69.4	262.5	467.3	537.6
1922	35.4	3.9	0.0	29.0	23.9	32.9	39.4	14.8	15.6	15.3	0.0	45.4	155.6	252.2	255.6
1923	11.9	0.8	23.2	4.3	11.2	130.7	54.8	12.5	16.0	35.5	28.4	31.5	229.5	387.3	360.8
1924	13.8	43.8	4.8	50.9	20.9	69.1	52.3	36.8	92.5	27.0	124.3	45.0	322.5	720.0	581.2
1925	116.6	56.7	27.9	3.0	52.7	161.9	36.0	25.9	9.5	25.2	111.7	8.6	289.0	614.2	635.7
1926	33.9	15.3	130.5	109.2	69.7	27.1	28.7	29.2	33.0	9.0	0.0	65.4	296.9	545.6	551.0
1927	85.9	6.8	81.6	40.4	9.7	24.2	1.1	26.2	55.9	44.5	68.6	74.2	157.5	651.2	519.1
1928	75.9	191.9	38.6	83.1	15.2	46.6	52.3	8.9	6.6	21.9	28.0	0.0	212.7	349.6	569.0
1929	13.2	61.9	11.9	26.4	15.6	13.2	7.4	43.8	28.5	38.4	28.4	54.3	134.9	331.4	343.0
1930	30.5	19.8	25.1	19.8	27.7	65.4	53.5	50.9	2.9	68.5	30.1	128.7	220.2	648.8	522.9
1931	40.3	12.2	148.8	91.8	144.4	103.1	61.1	8.6	24.5	20.4	31.9	68.3	433.5	650.3	755.4
1932	4.6	30.8	60.8	55.5	25.2	27.4	31.2	48.1	59.6	32.1	52.9	19.9	247.0	474.2	448.1
1933	66.0	1.5	54.8	114.3	40.4	36.4	44.5	15.8	63.1	40.8	72.3	45.0	314.5	616.8	594.9
1934	50.8	89.8	3.6	78.5	0.0	37.3	68.2	66.1	20.1	117.4	106.3	18.6	270.2	573.5	656.7
1935	33.2	27.5	0.3	58.3	22.9	16.6	35.8	23.1	24.1	76.0	18.6	25.2	180.8	521.3	361.6
1936	56.2	75.9	88.6	11.3	13.8	41.7	81.3	55.4	11.7	18.1	0.0	92.4	215.2	424.3	546.4
1937	40.6	20.5	37.5	24.4	28.5	40.5	1.3	82.1	16.3	50.0	17.8	7.1	193.1	335.2	366.6
1938	53.7	10.7	2.8	36.8	37.0	65.6	54.3	44.7	12.0	114.1	39.6	45.7	250.4	616.4	517.0
1939	15.2	83.1	68.3	51.6	8.2	32.6	18.3	82.6	10.2	46.8	72.8	22.3	203.5	380.5	512.0
1940	21.9	1.0	12.2	99.2	14.2	3.6	10.4	13.5	84.6	5.3	15.3	81.8	225.5	530.6	363.0
1941	167.9	8.4	26.4	0.5	25.7	52.7	22.6	14.7	26.2	24.8	40.1	10.4	142.4	333.0	420.4
1942	0.5	82.6	32.2	0.0	116.5	70.7	61.0	27.2	45.5	30.1	64.6	57.8	320.9	561.6	588.7
1943	56.0	28.6	3.6	58.9	59.7	19.7	37.5	49.8	32.2	44.7	113.0	16.7	257.8	481.2	520.4
1944	7.1	6.1	35.8	15.3	59.0	1.9	19.3	50.3	12.4	15.0	8.4	2.0	158.2	356.6	232.6
1945	105.4	61.0	6.6	47.9	86.5	87.1	31.4	59.5	2.7	18.9	17.3	11.2	315.1	545.7	535.5
1946	36.4	72.6	74.2	16.2	15.8	20.2	19.7	9.1	13.2	21.9	46.5	31.7	94.2	335.4	377.5
1947	5.3	100.7	35.1	11.7	45.7	16.5	77.7	36.6	65.6	73.5	114.8	124.9	253.8	718.7	708.1
1948	32.0	99.9	19.8	47.1	47.2	76.1	17.5	32.1	24.7	13.1	26.8	33.2	244.7	504.6	469.5
1949	18.8	83.9	84.1	27.7	42.2	43.7	39.7	26.8	66.0	68.1	73.4	22.4	246.1	834.7	596.8

Australian precipitation records from ten regionally-representative stations

B. Lavery and N. Nicholls (continued)

PEAK HILL POST OFFICE

(Inland New South Wales)

Precipitation Amount, 1910–90 (continued)

Precipitation (mm)															
Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	April– Sept	April– Mar ^a	Jan– Dec
1950	108.0	136.3	180.4	57.5	32.1	117.8	90.2	52.4	64.3	202.1	174.4	1.6	414.3	910.2	1217.1
1951	48.5	32.2	37.1	20.3	70.0	62.2	42.9	65.0	32.2	12.6	16.5	19.8	292.6	486.6	459.3
1952	0.8	23.4	120.9	77.6	65.5	47.0	84.9	83.3	25.0	71.3	40.2	37.0	383.3	623.0	676.9
1953	59.2	12.2	19.8	11.4	60.7	11.5	2.6	62.5	19.5	36.4	52.9	42.7	168.2	494.6	391.4
1954	105.7	88.7	0.0	48.3	3.8	36.9	7.8	21.3	22.3	134.7	100.5	55.3	140.4	761.5	625.3
1955	75.5	252.1	3.0	6.9	57.5	51.1	31.3	40.0	49.1	94.2	42.4	37.4	235.9	1061.1	740.5
1956	190.3	181.5	279.4	63.4	73.4	74.9	71.8	37.6	43.5	99.2	10.1	5.3	364.6	567.4	1130.4
1957	15.8	55.4	17.0	25.7	2.0	13.3	90.8	20.3	0.0	10.4	15.8	45.2	152.1	397.2	311.7
1958	119.3	17.6	36.8	26.4	71.2	21.6	25.4	64.8	63.8	58.8	21.1	38.1	273.2	761.7	564.9
1959	110.5	135.3	124.7	95.3	13.4	28.0	53.7	3.5	9.9	36.9	17.2	73.8	203.8	456.6	702.2
1960	54.4	48.4	22.1	45.8	42.2	12.2	65.1	89.9	74.7	21.2	68.1	17.5	329.9	531.9	561.6
1961	34.6	18.9	41.7	54.5	4.4	35.9	65.7	94.4	2.9	35.8	221.1	21.3	257.8	697.3	631.2
1962	80.9	46.6	33.8	10.7	87.3	19.1	36.4	77.6	10.2	43.3	16.5	152.8	241.3	708.6	615.2
1963	82.1	104.5	68.1	22.9	62.5	64.7	39.8	64.8	37.7	30.2	59.3	56.7	292.4	531.4	693.3
1964	54.9	7.9	30.0	34.6	48.3	49.4	43.0	36.4	58.8	69.2	39.6	10.9	270.5	403.4	483.0
1965	0.0	2.1	11.1	10.9	30.5	12.5	26.7	26.6	43.3	75.5	21.1	128.9	150.5	470.0	389.2
1966	31.2	8.7	54.1	21.9	42.4	15.2	23.3	79.1	49.0	74.6	85.3	46.7	230.9	548.4	531.5
1967	27.1	2.6	81.2	0.0	29.1	27.8	8.1	41.3	13.1	42.3	22.1	12.2	119.4	413.3	306.9
1968	173.4	0.8	43.1	51.8	96.3	8.8	40.4	43.3	28.9	21.5	30.5	122.8	269.5	676.7	661.6
1969	21.6	72.1	138.7	111.6	85.3	10.2	50.6	28.8	40.6	185.6	52.1	5.2	327.1	742.8	802.4
1970	83.3	52.6	36.9	48.8	44.0	15.3	2.6	42.4	87.9	78.0	70.9	137.0	241.0	863.7	699.7
1971	181.3	115.3	40.2	17.2	18.2	12.8	49.3	61.8	51.2	2.8	121.8	103.6	210.5	672.5	775.5
1972	173.8	32.8	27.2	7.4	35.3	3.1	13.0	33.3	12.2	52.1	56.4	29.4	104.3	646.4	476.0
1973	35.6	328.7	39.9	47.3	53.4	88.9	63.0	66.4	29.0	128.2	86.8	99.7	348.0	844.9	1066.9
1974	71.6	102.2	8.4	138.2	39.2	27.0	45.8	25.9	69.8	63.4	25.0	1.0	345.9	537.5	617.5
1975	11.2	46.4	44.6	3.8	13.4	32.8	22.6	55.2	93.6	78.0	8.8	49.8	221.4	732.6	460.2
1976	174.2	140.0	60.4	31.0	19.0	9.8	52.0	10.6	48.8	200.6	39.4	31.0	171.2	610.6	816.8
1977	42.0	35.4	91.0	24.6	175.0	32.0	13.2	20.4	27.9	25.8	0.6	10.2	293.1	527.4	498.1
1978	138.3	12.8	46.6	1.6	88.4	91.3	70.0	14.6	110.0	19.2	156.0	75.0	375.9	702.3	823.8
1979	6.0	5.0	65.2	92.6	77.2	14.6	34.6	44.5	55.4	31.6	28.2	0.0	318.9	506.5	454.9
1980	60.6	29.8	37.4	18.0	105.4	42.6	39.2	12.4	9.8	29.8	5.2	56.4	227.4	400.2	446.6
1981	33.4	48.0	0.0	18.6	54.4	62.4	95.2	16.8	7.8	73.8	66.4	20.0	255.2	573.4	496.8
1982	33.8	39.8	84.4	19.4	7.0	12.8	4.6	0.2	10.4	19.4	16.6	22.0	54.4	185.6	270.4
1983	30.6	19.4	23.2	41.4	114.4	16.4	73.8	56.4	36.8	65.0	122.8	48.0	339.2	951.4	648.2
1984	237.6	107.2	31.6	51.9	2.4	0.0	125.6	61.2	43.2	76.2	27.6	7.2	284.3	507.5	771.7
1985	3.4	31.2	77.6	46.6	38.6	35.0	10.4	81.6	34.0	61.4	119.6	72.6	246.2	546.8	612.0
1986	40.2	0.0	6.8	31.4	25.4	14.0	61.2	98.0	20.0	58.4	58.4	31.8	250.0	686.0	445.6
1987	30.8	33.6	223.0	7.8	69.8	52.6	23.9	78.4	15.6	49.2	65.0	54.4	248.1	520.9	704.1
1988	26.6	25.4	52.2	109.2	47.0	52.2	73.4	36.4	57.2	17.4	56.4	209.8	375.4	769.4	763.2
1989	38.6	12.8	59.0	126.4	107.0	48.0	62.2	35.8	6.6	36.0	27.6	9.8	386.0	618.8	569.8
1990	68.8	47.6	43.0	323.8	57.4	18.0	70.0	71.0	34.6	31.2	17.8	31.4	574.8		814.6

^aThe total in this column is calculated for April of the listed year through March of the following year.

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Precipitation

Century-scale series of standardized annual departures of African rainfall

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West Africa (Sahelo-Sahara, Sahel, Soudan, Soudano-Guinean, and Guinea Coast regions) • Eastern and Southern Africa (Eastern Africa, Southern Africa–North, and Southern Africa–South regions)

Period of Record

1901–90 for all regions except Sahelo-Sahara (1921–90) and Southern Africa–South (1901–89)

Methods

The unusually dry conditions experienced in the Sahelian region of West Africa over recent decades have gained wide attention in both the scientific literature and the news media. Several studies have shown that strong teleconnections often exist between rainfall conditions in the Sahel and those elsewhere in Africa, and it is with these findings in mind that Nicholson (1993) summarized historical fluctuations of African rainfall for eight regions of the continent: five in West Africa (Sahelo-Sahara, Sahel, Soudan, Soudano-Guinean, and Guinea Coast regions) and three in Eastern and Southern Africa (Eastern Africa, Southern Africa–North, and Southern Africa–South regions). Time series of annual departures from the long-term mean rainfall (i.e., the mean over the entire length of record) were constructed for the period 1901–90 for all regions but the Sahelo-Sahara (1921–90) and Southern Africa–South (1901–89) regions. The following summary of the methods used in constructing the series draws from Nicholson (1985, 1993). For additional details the reader is referred to these sources. (Other pertinent studies include Nicholson 1980, 1983, 1986, 1989; Nicholson and Palao 1993; and Nicholson et al. 1988.)

The rainfall data used in this study were obtained from the *Monthly Climatic Data for the World*, the Office of Overseas Scientific and Technical Research (France), publications of various African meteorological services, and, especially for recent records, direct communication with individual African meteorological services. To enable the derivation of annual rainfall departures that are representative of large regions, it is often necessary to combine data from stations that may have greatly differing means and variances. To minimize the effects of factors such as the inclusion of very dry stations (where departures are large compared with the mean rainfall) and a station network that changes over time, the following standardization procedure was used. For each station i and year j , the annual rainfall departure is expressed as

$$x_{ij} = \frac{(r_{ij} - \bar{r}_i)}{\sigma_i},$$

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Century-scale series of standardized annual departures of African rainfall

S.E. Nicholson (continued)

where r_{ij} represents the annual total for the station, $\bar{r}_i$ is the mean annual rainfall (over the whole period of record) at station i , and σ_i is the standard deviation of the annual totals for the station. The areally integrated annual rainfall departure for each region is then represented as

$$R_j = I_j^{-1} \sum_i x_{ij},$$

where I is the number of stations available for the year j .

African rainfall stations and geographical regions.

CITE AS: Nicholson, S.E. 1994. Century-scale series of standardized annual departures of African rainfall. pp. 952-962. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

WEST AFRICA

(Sahelo-Sahara, Sahel, Soudan,
Soudano-Guinean, and Guinea Coast regions)

Trends

The following background description of West African rainfall seasonality and the discussion of the time series of annual rainfall departures for the five West African regions are taken directly from Nicholson (1993).

The four northernmost zones have a single high-sun rainy season with a maximum in August nearly everywhere. These zones differ in season length and mean annual rainfall, both of which increase progressively southward. The three northernmost zones, all semiarid, are often collectively referred to as the "Sahel." The southernmost zone, the Guinea Coast, has two rainy seasons, separated by a relatively dry period during the high-sun season.

During the 1970–90 period, rainfall was markedly below normal throughout the semiarid region of West Africa. In the northernmost sector, or Sahelo-Saharan zone, annual rainfall exceeded the mean in only two years of the last decade, 1988 and 1989. In the Sahel and Soudan, rainfall has not exceeded the long-term mean since 1969. In the wetter, and more southern Soudano-Guinean zone, the situation has been similar; only 1978 exceeded the mean. These results are consistent with earlier analyses, which have shown a tendency for similar anomalies to prevail in these four zones (Nicholson 1980, 1985). The humid Guinea Coast, which previously tended to exhibit anomalies opposite in sign to those in the more northern zones, was also abnormally dry throughout both the 1970s and the 1980s.

Century-scale series of standardized annual departures of African rainfall

S.E. Nicholson (continued)

WEST AFRICA

(Sahelo-Sahara, Sahel, Soudan, Soudano-Guinean, and Guinea Coast regions)

Regionally averaged standardized departures of West African rainfall. The standardized departure equals the annual departure from the long-term (entire period of record) mean, divided by the standard departure.

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Precipitation

Century-scale series of standardized annual departures of African rainfall

S.E. Nicholson (continued)

WEST AFRICA

(Sahelo-Sahara, Sahel, Soudan, Soudano-Guinean, and Guinea Coast regions)

Standardized Annual Rainfall Departures^a

Year	Sahelo-Sahara	Sahel	Soudan	Soudano-Guinean	Guinea Coast
1901		0.43	-0.03	0.90	0.47
1902		-0.57	-0.52	0.29	-0.36
1903		-0.70	0.09	0.17	-0.87
1904		-0.17	-0.03	-0.44	-0.84
1905		0.50	0.26	0.91	-0.57
1906		1.20	1.44	0.30	-0.39
1907		-0.29	-0.54	-0.96	0.00
1908		-0.34	-0.07	0.16	-0.19
1909		0.08	0.86	1.00	0.25
1910		-0.58	-0.37	0.07	0.96
1911		-0.32	-0.37	0.38	0.55
1912		0.22	-0.92	-0.15	-1.04
1913		-0.85	-1.51	0.06	-0.18
1914		-0.82	-0.38	-0.93	0.26
1915		-0.39	0.01	-0.06	0.05
1916		0.14	0.25	0.57	0.02
1917		0.19	-0.07	0.55	1.71
1918		0.81	0.74	-0.32	-0.54
1919		-0.28	-0.29	-0.18	-1.14
1920		0.32	0.01	-0.31	-1.19
1921	-0.95	-0.04	-0.48	0.23	0.21
1922	-0.13	0.27	0.24	0.14	-0.32
1923	-0.42	-0.06	0.01	0.02	-0.12
1924	0.24	0.15	0.54	0.84	0.18
1925	0.00	0.00	-0.13	0.72	0.28
1926	-1.00	-0.41	-0.59	-0.29	-0.17
1927	0.92	1.09	1.05	0.20	-0.18
1928	0.04	-0.22	0.53	0.61	0.16
1929	0.30	0.27	0.20	0.56	0.45
1930	1.29	0.47	0.20	0.09	0.00
1931	-0.24	-0.50	-0.09	0.57	0.45
1932	-0.59	0.33	0.44	-0.13	-0.48
1933	0.71	0.71	0.75	0.56	1.10
1934	-0.08	-0.28	0.01	-0.04	0.11
1935	-0.08	0.12	0.65	0.27	0.51
1936	0.71	0.78	1.12	0.16	-0.25
1937	0.24	-0.12	-0.28	-0.17	-0.39
1938	-0.01	0.05	0.26	-0.22	-0.09
1939	-0.18	0.11	0.41	0.21	-0.21
1940	-0.17	-0.13	0.00	-0.22	-0.02
1941	-0.51	-0.49	-0.61	0.05	-0.07
1942	-0.40	-0.68	-0.25	-0.58	-0.34
1943	0.59	0.68	0.68	-0.13	0.28
1944	-0.19	-0.03	-0.46	-0.36	0.09
1945	-0.21	0.16	0.41	-0.21	-0.49
1946	0.38	0.15	0.54	-0.38	-0.77

Century-scale series of standardized annual departures of African rainfall

S.E. Nicholson (continued)

WEST AFRICA(Sahelo-Sahara, Sahel, Soudan,
Soudano-Guinean, and Guinea Coast regions)**Standardized Annual Rainfall Departures^a (continued)**

Year	Sahelo-Sahara	Sahel	Soudan	Soudano-Guinean	Guinea Coast
1947	0.13	0.07	-0.35	-0.22	0.73
1948	-0.31	-0.27	-0.12	0.00	-0.68
1949	-0.38	-0.63	-0.64	0.03	0.28
1950	0.75	1.12	1.15	-0.77	-0.64
1951	0.49	0.09	0.62	0.86	0.45
1952	0.64	0.93	0.87	0.02	0.49
1953	1.07	0.83	0.47	0.31	0.00
1954	0.16	1.03	0.75	0.82	0.35
1955	0.49	0.82	0.58	0.76	0.82
1956	0.64	0.49	0.23	-0.48	-0.48
1957	1.04	0.48	0.69	1.05	0.83
1958	0.33	1.04	0.77	-0.42	-0.87
1959	-0.18	0.26	0.08	0.05	0.52
1960	-0.21	-0.05	0.13	0.32	0.48
1961	0.03	0.30	0.31	-0.54	-0.31
1962	0.02	0.17	0.21	0.55	0.97
1963	-0.47	-0.01	0.03	0.59	1.43
1964	-0.06	0.18	0.51	0.23	-0.39
1965	0.59	0.08	0.14	-0.21	0.00
1966	0.30	0.09	-0.01	0.18	-0.07
1967	-0.40	0.22	0.35	0.05	-0.45
1968	-0.04	-0.32	-0.78	0.30	1.70
1969	0.19	0.21	0.11	0.48	-0.17
1970	-0.60	-0.44	-0.49	-0.46	-0.42
1971	-0.89	-0.66	-0.56	-0.54	-0.13
1972	-0.75	-1.21	-1.13	-0.44	-0.46
1973	-0.97	-1.00	-1.22	-0.70	-0.26
1974	-0.32	-0.24	-0.30	-0.19	-0.11
1975	-0.77	-0.03	-0.16	-0.32	-0.35
1976	0.19	-0.53	-0.26	-0.03	-0.48
1977	-0.82	-0.80	-0.77	-0.93	-1.06
1978	-0.24	-0.15	0.00	0.22	-0.46
1979	0.40	-0.49	-0.46	-0.23	0.54
1980	-0.06	-0.29	-0.67	-0.50	0.05
1981	-0.22	-0.45	-0.65	-0.31	-0.48
1982	-0.71	-1.05	-1.04	-0.29	-0.43
1983	-0.89	-1.30	-1.43	-1.56	-1.36
1984	-0.73	-1.41	-1.44	-0.69	-0.08
1985	-0.68	-0.76	-0.88	-0.33	-0.26
1986	-0.24	-1.02	-0.70	-0.70	-1.08
1987	-0.75	-1.17	-1.37	-0.86	-0.15
1988	0.40	-0.17	0.01	-0.17	0.04
1989	0.33	-0.59	-0.39	-0.24	0.20
1990	-1.01	-0.63	-0.92	-0.95	-0.44

^aThe standardized departure equals the annual departure from the long-term (entire period of record) mean, divided by the standard departure.

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EASTERN AND SOUTHERN AFRICA

(Eastern Africa, Southern Africa–North,
and Southern Africa–South regions)

Trends

The following background description of Eastern and Southern African rainfall seasonality and the discussion of the time series of annual rainfall departures for the three Eastern and Southern African regions are taken directly from Nicholson (1993).*

Eastern Africa, straddling equatorial latitudes, has in most areas two rainy seasons during the year. The northern portion of Southern Africa, a region with a single rainfall season during the high-sun period, represents the southern limit of the Intertropical Convergence Zone (ITCZ). The southern portion of South Africa also has a single, high-sun rainy season in most areas, but midlatitude systems have a stronger influence on rainfall than in the northern region.

In Eastern and Southern Africa, the situation has been markedly different than in West Africa. Eastern Africa was generally abnormally wet during the 1980s, a condition which began about 1977. Rainfall fluctuations in the northern and southern regions of South Africa have continued to parallel each other, a characteristic demonstrated previously (Nicholson 1986). The fluctuations also tended to parallel those in the three "Sahel" zones until recent decades. As in the Sahel, the Eastern and Southern Africa regions were abnormally dry in the 1980s, but unlike the Sahel, Southern African rainfall was above average for the 1970s decade as a whole.

*In Nicholson (1993) the Southern Africa–North region is referred to as the "Northern Kalahari", and the Southern Africa–South region is referred to as the "Southern Kalahari."

Century-scale series of standardized annual departures of African rainfall

S.E. Nicholson (continued)

EASTERN AND SOUTHERN AFRICA

(Eastern Africa, Southern Africa–North,
and Southern Africa–South regions)

Regionally averaged standardized departures of Eastern and Southern African rainfall. The standardized departure equals the annual departure from the long-term (entire period of record) mean, divided by the standard departure.

CITE AS: Nicholson, S.E. 1994. Century-scale series of standardized annual departures of African rainfall. pp. 952–962. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Precipitation

Century-scale series of standardized annual departures of African rainfall

S.E. Nicholson (continued)

EASTERN AND SOUTHERN AFRICA

(Eastern Africa, Southern Africa–North, and Southern Africa–South regions)

Standardized Annual Rainfall Departures^a

Year	Eastern Africa	Southern Africa–North	Southern Africa–South	Year	Eastern Africa	Southern Africa–North	Southern Africa–South
1901	−0.14	1.03	0.64	1938	−0.32	−0.03	0.02
1902	0.01	−0.11	−0.35	1939	−0.55	1.39	0.99
1903	0.02	−0.77	−1.30	1940	0.19	0.06	0.26
1904	0.31	−0.03	−0.20	1941	0.54	−0.45	−0.52
1905	0.78	−1.09	−0.25	1942	−0.01	−0.46	0.91
1906	0.97	−0.11	0.21	1943	−0.83	0.34	1.72
1907	−0.44	0.90	1.05	1944	0.22	−0.12	−0.13
1908	0.15	−0.42	−0.72	1945	−0.29	−0.35	−1.03
1909	−0.19	−0.13	1.52	1946	−0.33	−0.07	0.07
1910	−0.29	−0.04	−0.17	1947	0.58	−0.69	−0.07
1911	−0.22	0.19	0.19	1948	−0.26	0.12	−0.15
1912	0.30	−1.14	−0.57	1949	−0.88	−0.52	−0.22
1913	−0.30	−0.67	−0.27	1950	−0.28	−0.26	0.62
1914	0.04	0.33	0.00	1951	1.19	−0.37	−0.46
1915	−0.06	0.23	−0.31	1952	−0.53	0.52	−0.26
1916	0.27	−0.64	−0.72	1953	−0.40	0.97	−0.01
1917	0.55	0.11	0.52	1954	−0.39	0.33	−0.24
1918	−1.16	1.29	0.76	1955	−0.16	0.56	0.97
1919	−0.02	0.10	−1.11	1956	−0.04	0.44	0.56
1920	−0.16	0.02	0.20	1957	0.23	−0.23	0.90
1921	−1.04	0.55	0.47	1958	−0.28	0.97	0.34
1922	−0.33	−1.33	−0.76	1959	−0.23	−0.10	−0.14
1923	0.38	0.57	−0.25	1960	−0.15	−0.25	0.11
1924	−0.65	−0.21	0.42	1961	1.73	0.03	0.34
1925	−0.15	1.36	0.91	1962	0.27	0.73	−0.34
1926	0.07	0.70	−0.76	1963	1.03	−0.27	0.32
1927	−0.34	−0.66	−0.60	1964	0.02	−0.71	−0.61
1928	−0.36	−0.28	−0.35	1965	−0.44	−1.35	−1.10
1929	−0.34	0.64	0.65	1966	0.06	−0.02	−0.56
1930	0.58	−0.11	−0.68	1967	0.71	0.24	0.90
1931	0.12	−0.57	−0.37	1968	0.98	−0.54	−0.62
1932	0.21	0.22	−0.70	1969	−0.33	0.70	−0.03
1933	−0.44	−0.44	−0.70	1970	0.12	−1.24	−0.85
1934	−0.34	−0.01	1.07	1971	−0.42	−0.30	0.20
1935	−0.02	−1.11	−0.80	1972	0.30	0.14	0.00
1936	0.64	0.49	0.49	1973	−0.42	−0.01	0.11
1937	0.61	−0.34	−0.18	1974	−0.25	1.14	1.51

Century-scale series of standardized annual departures of African rainfall

S.E. Nicholson (continued)

EASTERN AND SOUTHERN AFRICA

(Eastern Africa, Southern Africa–North,
and Southern Africa–South regions)

Standardized Annual Rainfall Departures^a (continued)

Year	Eastern Africa	Southern Africa–North	Southern Africa–South	Year	Eastern Africa	Southern Africa–North	Southern Africa–South
1975	−0.23	0.07	0.92	1983	−0.31	−0.82	−0.78
1976	−0.65	0.52	1.55	1984	−0.16	−0.46	−1.17
1977	0.61	0.92	0.13	1985	0.05	0.12	−0.90
1978	0.79	1.29	0.34	1986	0.42	−0.01	−0.44
1979	0.58	−0.49	−0.51	1987	−0.07	−0.75	−0.04
1980	−0.28	−0.16	−0.25	1988	0.63	0.34	0.94
1981	0.05	0.60	0.44	1989	0.44	0.02	0.08
1982	0.76	−1.02	−0.67	1990	1.26	0.67	

^aThe standardized departure equals the annual departure from the long-term (entire period of record) mean, divided by the standard departure.

CITE AS: Nicholson, S.E. 1994. Century-scale series of standardized annual departures of African rainfall. pp. 952–962. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

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| Sahel • East Africa • Southwestern Africa

Period of Record

Sahel: 1900–91; East Africa: 1892–1991; Southwestern Africa: 1884–1991

Methods

Hulme's annual time series of regional rainfall anomalies for Africa have been constructed using the global monthly precipitation dataset held in the Climatic Research Unit (CRU) at the University of East Anglia. The following summary of the methods used in constructing the series draws from Hulme (1992) and Barring and Hulme (1991). For more specific details, the reader is referred to these sources.

The CRU precipitation dataset consists of historical time series of monthly precipitation for more than 8200 stations worldwide, of which 2150 lie within Africa. Time series of *regional* rainfall anomalies over three regions for about the last 100 years were produced using individual station time series. The three regions are the Sahel (defined as the portion of sub-Saharan Africa that received 100–600 mm mean annual rainfall over the period 1931–90); East Africa (Uganda, Kenya, and Tanzania); and Southwestern Africa (the area that received 100–600 mm mean annual rainfall over the period 1931/32–1990/91*). Annual rainfall anomalies for these regions are expressed as rainfall anomaly indices (RAIs), which are calculated by first computing individual stations' *standardized* rainfall,

$$x'_{ij} = \frac{(x_{ij} - \bar{x}_i)}{s_i},$$

where x'_{ij} is the standardized annual rainfall (z score) for station i and year j , x_{ij} is the annual rainfall total, $\bar{x}_i$ is the mean annual rainfall for station i over the period 1931–90, and s_i is the standard deviation of the annual rainfall totals over the same period. The RAI for a given year is the average of the standardized annual rainfall totals from all stations in the region for that particular year. The standardizing, or normalizing, of annual rainfall totals from individual stations is performed to minimize problems caused by a changing station network and by averaging the data from stations with greatly different mean rainfall.

*The rainfall year for Southwestern Africa is defined as July through June.

Century-scale time series of regional rainfall anomalies in Africa

M. Hulme (continued)

Africa and the three regions (darkened) for which time series of annual rainfall anomaly indices (RAIs) were constructed.

CITE AS: Hulme, M. 1994. Century-scale time series of regional rainfall anomalies in Africa. pp. 964–973. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

M. Hulme (continued)

SAHEL

Trends

Annual rainfall in the Sahel is mainly derived from a single wet season consisting of the boreal summer months June–August; the wet season results from the proximity of the Intertropical Convergence Zone at this time of year. Hulme (1992) described the Sahelian RAIs as strikingly persistent; the autocorrelation function of the annual anomalies (not shown) reveals a signature very different from those of both Eastern and Southwestern Africa. Folland et al. (1991) found that this persistence has increased in recent decades. The Sahelian RAIs show basically two rainfall regimes over the period of record (1900–91): mainly above-average amounts before 1968, although with a short dry period between 1911 and 1915, and, with the exception of 1978, periods of unparalleled below-average amounts thereafter. A comparison of summer rainfall climatologies worldwide for 1931–60 and 1961–90 indicates that the Sahel has experienced the largest relative rainfall change of any region of the world during this period (Hulme et al. 1992).

Hulme (1992) discusses several possible causes of the persistence in drought conditions in the Sahel during recent decades. Whereas a completely satisfactory explanation has been (and remains) elusive, the factor that may be most closely associated with maintenance of the drought is the persistence of recent global sea surface temperature (SST) anomalies (Folland et al. 1991), specifically warm anomalies in the southern oceans (including the Indian Ocean) and cool anomalies in the northern oceans. Hulme (1992) also points out that this pattern describes the dominant mode of global SSTs during the past 30 years and that modeling studies (e.g., Rowell et al. 1991) support this explanation for interdecadal rainfall fluctuations in the Sahel.

Century-scale time series of regional rainfall anomalies in Africa

M. Hulme (continued)

SAHEL

Annual (January–December) rainfall anomaly indices for the Sahel. Anomalies are calculated in relation to the mean rainfall during 1931–90. The smooth curve represents the effect of a 10-point Gaussian filter, which suppresses variations on time scales of less than a decade.

CITE AS: Hulme, M. 1994. Century-scale time series of regional rainfall anomalies in Africa. pp. 964–973. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Precipitation

Century-scale time series of regional rainfall anomalies in Africa

M. Hulme (continued)

SAHEL

Annual Rainfall Anomaly Indices for the Sahel Region

Year	Number of stations	Rainfall anomaly index	Year	Number of stations	Rainfall anomaly index	Year	Number of stations	Rainfall anomaly index
1900	3	-0.51	1931	71	0.00	1962	152	0.55
1901	3	0.01	1932	71	0.33	1963	149	0.24
1902	6	-0.47	1933	72	0.66	1964	148	0.70
1903	7	-0.09	1934	72	0.26	1965	149	0.05
1904	8	-0.17	1935	74	0.54	1966	149	-0.27
1905	13	0.30	1936	79	0.80	1967	145	0.28
1906	17	1.02	1937	78	-0.05	1968	145	-0.36
1907	21	-0.30	1938	80	0.27	1969	146	-0.39
1908	26	0.29	1939	82	0.64	1970	149	-0.40
1909	28	1.11	1940	83	-0.10	1971	149	-0.55
1910	30	0.18	1941	83	-0.40	1972	146	-0.87
1911	31	-0.10	1942	85	-0.25	1973	149	-1.19
1912	31	-0.57	1943	95	0.39	1974	145	-0.42
1913	31	-1.32	1944	96	-0.36	1975	148	-0.20
1914	27	-0.19	1945	94	0.29	1976	144	-0.43
1915	23	0.02	1946	102	0.91	1977	145	-0.73
1916	25	0.26	1947	99	-0.30	1978	146	0.10
1917	24	-0.11	1948	119	-0.09	1979	141	-0.43
1918	29	0.02	1949	122	-0.68	1980	134	-0.48
1919	32	-0.40	1950	139	0.80	1981	120	-0.59
1920	40	0.44	1951	143	0.29	1982	108	-1.09
1921	46	-0.01	1952	144	0.41	1983	108	-1.57
1922	59	0.82	1953	149	0.72	1984	104	-1.88
1923	60	0.26	1954	149	0.83	1985	100	-0.99
1924	63	0.49	1955	153	0.39	1986	85	-0.98
1925	62	-0.03	1956	150	0.70	1987	62	-1.42
1926	63	-0.46	1957	152	0.45	1988	59	-0.20
1927	64	0.57	1958	151	0.44	1989	48	-0.71
1928	65	0.26	1959	152	0.31	1990	55	-1.58
1929	72	0.87	1960	151	-0.24	1991	38	-0.48
1930	73	0.33	1961	150	0.36			

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Century-scale time series of regional rainfall anomalies in Africa

M. Hulme (continued)

EAST AFRICA

Trends

Annual rainfall in the immediate equatorial zone of East Africa is derived primarily from two wet seasons that result from the seasonal shifts in the position of the Intertropical Convergence Zone (ITCZ). Despite the proximity of the ITCZ, most of this region has a relatively dry climate; humid climates are confined mainly to the higher elevations (Trewartha 1981).

According to Hulme (1992), the RAIs for this region have little temporal organization; the most noteworthy features of the series are the unusually wet years experienced in the early 1960s and in 1905 and 1906. However, through comparative analysis of African rainfall climatologies for the periods 1931–60 and 1961–90, Hulme (1992) found that East African rainfall during the latter period increased by about 15%.

Annual (January–December) rainfall anomaly indices for East Africa. Anomalies are calculated in relation to the mean rainfall during 1931–90. The smooth curve represents the effect of a 10-point Gaussian filter, which suppresses variations on time scales of less than a decade.

CITE AS: Hulme, M. 1994. Century-scale time series of regional rainfall anomalies in Africa. pp. 964–973. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Precipitation

Century-scale time series of regional rainfall anomalies in Africa

M. Hulme (continued)

EAST AFRICA

Annual Rainfall Anomaly Indices for East Africa

Year	Number of stations	Rainfall anomaly index	Year	Number of stations	Rainfall anomaly index	Year	Number of stations	Rainfall anomaly index
1892	3	-1.16	1926	39	0.11	1960	47	-0.16
1893	3	0.59	1927	40	-0.37	1961	46	1.83
1894	5	-0.50	1928	36	-0.56	1962	47	0.11
1895	4	-0.79	1929	31	-0.52	1963	49	1.08
1896	3	0.46	1930	32	0.42	1964	49	0.04
1897	3	0.00	1931	47	0.19	1965	49	-0.47
1898	3	-1.85	1932	48	0.02	1966	49	-0.08
1899	4	-1.12	1933	48	-0.70	1967	49	0.61
1900	4	0.65	1934	47	-0.54	1968	49	1.21
1901	6	-0.57	1935	48	-0.15	1969	49	-0.41
1902	10	-0.27	1936	49	0.55	1970	48	0.13
1903	13	0.08	1937	49	0.71	1971	49	-0.47
1904	14	0.77	1938	49	-0.31	1972	47	0.31
1905	15	1.39	1939	48	-0.59	1973	47	-0.50
1906	16	1.38	1940	48	0.31	1974	44	-0.51
1907	16	0.37	1941	48	0.59	1975	44	-0.41
1908	21	0.57	1942	49	0.14	1976	44	-0.72
1909	20	0.09	1943	49	-0.89	1977	44	0.68
1910	18	-0.35	1944	49	0.23	1978	41	0.71
1911	20	-0.26	1945	49	-0.39	1979	41	0.60
1912	17	0.53	1946	49	-0.35	1980	36	-0.63
1913	15	-0.27	1947	49	0.68	1981	48	-0.06
1914	17	-0.13	1948	49	-0.27	1982	44	0.81
1915	18	0.03	1949	49	-0.96	1983	33	-0.52
1916	18	0.44	1950	48	-0.26	1984	34	-0.53
1917	18	0.34	1951	49	1.46	1985	29	-0.12
1918	21	-1.32	1952	49	-0.63	1986	30	0.17
1919	21	0.08	1953	49	-0.31	1987	30	-0.53
1920	21	0.00	1954	49	-0.42	1988	27	0.33
1921	21	-1.19	1955	49	-0.40	1989	17	0.41
1922	39	-0.29	1956	46	-0.43	1990	15	0.15
1923	38	0.59	1957	49	0.39	1991	9	-0.40
1924	37	-0.67	1958	49	-0.29			
1925	39	-0.14	1959	49	-0.35			

CITE AS: Hulme, M. 1994. Century-scale time series of regional rainfall anomalies in Africa. pp. 964-973. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

SOUTHWESTERN AFRICA

Trends

The northern portion of the Southwestern Africa region receives most of its rainfall during the austral summer (high-sun) months (December–February) because of the proximity of the Intertropical Convergence Zone. The southern portion of the region also experiences a high-sun rainy season (although low-sun rains are significant), but rainfall is derived mainly from midlatitude systems (Trewartha 1981; Nicholson 1993). The relative dryness (100–600 mm annual mean rainfall) of the region as a whole is related to the persistence (especially in winter) of subtropical anticyclones over the south Atlantic and south Indian oceans (Trewartha 1981).

The time series of RAIs for Southwestern Africa shows alternate wet and dry episodes, which have a quasi-periodicity of 18 years (Tyson et al. 1975 and Tyson 1991). The alternating episodes are evident from the smooth curve in the thick black line on the graph below. Mason (1990) suggests that this periodicity may be related to local sea surface temperature anomalies around the southern African coast. Hulme (1992) notes that the coincidence in the early 1980s of a dry phase in Southwestern Africa with severe rainfall deficits in the Sahel and two dry years in equatorial East Africa in 1983 and 1984 resulted in the near continent-wide drought between 1983 and 1987.

Annual (July–June) rainfall anomaly indices for Southwestern Africa. Anomalies are calculated in relation to the mean rainfall during 1931–90. The smooth curve represents the effect of a 10-point Gaussian filter, which suppresses variations on time scales of less than a decade.

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Precipitation

Century-scale time series of regional rainfall anomalies in Africa

M. Hulme (continued)

SOUTHWESTERN AFRICA

Annual Rainfall Anomaly Indices for Southwestern Africa^a

Year	Number of stations	Rainfall anomaly index	Year	Number of stations	Rainfall anomaly index	Year	Number of stations	Rainfall anomaly index
1884	2	0.57	1920	14	-0.06	1956	39	0.31
1885	2	-1.42	1921	20	0.24	1957	40	-0.01
1886	3	-0.25	1922	19	-0.73	1958	39	0.54
1887	3	0.50	1923	26	0.67	1959	40	-0.02
1888	3	0.76	1924	28	-0.85	1960	38	-0.48
1889	3	-0.04	1925	30	1.99	1961	40	0.58
1890	3	0.49	1926	23	-0.46	1962	34	-0.46
1891	3	2.18	1927	34	-0.72	1963	40	0.28
1892	4	1.22	1928	34	-0.37	1964	39	-0.68
1893	4	0.47	1929	34	0.01	1965	39	-0.79
1894	3	0.43	1930	37	0.24	1966	40	-0.53
1895	4	0.29	1931	39	-0.43	1967	40	0.69
1896	4	-0.31	1932	37	0.00	1968	40	-0.55
1897	3	0.29	1933	38	-1.11	1969	40	-0.33
1898	5	0.03	1934	39	0.51	1970	40	-0.95
1899	6	0.39	1935	39	-0.08	1971	40	0.09
1900	5	-0.05	1936	39	-0.29	1972	39	0.72
1901	8	0.08	1937	40	0.16	1973	40	-0.95
1902	12	-0.06	1938	40	-0.56	1974	31	1.71
1903	13	-0.70	1939	40	0.68	1975	30	0.95
1904	16	-0.30	1940	38	0.61	1976	33	1.33
1905	16	-0.72	1941	40	0.05	1977	38	0.61
1906	17	-0.36	1942	40	-0.44	1978	36	0.89
1907	17	1.11	1943	39	0.26	1979	31	-0.47
1908	18	-0.64	1944	39	1.03	1980	30	-0.02
1909	12	1.24	1945	40	-0.57	1981	28	0.61
1910	10	-0.12	1946	39	-0.07	1982	30	-0.82
1911	12	0.40	1947	39	-1.04	1983	37	-0.76
1912	15	-0.55	1948	38	0.59	1984	38	-0.49
1913	18	-1.00	1949	40	-0.67	1985	38	-0.47
1914	15	-0.71	1950	39	0.11	1986	37	-0.36
1915	12	1.35	1951	38	-0.07	1987	37	-0.66
1916	10	-1.10	1952	36	-0.54	1988	31	1.66
1917	14	-0.42	1953	36	0.49	1989	31	0.17
1918	15	0.85	1954	39	0.13	1990	5	-0.35
1919	15	0.15	1955	39	0.92	1991	4	0.35

^aThe rainfall year for Southwestern Africa is defined as July to June, with each year in the table referring to the end of the rainfall year; e.g., 1991 rainfall is for the period July, 1990 through June, 1991.

CITE AS: Hulme, M. 1994. Century-scale time series of regional rainfall anomalies in Africa. pp. 964-973. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

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England and Wales area-average precipitation amount

P.D. Jones, T.M.L. Wigley, J.M. Gregory

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Period of Record

1766–1991

Methods

Area-average precipitation amount for England and Wales (EW) has been analyzed by Wigley et al. (1984), Wigley and Jones (1987), and Gregory et al. (1991). Using homogeneous precipitation records compiled by Tabony (1980) for 55 stations for the period 1861–1970, Wigley et al. (1984) identified five regions of spatially coherent precipitation within EW (see figure below) by means of principal components analysis. The five regions are northwestern England and northern Wales (NW), northeastern England (NE), central and eastern England (CE), southwestern England and southern Wales (SW), and southeastern England (SE). Averaged data from a network of seven evenly spaced observing sites (chosen mainly on the basis of length of record) were found to accurately represent the overall character of precipitation changes in each region. Regional time series were produced by unweighted averaging of the seven series from each region. The regional series were then weighted as described in Wigley et al. (1984) to produce the EW average series.

England and Wales

CITE AS: Jones, P.D., T.M.L. Wigley, and J.M. Gregory. 1994. England and Wales area-average precipitation amount. pp. 975–983. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Precipitation

England and Wales area-average precipitation amount

P.D. Jones, T.M.L. Wigley, and J.M. Gregory (continued)

ENGLAND AND WALES

Trends

The England and Wales area-average precipitation time series produced by Jones, Wigley, and Gregory show no obvious long-term trends in precipitation amount. Wigley and Jones (1987), in analyzing these series (which at that point extended through 1985), observed a tendency towards wetter springs over the period 1956–69 and drier summers from the late 1960s through the mid-1970s. When the series were updated and analyzed through 1989, however, Gregory et al. (1991) found no further evidence of these trends, pointing out that they may represent normal fluctuations that help to illustrate the scale of natural climatic variability.

Annual precipitation for England and Wales. Annual totals are depicted by the thin line, while the thick line represents the annual totals smoothed with a five-term binomial filter.

CITE AS: Jones, P.D., T.M.L. Wigley, and J.M. Gregory. 1994. England and Wales area-average precipitation amount. pp. 975–983. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

England and Wales area-average precipitation amount

P.D. Jones, T.M.L. Wigley, and J.M. Gregory (continued)

ENGLAND AND WALES

Seasonal precipitation for England and Wales. Seasonal totals are depicted by the thin line, while the thick line represents the seasonal totals smoothed with a five-term binomial filter. DJF denotes winter (December, January, and February; dated by January), MAM denotes spring, etc.

CITE AS: Jones, P.D., T.M.L. Wigley, and J.M. Gregory. 1994. England and Wales area-average precipitation amount. pp. 975-983. In T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds.), *Trends '93: A Compendium of Data on Global Change*. ORNL/CDIAC-65. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tenn., U.S.A.

Precipitation

England and Wales area-average precipitation amount

P.D. Jones, T.M.L. Wigley, and J.M. Gregory (continued)

ENGLAND AND WALES

Area-Average Precipitation Amount, 1766–1991

Year	Precipitation (mm)												Ann
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	
1766	4.4	66.7	48.2	60.9	108.1	109.2	101.7	38.1	53.8	71.9	75.4	67.1	805.5
1767	92.7	115.3	68.9	38.9	84.2	47.7	148.0	75.4	63.7	103.2	73.6	29.6	941.2
1768	109.2	129.1	12.8	85.6	46.1	148.7	121.9	91.6	136.8	119.4	142.5	103.6	1247.4
1769	74.7	81.1	40.4	46.0	73.5	122.8	56.9	98.8	133.5	51.3	90.8	81.1	951.0
1770	52.7	56.6	77.8	75.5	63.8	118.1	63.0	52.6	85.8	115.8	200.8	116.9	1079.4
1771	68.8	32.7	46.4	31.3	51.6	43.0	50.7	113.6	64.4	137.8	49.5	103.1	792.8
1772	79.1	95.2	88.6	58.5	53.1	77.8	61.7	75.0	141.6	101.7	157.3	42.2	1031.8
1773	68.8	72.4	19.9	54.4	151.8	65.5	37.3	83.6	141.6	112.3	125.0	101.2	1033.7
1774	105.4	102.6	85.6	53.8	75.4	72.3	94.1	91.0	161.0	40.9	48.4	64.2	994.7
1775	76.9	99.2	64.4	30.0	21.7	46.3	158.4	142.6	130.4	114.9	89.3	37.9	1011.9
1776	51.6	113.5	50.5	22.4	46.4	74.9	82.9	136.1	99.7	49.6	76.2	43.6	847.4
1777	39.8	44.0	58.2	70.1	91.2	103.9	116.6	70.2	28.7	144.7	55.8	37.1	860.4
1778	77.5	30.8	45.9	23.0	69.4	74.9	129.4	20.2	61.1	126.0	122.0	107.7	888.0
1779	15.3	13.5	15.6	67.2	81.0	76.6	149.3	53.5	100.2	106.4	77.5	144.4	900.6
1780	32.0	36.6	53.8	98.2	50.6	48.3	51.4	24.3	119.7	110.5	62.5	11.1	698.9
1781	61.0	85.3	5.6	55.6	39.8	71.2	50.3	75.9	86.7	8.8	121.3	72.7	734.1
1782	99.1	26.8	81.6	139.0	142.4	55.3	131.7	150.8	128.1	71.2	44.4	38.9	1109.4
1783	95.3	97.0	55.4	15.2	83.9	91.6	57.6	76.7	125.4	50.2	61.5	23.8	833.6
1784	64.1	44.3	67.9	81.5	59.8	120.1	98.6	74.8	41.3	15.7	90.2	52.7	811.0
1785	50.3	34.9	18.8	10.1	25.9	45.4	62.0	119.5	105.1	99.3	67.3	80.8	719.4
1786	118.6	32.0	36.7	34.7	72.8	60.7	36.1	87.1	109.0	108.9	95.2	97.0	888.8
1787	20.0	65.1	93.7	36.0	49.9	50.0	155.0	62.5	61.6	133.1	81.6	109.1	917.5
1788	45.9	71.2	39.4	29.8	43.7	59.4	81.6	88.3	84.9	35.8	25.1	8.9	614.0
1789	105.6	92.4	55.9	51.0	93.1	128.0	128.0	39.6	97.5	130.7	80.2	107.3	1109.3
1790	72.8	20.9	16.8	54.4	93.6	60.9	94.5	77.9	60.0	56.9	121.9	125.5	855.9
1791	123.4	70.7	30.7	68.3	37.8	36.1	100.4	79.9	38.6	104.9	150.0	87.3	928.1
1792	75.5	44.1	85.2	97.7	86.7	84.3	114.1	116.4	151.5	98.6	47.5	115.2	1116.8
1793	66.6	58.7	74.4	62.5	29.2	38.3	35.1	99.7	97.9	52.9	84.1	77.3	776.7
1794	34.0	66.0	59.8	70.5	52.1	18.7	69.9	80.7	120.1	128.3	129.4	65.1	894.7
1795	27.2	75.4	80.2	68.1	15.7	101.8	53.5	82.0	12.9	173.2	106.6	81.3	878.0
1796	116.2	71.1	17.5	27.2	110.4	57.0	135.2	40.0	62.1	83.9	68.8	73.1	862.6
1797	69.8	15.3	40.7	68.7	109.5	134.9	79.4	114.8	185.4	68.4	84.7	118.8	1090.6
1798	72.4	44.6	32.8	56.3	47.6	31.0	149.5	78.8	95.7	116.0	94.7	49.5	868.8
1799	64.8	94.8	40.5	80.8	58.1	23.7	108.3	192.1	186.8	111.8	98.3	19.0	1079.1
1800	117.6	20.4	50.7	103.2	75.5	26.7	9.1	55.7	112.2	93.8	145.8	91.0	901.8
1801	74.1	82.8	84.7	21.6	87.4	30.0	121.9	40.7	114.0	87.4	106.6	96.9	947.9
1802	37.0	84.8	18.7	33.7	49.3	76.6	126.3	48.7	35.1	108.0	60.3	78.4	757.0
1803	62.2	55.0	29.9	47.5	59.9	92.2	30.3	44.2	41.6	29.3	113.0	145.8	750.8
1804	128.8	38.4	83.4	69.9	63.0	28.9	99.9	81.0	11.9	115.7	115.8	46.6	883.3
1805	79.1	58.5	37.3	67.7	55.8	67.5	71.1	83.6	64.4	51.1	23.1	75.6	734.9
1806	128.6	54.7	52.0	26.8	44.2	36.4	106.6	86.8	58.8	41.9	117.9	137.5	892.1
1807	41.5	48.2	20.4	22.9	113.9	45.7	67.6	57.6	87.7	68.2	115.5	56.5	745.7
1808	36.1	34.8	12.4	93.4	69.4	53.0	100.0	76.0	90.4	115.0	76.2	52.0	808.7
1809	134.3	88.2	29.3	91.9	57.9	58.5	78.3	130.6	114.1	10.9	55.0	92.3	941.3
1810	27.8	53.1	77.5	58.6	68.3	41.9	117.4	94.6	45.5	79.6	174.4	134.4	973.1
1811	54.7	84.3	53.3	57.8	121.9	66.0	94.4	66.1	74.7	111.7	94.3	70.4	949.5
1812	48.8	115.3	110.7	43.0	87.6	95.4	75.4	54.6	45.8	136.3	85.6	24.4	922.9
1813	37.4	103.7	29.4	53.6	110.1	53.5	87.0	34.7	64.7	157.3	66.7	30.1	828.2
1814	62.9	21.8	43.8	88.7	42.8	70.8	83.0	73.6	41.9	98.9	78.0	122.3	828.7

England and Wales area-average precipitation amount

P.D. Jones, T.M.L. Wigley, and J.M. Gregory (continued)

ENGLAND AND WALES

Area-Average Precipitation Amount, 1766–1991 (continued)

Year	Precipitation (mm)												
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1815	27.9	44.0	89.8	45.2	76.1	71.5	50.0	82.0	77.4	93.9	51.0	90.5	799.0
1816	81.4	44.3	56.1	75.8	74.3	77.9	152.0	81.7	79.0	106.3	75.7	102.6	1007.0
1817	76.0	59.4	52.5	7.9	101.4	92.1	119.7	133.9	26.6	34.0	71.3	107.7	882.5
1818	98.0	65.8	134.7	135.6	55.9	31.2	50.4	21.0	115.6	75.8	112.0	46.8	942.7
1819	101.1	95.1	36.8	64.6	84.8	76.9	68.2	44.9	81.6	82.6	71.9	93.9	902.2
1820	66.7	47.8	24.1	47.6	98.4	57.6	67.7	78.4	67.4	97.9	52.7	69.5	775.9
1821	68.9	10.3	102.4	83.0	62.4	40.9	77.4	81.5	108.8	96.1	140.6	166.0	1038.4
1822	32.2	63.1	69.2	72.1	51.1	32.5	145.2	58.5	40.5	142.9	145.4	52.0	904.6
1823	85.7	114.0	45.6	56.6	63.3	51.0	106.9	103.4	66.3	120.4	58.5	119.1	991.0
1824	30.6	65.3	76.9	63.1	55.7	96.3	47.0	74.5	111.8	140.7	135.4	129.7	1026.9
1825	47.0	42.3	47.5	66.2	83.3	58.1	8.2	94.0	81.9	99.6	111.7	99.9	839.7
1826	34.9	104.9	53.1	35.6	35.0	12.4	49.4	60.0	135.6	68.8	62.6	77.7	730.1
1827	61.1	33.1	108.9	39.9	77.2	44.3	52.2	76.0	100.4	142.0	67.9	132.1	934.9
1828	122.7	60.0	34.3	102.8	72.4	74.5	182.6	98.8	93.5	66.4	64.3	100.9	1073.2
1829	34.9	44.0	25.7	123.4	16.6	103.3	143.7	149.3	126.7	65.2	52.8	27.1	912.7
1830	46.1	60.0	27.1	95.4	100.1	128.9	94.0	98.2	135.0	31.7	116.4	73.2	1006.1
1831	62.1	89.4	78.7	58.2	52.0	60.1	97.5	70.9	98.4	136.2	88.8	112.7	1005.0
1832	38.0	28.8	66.1	53.9	67.8	89.6	49.3	131.3	26.6	109.4	114.9	88.8	864.6
1833	27.9	158.6	52.6	76.9	21.9	107.9	47.8	59.1	62.0	87.3	82.4	129.2	913.6
1834	149.8	51.6	43.3	33.4	34.4	71.7	164.2	80.3	67.9	41.6	60.8	36.2	835.2
1835	56.0	92.7	83.4	37.4	77.8	61.0	43.7	52.6	126.5	137.9	103.8	27.6	900.4
1836	75.1	61.9	119.5	74.0	16.0	86.0	93.2	45.4	96.2	111.8	154.0	81.7	1014.8
1837	90.6	89.3	30.4	50.4	36.7	52.3	70.9	92.9	72.9	85.7	77.9	78.3	828.1
1838	31.7	71.2	57.2	49.6	62.6	112.9	68.1	80.8	76.1	90.0	131.7	62.4	894.4
1839	58.7	62.7	75.7	38.8	27.2	114.9	152.9	83.4	129.8	96.3	132.3	103.5	1076.2
1840	101.7	65.0	9.8	24.2	79.8	54.4	88.9	69.3	89.7	53.6	139.7	25.1	801.1
1841	76.9	54.1	62.9	49.1	75.3	74.2	91.3	103.9	133.4	134.7	116.5	92.1	1064.3
1842	67.8	48.0	83.0	14.3	58.1	59.5	74.0	64.1	93.2	46.1	160.9	50.9	819.9
1843	76.5	76.9	35.8	93.4	129.1	82.7	72.2	101.4	24.3	150.4	93.8	18.2	954.9
1844	63.8	84.6	77.5	16.6	7.9	40.4	70.4	78.0	64.9	97.6	95.4	20.8	717.8
1845	70.3	37.8	43.4	46.7	67.0	78.8	80.9	111.9	80.7	71.3	81.7	103.5	874.0
1846	101.6	37.1	63.4	112.0	51.3	50.6	99.7	105.9	53.8	148.8	59.4	43.8	927.5
1847	62.2	51.4	46.1	49.8	104.1	66.6	34.3	51.2	62.6	117.9	74.3	127.9	848.4
1848	48.8	130.0	102.2	84.1	25.7	141.5	85.1	117.7	107.6	133.9	57.4	96.1	1130.3
1849	81.6	46.8	28.4	83.3	80.2	41.8	80.3	56.8	108.5	95.6	63.1	100.4	866.8
1850	60.4	56.7	19.8	89.1	67.6	42.0	108.2	66.2	72.3	63.5	93.0	62.2	801.0
1851	116.5	32.0	106.9	48.5	35.8	75.0	94.8	66.8	31.4	89.0	47.2	36.6	780.3
1852	136.6	58.6	17.1	20.1	62.2	134.1	68.0	134.9	131.0	122.3	202.5	125.6	1212.9
1853	94.8	47.0	44.8	67.1	47.4	99.5	110.0	79.8	67.9	121.7	57.8	36.1	873.9
1854	82.5	32.5	20.7	14.1	82.1	61.1	67.7	56.3	34.8	81.2	68.6	71.3	672.9
1855	16.3	44.6	57.2	19.9	62.2	78.9	129.8	60.0	37.1	157.2	38.4	42.9	744.6
1856	92.0	58.7	29.1	82.3	96.1	59.6	53.8	110.7	104.1	74.7	46.1	93.9	901.2
1857	89.5	33.4	71.1	77.8	47.7	70.5	69.3	102.2	94.0	101.8	56.7	31.0	845.2
1858	32.0	29.2	42.3	81.6	64.4	45.6	79.0	65.0	78.0	91.7	47.4	83.0	739.2
1859	55.4	55.0	76.6	91.9	32.6	64.2	66.5	97.3	114.9	101.0	94.6	89.2	939.3
1860	112.3	41.5	82.0	40.1	93.0	157.1	65.2	148.5	79.0	83.9	84.5	96.1	1083.1
1861	32.5	81.2	91.2	29.5	32.5	80.8	124.5	48.3	84.9	48.2	139.7	55.0	848.1
1862	78.0	21.4	114.8	66.3	94.6	78.6	72.1	72.2	83.1	134.7	42.4	70.4	928.7
1863	110.3	31.4	36.8	38.3	44.7	109.4	29.3	91.0	110.6	112.5	85.0	62.5	861.7
1864	49.1	52.4	84.2	38.0	54.3	52.2	26.9	39.0	88.5	67.8	93.2	57.7	703.4

Precipitation

England and Wales area-average precipitation amount

P.D. Jones, T.M.L. Wigley, and J.M. Gregory (continued)

ENGLAND AND WALES

Area-Average Precipitation Amount, 1766–1991 (continued)

Year	Precipitation (mm)												Ann
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	
1865	98.9	71.9	40.5	28.0	83.2	46.6	84.4	126.0	9.5	168.4	90.3	55.4	903.1
1866	117.6	107.4	64.6	47.7	38.2	87.5	74.3	99.1	167.4	62.1	90.0	92.6	1048.5
1867	106.8	70.3	78.1	92.9	74.9	40.3	105.7	62.9	64.6	95.7	30.6	68.3	891.0
1868	99.9	62.2	71.1	61.4	36.7	16.5	20.0	106.7	90.2	95.6	61.4	185.6	907.3
1869	101.8	93.2	53.7	50.9	121.5	34.2	21.6	43.1	144.5	63.9	90.2	124.7	943.3
1870	65.9	62.1	55.8	21.5	40.0	31.4	39.4	60.3	49.8	159.3	66.8	80.8	733.1
1871	61.3	60.5	38.9	100.4	27.5	84.9	116.1	49.7	140.8	90.0	40.4	58.3	868.7
1872	140.2	88.2	84.9	69.1	66.2	100.0	122.9	80.8	104.1	149.5	140.7	138.3	1284.9
1873	109.1	51.3	75.8	23.1	61.6	62.3	84.4	98.8	72.0	97.7	71.7	26.6	834.5
1874	78.8	61.6	43.2	47.9	36.3	42.0	46.5	91.2	104.5	110.4	93.1	96.6	852.1
1875	122.8	46.5	27.2	39.1	52.0	92.8	142.7	67.5	96.2	157.3	145.6	47.5	1037.1
1876	47.1	97.7	99.4	84.7	23.6	55.6	47.2	83.5	141.5	74.4	108.4	193.9	1057.1
1877	146.8	77.6	76.3	93.6	79.5	46.3	108.5	136.1	74.3	86.0	141.5	77.6	1144.1
1878	68.4	50.6	38.7	69.2	117.6	76.4	39.3	155.2	72.6	104.4	118.0	73.1	983.6
1879	71.5	105.4	36.9	72.4	81.4	139.3	121.4	148.5	89.7	41.0	37.3	38.1	983.0
1880	16.2	84.1	52.1	56.4	38.6	81.3	157.5	40.1	119.8	161.4	97.9	122.8	1028.2
1881	35.5	109.9	81.9	34.2	53.1	68.9	75.3	143.7	73.0	82.0	105.9	103.3	966.5
1882	68.9	62.5	52.4	114.0	50.3	104.7	113.1	85.0	75.8	162.6	131.4	125.5	1146.2
1883	98.5	107.7	37.7	45.4	49.3	85.2	96.7	46.4	140.8	97.0	117.7	52.0	974.3
1884	108.7	70.7	66.4	47.2	39.1	41.3	97.5	47.7	66.4	51.8	51.2	103.5	791.5
1885	68.3	93.1	49.5	63.2	80.1	62.5	24.5	61.2	127.1	147.6	98.5	42.0	917.6
1886	120.2	29.5	77.6	59.0	123.1	31.9	105.3	52.2	72.1	135.6	99.4	145.2	1050.9
1887	71.8	24.1	49.8	36.6	54.0	20.8	38.1	53.4	94.2	71.4	86.1	69.0	669.3
1888	39.0	38.9	97.2	49.8	35.7	73.9	156.6	86.3	34.2	43.5	150.1	73.1	878.4
1889	38.2	60.2	78.0	80.3	94.8	23.2	87.8	98.3	58.8	127.9	43.5	58.2	849.2
1890	106.3	29.0	61.0	44.5	68.1	79.8	87.1	97.5	45.3	56.2	117.2	34.4	826.3
1891	67.2	3.6	59.0	45.0	83.2	53.9	84.6	149.3	65.6	162.3	90.7	132.2	996.6
1892	53.5	58.1	29.5	38.0	60.9	80.5	67.4	100.5	87.5	131.6	69.2	52.5	829.4
1893	57.8	103.5	15.8	9.9	45.8	38.9	104.4	61.4	58.2	98.6	74.0	87.9	756.3
1894	89.0	85.8	56.1	55.0	65.8	72.8	102.4	88.7	50.1	120.8	114.2	79.4	980.2
1895	100.9	11.1	73.9	55.2	17.7	38.1	116.9	92.4	23.3	113.3	122.2	90.8	855.8
1896	36.0	24.4	99.6	30.4	12.0	69.5	52.5	62.6	160.7	113.0	40.7	137.3	838.7
1897	61.7	90.8	108.8	69.3	39.8	77.7	36.5	117.5	93.9	38.2	69.2	112.4	915.8
1898	40.6	51.8	40.1	57.9	88.9	55.9	25.2	85.1	27.8	117.5	87.5	92.1	770.3
1899	119.3	75.5	35.6	79.8	70.1	43.2	49.8	39.9	92.9	81.6	79.2	73.2	839.9
1900	118.0	131.7	30.7	43.7	46.6	85.2	48.1	112.0	31.8	104.6	99.2	123.6	975.2
1901	56.3	41.7	70.4	73.8	35.0	57.2	71.9	68.0	56.0	72.3	66.5	136.1	805.2
1902	44.9	44.4	54.2	45.8	72.5	71.5	57.1	93.7	48.5	78.2	75.2	71.6	757.5
1903	96.7	58.8	109.5	58.5	83.7	82.9	103.9	122.7	102.9	218.1	70.1	72.5	1180.2
1904	99.0	112.1	50.7	46.1	74.4	32.8	74.9	82.4	58.1	44.4	62.7	77.6	815.1
1905	38.8	36.3	102.4	72.4	22.5	81.5	37.4	105.4	57.0	67.1	111.9	31.8	764.5
1906	135.7	78.7	57.6	29.4	84.0	66.2	34.0	70.1	33.7	146.9	109.8	80.1	926.3
1907	38.5	46.8	43.2	81.3	91.4	91.0	67.3	73.9	22.6	152.6	78.0	112.5	899.0
1908	55.7	54.6	91.9	76.2	60.1	36.1	85.4	94.8	69.0	56.2	48.6	78.2	806.7
1909	46.3	26.8	106.5	64.3	45.8	84.6	91.7	79.0	77.6	141.6	33.0	135.4	932.6
1910	90.6	103.4	27.2	68.9	63.9	70.0	83.7	106.4	16.4	100.0	128.0	138.5	997.0
1911	39.5	62.0	57.9	46.8	37.2	79.1	15.8	54.9	64.2	95.9	116.2	169.6	839.0
1912	107.2	60.9	118.4	9.0	56.6	122.4	94.4	192.9	50.0	98.7	76.3	111.8	1098.7
1913	124.4	34.0	106.8	98.2	68.6	39.9	32.6	41.9	65.6	105.5	96.7	54.2	868.4
1914	48.6	82.1	119.7	37.0	47.9	61.8	94.2	61.5	48.5	68.9	109.5	190.8	970.5

England and Wales area-average precipitation amount

P.D. Jones, T.M.L. Wigley, and J.M. Gregory (continued)

ENGLAND AND WALES

Area-Average Precipitation Amount, 1766–1991 (continued)

Year	Precipitation (mm)												
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
1915	108.7	123.5	35.4	35.7	69.8	35.0	126.0	76.7	47.0	72.7	75.0	184.9	990.4
1916	56.6	132.0	107.1	47.4	71.7	70.4	55.4	88.8	51.9	138.9	111.9	95.9	1027.7
1917	58.4	31.9	68.4	54.3	60.7	65.8	65.1	172.0	55.5	129.6	60.3	41.1	863.1
1918	91.2	61.6	36.7	63.3	58.5	30.9	110.0	62.9	189.5	69.1	66.3	122.5	962.6
1919	122.4	79.0	120.0	66.3	25.4	36.5	57.9	79.0	52.4	62.3	77.8	146.7	925.7
1920	108.3	43.0	82.0	116.5	74.6	66.9	132.4	50.6	71.1	70.9	44.9	92.1	953.4
1921	107.2	10.2	58.5	33.3	46.5	10.3	29.3	93.5	40.9	52.2	70.9	76.2	629.1
1922	109.4	89.7	68.0	82.3	34.0	40.4	126.3	100.3	79.4	33.4	48.7	116.4	928.4
1923	63.5	152.7	52.8	70.6	69.8	19.4	79.4	92.7	82.5	137.4	92.3	100.0	1013.1
1924	94.1	27.6	37.6	72.9	122.4	67.2	118.4	98.5	114.6	132.7	72.8	123.9	1082.7
1925	82.3	124.2	32.8	74.2	96.5	4.3	81.3	91.0	98.6	106.7	76.6	98.8	967.3
1926	114.1	80.3	24.5	65.2	69.3	81.1	76.2	66.0	58.1	87.6	157.9	24.5	904.9
1927	94.7	80.5	89.0	59.2	37.8	101.3	96.0	139.5	154.0	70.8	101.9	83.5	1108.1
1928	160.3	76.3	78.6	39.2	40.0	97.0	60.3	95.2	29.8	144.4	112.1	90.0	1023.0
1929	49.1	31.5	8.0	34.9	62.6	46.7	66.4	71.8	23.6	124.3	195.9	179.0	893.8
1930	125.1	26.1	65.3	71.0	62.0	33.1	109.1	104.4	110.8	92.4	128.1	97.5	1024.8
1931	79.6	79.1	26.0	93.8	93.6	93.2	108.4	116.8	78.0	32.1	135.6	45.8	981.8
1932	90.0	8.9	59.7	83.0	129.6	35.6	99.9	48.8	94.0	162.2	61.1	49.9	922.5
1933	66.9	95.8	75.0	36.8	55.8	56.6	63.7	33.3	60.6	98.3	46.3	28.6	717.7
1934	78.2	11.9	72.2	75.2	39.6	48.4	45.7	79.1	70.2	82.4	63.4	183.5	849.8
1935	42.3	102.5	25.4	101.6	37.2	96.2	27.2	65.1	137.2	135.2	151.6	93.6	1015.3
1936	124.5	71.9	58.2	54.5	30.8	99.5	138.0	28.3	90.8	60.8	107.3	91.0	955.7
1937	129.0	142.1	89.5	81.3	77.5	42.1	63.8	42.8	62.8	81.2	51.0	98.5	961.7
1938	114.5	33.0	16.5	7.1	71.8	54.9	80.9	90.0	60.2	134.4	120.5	108.6	892.5
1939	156.2	54.1	57.2	68.8	32.7	63.1	118.7	78.4	31.7	124.5	162.1	60.5	1007.8
1940	73.5	75.5	79.9	61.3	41.4	20.9	112.5	15.0	48.6	108.7	196.5	73.1	906.9
1941	90.5	100.9	90.9	42.0	63.6	36.2	74.8	126.7	20.4	79.2	84.4	57.1	866.7
1942	106.8	28.8	65.9	43.1	105.6	21.0	75.7	86.3	66.3	100.4	41.9	98.3	840.1
1943	147.1	46.9	26.1	37.5	84.4	59.0	55.9	83.7	85.7	85.2	68.5	52.2	832.3
1944	82.4	39.4	11.5	58.8	41.1	61.6	70.2	81.1	104.4	118.0	155.2	70.3	894.0
1945	82.3	80.3	32.5	43.5	83.2	83.1	81.4	70.8	64.6	106.2	17.0	102.3	847.2
1946	85.8	89.1	37.6	45.4	78.8	85.9	73.7	138.1	125.1	40.2	158.1	94.4	1052.1
1947	82.5	58.3	177.5	77.5	58.8	66.6	65.4	14.4	46.6	22.2	81.3	81.7	832.8
1948	176.7	49.9	34.9	53.8	72.7	91.2	45.2	122.8	72.5	77.3	55.8	110.2	963.0
1949	42.3	40.6	42.8	63.4	68.2	18.1	50.6	53.1	47.1	162.0	111.4	89.8	789.6
1950	38.9	143.6	39.3	72.3	56.8	45.7	105.6	121.2	126.7	41.0	152.3	71.5	1014.9
1951	98.9	114.1	116.1	73.0	80.3	36.8	52.7	131.2	81.5	33.2	180.4	96.4	1094.6
1952	86.9	25.7	77.0	60.8	66.0	55.0	34.7	104.1	95.3	107.3	100.5	88.0	901.5
1953	31.8	50.5	30.1	72.8	62.0	66.4	98.9	84.6	83.2	71.4	68.9	34.5	755.0
1954	63.0	81.6	76.5	16.1	80.4	94.2	88.8	123.7	96.5	117.6	163.9	90.2	1092.6
1955	84.9	64.0	53.9	32.1	104.1	84.7	26.1	27.0	52.2	75.7	58.7	110.0	773.2
1956	123.1	25.6	31.7	42.9	21.8	71.1	101.3	158.5	92.5	56.5	33.3	106.9	865.3
1957	74.5	100.7	72.1	9.7	44.8	51.8	104.0	109.2	121.6	73.6	65.1	76.8	903.9
1958	99.9	116.0	49.9	30.8	85.2	110.9	95.7	102.9	120.6	82.3	58.6	104.6	1057.5
1959	104.5	8.7	70.3	78.9	27.6	46.7	69.6	38.0	8.0	90.7	119.8	164.9	827.8
1960	125.3	84.0	52.4	46.6	47.7	51.9	119.7	111.4	117.8	171.0	149.8	117.2	1194.9
1961	118.9	73.7	15.6	98.9	39.0	39.5	67.6	85.2	80.1	117.9	62.7	106.1	905.2
1962	114.0	37.1	46.5	72.9	64.3	17.8	59.2	109.0	106.9	38.0	69.7	78.4	813.8
1963	31.9	34.9	101.6	80.0	49.5	84.9	54.9	111.3	71.6	61.4	165.8	30.1	877.9
1964	26.4	32.4	98.0	68.6	59.5	77.9	49.7	54.4	34.2	62.1	62.3	99.8	725.4

Precipitation

England and Wales area-average precipitation amount

P.D. Jones, T.M.L. Wigley, and J.M. Gregory (continued)

ENGLAND AND WALES

Area-Average Precipitation Amount, 1766–1991 (continued)

Year	Precipitation (mm)												Ann
	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	
1965	104.8	16.4	75.4	61.7	67.5	74.1	97.4	75.2	138.3	34.0	114.2	173.1	1032.0
1966	60.4	129.6	34.7	111.5	69.4	88.0	73.7	112.1	55.7	129.5	78.9	117.6	1061.1
1967	62.1	92.2	55.9	47.6	140.8	41.3	66.7	77.3	102.6	171.9	73.2	78.5	1010.0
1968	85.8	47.6	59.5	68.8	78.7	94.0	107.8	72.2	148.1	99.0	69.6	84.2	1015.4
1969	101.5	69.0	79.4	57.0	115.8	51.3	70.3	76.5	41.3	17.5	138.3	87.1	905.1
1970	109.9	90.6	64.2	88.7	24.2	40.7	73.8	80.1	67.7	61.9	178.7	53.9	934.4
1971	112.5	35.0	69.0	55.0	51.5	110.7	44.4	111.6	26.3	77.2	93.6	37.6	824.5
1972	100.8	75.6	75.4	69.4	75.0	71.8	53.1	35.5	41.5	33.7	108.1	113.5	853.4
1973	46.1	45.8	23.0	67.6	86.1	61.5	93.5	63.8	75.5	57.5	50.9	68.6	739.8
1974	120.6	105.9	46.6	14.3	40.7	70.4	72.5	99.8	152.6	92.2	133.1	79.7	1028.3
1975	124.2	32.5	81.9	67.9	50.5	22.1	62.5	51.6	106.5	37.9	73.2	48.0	758.6
1976	57.8	39.9	48.0	19.0	62.1	18.7	30.0	25.2	150.8	154.3	91.7	94.0	791.4
1977	102.8	143.2	75.6	52.6	51.0	84.5	23.7	107.3	40.6	70.6	110.1	97.4	959.4
1978	113.1	86.1	84.7	54.4	47.6	62.1	83.9	63.5	55.3	17.2	56.2	172.8	896.8
1979	89.6	72.7	127.0	70.0	119.1	38.8	34.2	91.0	39.8	88.3	93.7	159.1	1023.3
1980	75.4	92.0	102.3	17.5	32.6	123.3	75.8	88.9	61.9	131.2	91.1	75.2	967.0
1981	57.9	52.0	160.4	59.4	90.0	44.4	53.3	43.6	139.9	130.2	67.2	93.5	991.8
1982	76.1	45.9	104.0	25.4	45.8	129.1	33.9	87.9	81.3	121.7	128.4	109.9	989.4
1983	102.3	40.4	64.1	110.6	115.2	38.3	39.2	33.3	100.8	79.9	53.2	108.1	885.4
1984	149.3	60.1	64.8	10.8	64.8	42.8	28.6	56.6	121.4	99.9	151.6	79.0	929.5
1985	75.3	31.6	66.4	67.7	68.5	101.7	77.2	114.1	45.9	46.7	72.9	124.9	892.8
1986	127.6	19.9	83.4	86.8	87.6	45.0	55.1	118.3	28.6	97.7	120.8	142.4	1013.2
1987	34.0	59.7	93.0	69.3	49.0	109.1	73.2	68.7	66.4	180.2	82.4	59.8	944.8
1988	169.0	64.6	107.3	44.6	65.8	40.2	139.0	89.0	71.9	94.2	50.2	45.7	981.5
1989	49.4	90.6	96.1	88.3	20.7	57.6	38.6	59.4	41.6	103.0	62.7	149.3	857.3
1990	128.2	143.0	22.5	39.6	23.2	73.7	35.5	47.9	53.5	108.5	68.7	96.3	840.6
1991	97.3	64.2	74.2	70.7	13.6	102.8	70.5	27.7	64.7	72.0	93.3	49.2	800.3

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England and Wales area-average precipitation amount

P.D. Jones, T.M.L. Wigley, and J.M. Gregory (continued)

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APPENDICES

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Appendix A

CARBON DIOXIDE INFORMATION ANALYSIS CENTER

The Carbon Dioxide Information Analysis Center (CDIAC) was established in 1982 to provide data and information to the U.S. Department of Energy's Global Change Research Program. In 1992, CDIAC was designated the World Data Center-A for Atmospheric Trace Gases, a component of the World Data Center System of the International Council of Scientific Unions. CDIAC, in cooperation with the ORNL Central Research Library, also serves as a Regional Information Center for the International Geosphere-Biosphere Programme. CDIAC attends to the broad, multidisciplinary data and information needs of a worldwide community of researchers, policymakers, managers, administrators, educators, and others concerned with issues related to global environmental change.

The primary focus of CDIAC is the production and distribution of numeric data packages (NDPs) and Data Bases (DBs). CDIAC has produced approximately 50 NDPs, which are quality-assured and documented data bases on various global change topics. CDIAC now offers eight DBs, which are similar to NDPs but are distributed in digitized form only. CDIAC's NDPs and DBs cover a wide variety of data, including long-term temperature and precipitation records, atmospheric and oceanic concentrations of carbon dioxide and other greenhouse gases, distribution of ecosystem complexes, intensity and frequency of occurrence of storms, vulnerability of coastal regions to rising sea level, and effects of elevated atmospheric carbon dioxide levels on plant growth.

In addition to evaluating data and producing NDPs and DBs, CDIAC distributes CO₂-related reports and computer model packages. CDIAC also produces the newsletters *CDIAC Communications* and *ARM Outreach*, a newsletter for DOE's Atmospheric Radiation Measurement (ARM) Program. Other CDIAC publications include: *Catalog of Data Bases and Reports*; *Catalog of Numeric Data Packages and Computer Model Packages*; *Glossary: Carbon Dioxide and Climate*; *Selected Translated Abstracts of Russian-Language Climate-Change Publications, Vol. I. Surface Energy Balance, Vol. II. Clouds*; and the *DOE Research Summary* (a periodic 4-page synopsis highlighting DOE-sponsored research projects).

Since 1985, CDIAC staff have responded to approximately 45,000 requests for information and distributed nearly 100,000 reports and other documents to more than 150 countries. CDIAC staff are available to discuss both general and technical aspects of issues related to the carbon-cycle; carbon dioxide, methane, and other trace gas emissions; and other climate change topics, including data and information management issues. For further information about CDIAC's services or to obtain any publications or information products listed above, complete and return the order form in Appendix B to:

Carbon Dioxide Information Analysis Center
Oak Ridge National Laboratory
Building 1000, MS-6335
P.O. Box 2008
Oak Ridge, TN 37831-6335
(615) 574-3645
(615) 574-2232 FAX
BITNET: CDP@ORNLSTC
OMNET: CDIAC
INTERNET: CDP@ORNL.GOV

Appendix B

NUMERIC DATA PACKAGES AND SELECT DATA BASES SUPPORTING *TRENDS* '93

This appendix presents detailed descriptions of data sets, referred to as CDIAC Numeric Data Packages (NDPs) and Data Bases (DBs), which complement the data presented in *Trends* '93. To order these NDPs and DBs or to inquire about other CDIAC information products, please use the form provided at the end of this appendix. Complete the order form and return it to CDIAC. If you have any questions about the availability of these NDPs or DBs, you may contact CDIAC by phone or FAX or through any of the telecommunication networks listed below:

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An increasingly popular way to obtain data from CDIAC is by accessing our anonymous FTP area. This requires a computer with access to the Internet. A sampling of commands used to obtain *Trends* '93 CO₂ data from CDIAC's anonymous FTP area is shown below. CDIAC FTP server responses are shown in italics. For a full description of user commands, contact CDIAC.

```
>ftp cdiac.esd.ornl.gov
Name: anonymous
Password: YOU@your e-mail address
Guest login ok, access restrictions apply.
ftp> cd /pub/trends93
ftp> dir
ftp> cd co2
ftp> get maunaloa.018.Z
ftp> quit
ftp> Goodbye
```

Atmospheric CO₂ Concentrations—Mauna Loa Observatory, Hawaii, 1958–1993. C.D. Keeling, Scripps Institution of Oceanography. CDIAC NDP-001/R4 (Rev. 1994)

Since 1958, air samples have been continuously collected at Mauna Loa Observatory and analyzed by infrared spectroscopy for CO₂ concentrations. Data are averaged to provide monthly and annual atmospheric CO₂ concentrations.

These data represent the longest continuous record of atmospheric CO₂ concentrations in the world. This precise data record covers a single site, Mauna Loa Observatory, Hawaii, which is a reliable indicator of the regional trend in the concentration of atmospheric CO₂ in the middle layers of the troposphere and thus is critical to CO₂-related research. The data are in one file (3.5 kB).

Global Surface-Air Temperature Variations: 1851–1984. P.D. Jones, S.C.B. Raper, P.M. Kelly, and T.M.L. Wigley, University of East Anglia. CDIAC NDP-003/R1 (Rev. 1986)

Anomalies in monthly and annual surface-air temperatures in relation to the 1951–1970 mean surface-air temperature were calculated for several periods: 1851–1984 for the Northern Hemisphere; 1858–1984 for the Southern Hemisphere, excluding Antarctica; and 1958–1984 for the Southern Hemisphere, including Antarctica. These estimates are derived from land-based meteorological station data and fixed-position weather-ship data interpolated onto a 5° latitude by 10° longitude grid. The data are in three files, one for the anomalies in Northern Hemisphere temperatures (10 kB) and two for the anomalies in Southern Hemisphere temperatures (9 kB and 2 kB).

Atmospheric CO₂ Concentrations—The NOAA/GMCC Flask Sampling Network. T. J. Conway and P. Tans, National Oceanic

and Atmospheric Administration. CDIAC NDP-005/R2 (Rev. 1994)

Flask air samples are collected approximately once per week at 36 stations scattered around the globe and on merchant vessels crossing the Pacific Ocean. The earliest samples were taken in 1968, but the period of record varies from station to station. Most records are complete through 1992. The samples are analyzed for atmospheric CO₂ concentration on a nondispersive infrared gas analyzer apparatus at the NOAA/CMDL laboratory in Boulder, Colorado. The measurements are directly traceable to the primary CO₂ standards of the World Meteorological Organization. Each sample is characterized by station, year, sampling date and time, flask identification number, CO₂ concentration, date and time of analysis, and quality indicators. Separate files are provided for each site and Pacific Ocean latitude band. The largest single file is 331 kB.

Production of CO₂ from Fossil-Fuel Burning. R.M. Rotty and G. Marland, Oak Ridge Associated Universities. CDIAC NDP-006 (1984)

Global CO₂ emissions for 1950 through 1982 were estimated by Marland and Rotty from fuel-production data from the U.N. *Energy Statistics Yearbook* (1983, 1984). Data before 1950 came from C.D. Keeling. Fuel-production data were used in these calculations because they appeared to be more reliable on a global basis than fuel-consumption data. The data given are the year and annual global CO₂ emissions (annual global total; cumulative global total since 1860; and annual global emissions from solid fuels, liquid fuels, natural gas, gas flaring, and cement manufacturing). These data provide the only pre-1950 estimates of the amount of carbon emitted to the atmosphere from fossil-fuel burning. The CO₂ emission record since 1950 has been updated and

revised several times, with the most recent estimates published by Marland et al. The data are in one file (7.5 kB).

Atmospheric CO₂ Concentrations—The CSIRO (Australia) Monitoring Program from Aircraft for 1972–1981.

D.J. Beardsmore and G.I. Pearman, Commonwealth Scientific and Industrial Research Organisation. CDIAC NDP-007 (1984)

From 1972 through 1981, air samples were collected in glass flasks from aircraft at a variety of latitudes and altitudes over Australia, New Zealand, and Antarctica. The samples were analyzed for CO₂ concentrations by using a nondispersive infrared gas analysis. The resulting data contain the sampling dates, type of aircraft, flight number, flask identification number, sampling time, geographic sector, distance in kilometers from the listed distance measuring equipment station, station number of the radio navigation distance measuring equipment, altitude of the aircraft above mean sea level, sample analysis date, flask pressure, tertiary standards used for the analysis, type of analyzer used, and CO₂ concentration. These data represent the first published record of CO₂ concentrations in the Southern Hemisphere expressed in the 1981 CO₂ Calibration Scale of the World Meteorological Organization and provide a precise record of atmospheric CO₂ concentrations in the troposphere and lower stratosphere over Australia and New Zealand. The data are in one file (263 kB).

Annual and Seasonal Global Temperature Anomalies in the Troposphere and Low Stratosphere, 1958–1992. J.K. Angell and J. Korshover, National Oceanic and Atmospheric Administration. CDIAC NDP-008/R3 (Rev. 1993)

For 1958 through 1992, anomalies in annual and seasonal temperatures in relation to a 1958–1977 mean (expressed in degrees

Celsius) were calculated for the surface, troposphere (850–300 mb), tropopause (300–100 mb), and low stratosphere (100–50 mb and 100–30 mb) layers on the basis of region, hemispheres, and the globe. Most of the values are column-mean temperatures obtained from the differences in the heights of constant-pressure surfaces at individual radiosonde stations. The pressure-height data before 1980 were obtained from published values in *Monthly Climatic Data for the World*. These temperature anomalies may be used to analyze long-term temperature trends for a layer of the atmosphere (i.e., surface, troposphere, tropopause, and low stratosphere), a region (i.e., polar, temperate, subtropical, and equatorial regions), a hemisphere, or the globe. Eleven data files are provided, each 8 kB in size.

Atmospheric CO₂ Concentrations —The CSIRO Monitoring Program: Surface Data for Cape Grim, Tasmania.

D.J. Beardsmore, G.I. Pearman, and R.C. O'Brien, Commonwealth Scientific and Industrial Research Organisation. CDIAC NDP-010 (1985)

From 1976 through 1983, air samples collected from a high-volume general intake 10 m above the roof of the laboratory at Cape Grim, Tasmania, were dried and analyzed for CO₂ concentrations with a nondispersive infrared gas analyzer. This baseline CO₂ record from Cape Grim indicates that the CO₂ concentrations in large maritime air masses are devoid of vegetative influences in this region of the Southern Hemisphere. The data available on each sample are sampling date; daily, monthly, and annual CO₂ concentrations; standard deviation associated with each concentration; number of hours of data used to calculate the CO₂ values; and the analyzer used. The data are in three files: daily (17 kB), monthly (3 kB), and annual (310 B).

United States Historical Climatology Network (HCN) Serial Temperature and Precipitation Data. T.R. Karl, C.N. Williams, Jr., and F.T. Quinlan, National Oceanic and Atmospheric Administration. CDIAC NDP-019/R1 (Rev. 1990)

Extending through 1987, this data base contains information on monthly total precipitation and temperatures from 1219 stations in the contiguous United States. To be included in the Historical Climatology Network (HCN), a station had to be currently active (1987), have at least 80 years of monthly temperature and precipitation data, and have experienced few station changes. These data were derived from a variety of sources, including the National Climatic Data Center archives, state climatologists, and published literature. The data base contains several hundred variables, including state number, station number, monthly temperatures (minimum, maximum, and mean), total monthly precipitation, and time of observation. This is probably the best monthly temperature and precipitation data set available for the contiguous United States because station moves, instrument changes, urbanization effects, and time-of-observation differences have been considered and, where necessary, the data have been corrected. The data are in 13 files (one station inventory file, one station history file, six temperature files, one precipitation file, one time-of-observation correction file, and two quality-assessment files). The file sizes range from 5 kB to ~50 MB and are available on nine-track magnetic tape only.

An Updated Global Grid Point Surface Air Temperature Anomaly Data Set: 1851–1990. P.D. Jones, S.C.B. Raper, B.S.G. Cherry, C.M. Goodess, T.M.L. Wigley, B. Santer, P.M. Kelly, University of East Anglia; R.S. Bradley, University of Massachusetts; and H.F. Diaz, National

Oceanic and Atmospheric Administration, Environmental Research Laboratories. CDIAC NDP-020/R1 (1991).

This data set contains land-based monthly surface air temperature anomalies (departures from a 1951–1970 reference period mean) on a 5° latitude by 10° longitude global grid. Monthly surface air temperature anomalies (departures from a 1957–1975 reference period mean) for the Antarctic (grid points from 65°S to 85°S) are presented in a similar way as a separate data set. The data were derived primarily from the *World Weather Records* and the archives of the United Kingdom Meteorological Office. This long-term record of temperature anomalies may be used in studies addressing possible greenhouse-gas-induced climate changes. To date, the data have been employed in generating regional, hemispheric, and global time series for determining whether recent (i.e., post-1900) warming trends have taken place.

This data set also presents the monthly mean temperature records for the individual stations that were used to generate the set of gridded anomalies. The periods of record vary by station. Northern Hemisphere station data have been corrected for inhomogeneities, whereas Southern Hemisphere data are presented in uncorrected form.

All data have been assessed for quality (gross accuracy and consistency, temporal variability, and spatial and temporal completeness of record) and for long-term homogeneity. Although the period of record extends from 1851 to 1990, few grid point locations have contributed data for the entire period of record. The data are in four files, two exceeding 20 MB in size and are available on nine-track magnetic tape only.

Global and Hemispheric Annual Temperature Variations between 1861 and 1991. P.D. Jones, T.M.L. Wigley, and P.B. Wright, University of East Anglia. CDIAC NDP-022/R2 (Rev. 1993)

This data set contains estimates of variation in global and hemispheric annual temperatures for 1861 through 1991 in relation to a 1950–1979 reference period. The estimates are based on corrected land and ocean data. Land data were derived from meteorological data and fixed-position weather-ship data that were corrected for nonclimatic errors, such as station shifts and/or instrument changes. The marine data were from the compilation of the Comprehensive Ocean-Atmosphere Data Set (COADS), which with updates extends to 1986. Updates to 1991 were made with hemispheric sea-surface temperature estimates produced by the U.K. Meteorological Office. Each record includes year and six annual temperature variations: one estimate each for the globe, the Northern Hemisphere, and the Southern Hemisphere and another estimate each that reflects an adjustment to account for the influence of El Niño/Southern Oscillation events. The data are in one file (5.8 kB).

Estimates of CO₂ Emissions from Fossil-Fuel Burning and Cement Manufacturing, Based on the U.N. Energy Statistics and the U.S. Bureau of Mines Cement Manufacturing Data. G. Marland, T.A. Boden, P. Kanciruk, S.F. Huang, and T.R. Nelson, Oak Ridge National Laboratory; R. C. Griffin, Kentucky Wesleyan College. CDIAC NDP-030/R4 (Rev. 1993)

For 1950 through 1990, global and national annual estimates of CO₂ emissions from fossil-fuel burning and cement production were calculated from energy statistics compiled by the U.N. Statistical Office and from cement-manufacturing data compiled by the U.S. Bureau of Mines. The resulting

data base contains the annual amounts of global CO₂ emissions and estimates of national CO₂ emissions for more than 200 countries. Among many variables, these data include total emissions; emissions from gas, liquid, and solid fuels; and emissions from cement production. The data are in six files (three for the U.N. statistics, one for the Bureau of Mines data, one for global CO₂ emission estimates, and one for the national CO₂ emission estimates) ranging in size from 427 bytes to 4.85 MB.

Atmospheric CO₂ Concentrations Derived from Flask Samples Collected at USSR-Operated Sampling Sites. A.M. Brounshtein, E.V. Faber, and A.A. Shashkov. Main Geophysical Observatory. CDIAC NDP-033 (1991).

This numeric data package presents daily atmospheric CO₂ concentrations from four U.S.S.R.-operated sampling sites (Teriberka Station, Ocean Station Charlie, Bering Island, and Kotelny Island). The period of record varies by station with the earliest measurements dating back to 1983 and recent estimates from early 1991. These CO₂ concentrations are derived from air samples collected in 1.5 liter stainless steel electropolished flasks and later analyzed at the Main Geophysical Observatory (Leningrad, U.S.S.R.) by using a nondispersive infrared gas analyzer. Measurements not meeting wind direction, wind speed, inter-flask agreement, and climate condition criteria were either discarded or flagged. All measurements have been corrected for drift biases introduced during flask storage.

These atmospheric CO₂ concentrations are considered indicative of regional background air conditions and are directly traceable to WMO primary CO₂ standards. These measurements support the rising trend in atmospheric CO₂ concentrations measured at other monitoring sites around the world and may be compared with

Appendix B

similar measurements made by various monitoring programs at other northern latitude sites. The data are presented in four files, one for each site, and range in size from 0.97 kB to 20.01 kB.

Atmospheric CO₂ Concentrations—The Canadian Background Air Pollution Monitoring Network. N.B.A. Trivett, Environment Canada. CDIAC NDP-034/R1 (Rev. 1993)

Flask air samples collected at roughly weekly intervals at three Canadian sites [Alert, Northwest Territories (July 1975 through August 1992); Sable Island, Nova Scotia (June 1975 through August 1992); and Cape St. James, British Columbia (May 1979 through August 1992)] were analyzed for CO₂ concentration with the measurements directly traceable to the primary CO₂ standards of the World Meteorological Organization (WMO). Each record includes the date, atmospheric CO₂ concentration, and flask classification code. They provide an accurate record of CO₂ concentrations in Canada during the past decade. Because these data are directly traceable to WMO standards, this record may be compared with records from other Background Air Pollution Monitoring Network stations. The data are in three files (one for each of the monitoring stations) ranging from 9.4 kB to 20.1 kB.

Atmospheric Halocarbons and Nitrous Oxide from the ALE/GAGE Network, 1978–1991. R.F. Prinn, Massachusetts Institute of Technology; R.F. Weiss, Scripps Institution of Oceanography; F.N. Alyea and D.M. Cunnold, Georgia Institute of Technology; P.J. Fraser and L.P. Steele, Commonwealth Scientific and Industrial Research Organisation; P.G. Simmonds, University of Bristol; A.J. Crawford and R.A. Rasmussen, Oregon Graduate Institute of Science and Technology; R.D. Rosen,

Atmospheric and Environmental Research, Inc. CDIAC DB-1001 (1994)

In the ALE/GAGE/AGAGE global network program, continuous high frequency gas chromatographic measurements of two biogenic/anthropogenic gases (methane, CH₄; nitrous oxide, N₂O) and five anthropogenic gases [chlorofluorocarbons CFCl₃ (CFC-11), CF₂Cl₂ (CFC-12), and CF₂ClCFCl₂ (CFC-113); methyl chloroform, CH₃CCl₃; carbon tetrachloride, CCl₄] are carried out at globally distributed sites. The program, which began in 1978, is conveniently divided into three parts associated with three changes in instrumentation: the Atmospheric Lifetime Experiment (ALE), which utilized Hewlett Packard HP5840 gas chromatographs; the Global Atmospheric Gases Experiment (GAGE), which utilizes HP5880 gas chromatographs; and the recently initiated Advanced GAGE (AGAGE), which uses a new fully automated system containing a custom-designed sample module and HP5890 and Carle Instruments gas chromatographic components. At the present time, data are available only from ALE and GAGE, for the gases CFC-11, CFC-12, methyl chloroform, carbon tetrachloride, and nitrous oxide. The current station locations are Cape Grim, Tasmania; Point Matatula, American Samoa; Ragged Point, Barbados; and Mace Head, Ireland. Stations also previously existed at Cape Meares, Oregon, and at Adrigole, Ireland. The current Mace Head station replaced the Adrigole station, and a station is planned at Trinidad Head, California, to replace Cape Meares.

The data for the complete set of ALE/GAGE measurements are contained in 771 separate files (395 files for ALE and 376 files for GAGE), ranging in size from 0.12 kB to 37.5 kB and totaling 13.0 MB.

Each file contains the data for all ALE or GAGE measurements for one month at a particular site. An additional 20 files, ranging in size from 5.1 kB to 12.3 kB and totaling 159 kB, contain monthly summary data covering the entire record period at each site. For each site and each experiment (i.e., ALE or GAGE), two sets of monthly summary data are available: in one set, averages encompass only those measurements not influenced by pollution events; in the second set, averages encompass all measurements made during a given month. The data and accompanying descriptive material are available in digitized form only; hardcopy documentation is not available.

Atmospheric Methane at Cape Meares, Oregon, U.S.A.: A High-Resolution Data Base for the Period 1979–1992. M.A.K. Khalil and R.A. Rasmussen, Oregon Graduate Institute of Science and Technology. CDIAC DB-1007 (1994)

The atmospheric monitoring facility at Cape Meares, Oregon, U.S.A., is operated by the Oregon Graduate Institute of Science and Technology and was the first station in the world to carry out continuous automated measurements of atmospheric methane. The Cape Meares data represent some 119,000 individual atmospheric methane measurements carried out during 1979–92. Analysis of ambient air, collected 12 to 72 times daily, was carried out by means of an automated sampling and measurement system, using the method of gas chromatography and flame ionization detection. Despite the long course of the record and the large number of individual measurements, these data may all be linked to a single absolute calibration standard.

The data are contained in three files. The largest file (2.14 MB) contains all individual atmospheric methane measurements, collected at Cape Meares over the period January 1979–January 1992. A second file (205 kB) contains daily average

concentrations of methane, sampling statistics, and interpolations for days when data were not taken. The last file (14 kB) contains monthly averages (derived from the daily data) and statistics of dispersion, calculated by three different methods: the arithmetic mean (along with 90% confidence limits), the median (along with 5th and 95th percentile values), and a middle value (also with accompanying 90% confidence limits) based on a non-parametric statistical method. The data and accompanying descriptive material are available in digitized form only; hardcopy documentation is not available.

Atmospheric Methane Mixing Ratios—The NOAA/CMDL Global Cooperative Air Sampling Network, 1983–1993. E.J. Dlugokencky, P.M. Lang, and K.A. Masarie, National Oceanic and Atmospheric Administration; L.P. Steele, Commonwealth Scientific and Industrial Research Organisation. CDIAC DB-1008 (1994)

This data base presents atmospheric methane (CH_4) mixing ratios from flask air samples collected over the period 1983–1993 by the National Oceanic and Atmospheric Administration Climate Monitoring and Diagnostics Laboratory's (NOAA/CMDL's) global cooperative air sampling network. Air samples were collected approximately once per week at 44 fixed sites (37 of which were still active at the end of 1993). Samples were also collected at 5° latitude intervals along shipboard cruise tracks in the Pacific Ocean between North America and New Zealand (or Australia) and at 3° latitude intervals along cruise tracks in the South China Sea between Singapore and Hong Kong. The shipboard measurements were made approximately every 3 weeks per latitude zone by each of two ships in the Pacific Ocean and approximately once every week per latitude zone in the South China Sea. All samples were analyzed for CH_4 at the NOAA/CMDL laboratory in Boulder,

Appendix B

Colorado, U.S.A., by gas chromatography with flame ionization detection, and each aliquot was referenced to the NOAA/CMDL methane standard scale.

In addition to providing the complete set of atmospheric CH₄ measurements from flask air samples collected at the NOAA/CMDL network sites, this data base also includes files which list monthly mean mixing ratios derived from the individual flask air measurements. These monthly summary data are available for 35 of the fixed sites and 21 of the shipboard sampling sites. (Shipboard sites are actually 3° or 5°

latitudinal bands where samples were collected at a minimum of two different longitudes.)

The data for the complete set of individual measurements are contained in 85 files, ranging in size from 2.7 kB to 187 kB and totaling 2.7 MB. An additional 56 files contain the monthly summary data; these files range in size from 0.32 kB to 2.8 kB and total 97 kB. The data and accompanying descriptive material are available in digitized form only; hardcopy documentation is not available.

Appendix B

☐ Please send the data presented in *Trends '93* on floppy diskette (check appropriate boxes below)

☐ Please send another copy of *Trends '93*

NDP/DB Number	Documentation Only	Documentation and Media*
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NDP-003/R1	☐	☐
NDP-005/R2	☐	☐
NDP-006	☐	☐
NDP-007	☐	☐
NDP-008/R3	☐	☐
NDP-010	☐	☐
NDP-019/R1	☐	☐
NDP-020/R1	☐	☐
NDP-022/R2	☐	☐
NDP-030/R4	☐	☐
NDP-033	☐	☐
NDP-034/R1	☐	☐
DB1001**		☐ **
DB1007**		☐ **
DB1008**		☐ **

Floppy diskette		9-Track magnetic tape			8mm tape
Size	Density	Density	Label	Character set	Capacity
☐ 5¼"	☐ High	☐ 1600 BPI	☐ Nonlabeled	☐ EBCDIC	☐ 8200 (2.3 GB)
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Appendix C

ACRONYMS, ABBREVIATIONS, AND CHEMICAL FORMULAS

A

A.D.	<i>anno Domini</i>
Al ₂ O ₃	alumina (aluminum oxide)
AOD	aerosol optical depth
Ann	annual
AES	Atmospheric Environment Service (Downsview, Ontario, Canada)
AFEAS	Alternative Fluorocarbons Environmental Acceptability Study
AFR	Africa
ALE	Atmospheric Lifetime Experiment
AMD	Developing America
Ar	argon
ASL	above sea level
ATF	atmospheric transmission factor
atm	atmosphere

B

BAPMoN	Background Air Pollution Monitoring Network (WMO)
BHD	designation of an ice core drilled in 1977 at Law Dome, Antarctica
BP	before present

C

C	Celsius
¹³ C	carbon-13 (carbon isotope with an atomic weight of 13)
¹⁴ C	carbon-14 (carbon isotope with an atomic weight of 14)
ca.	circa
CCl ₂ F ₂	dichlorodifluoromethane (CFC-12)
CCl ₃ F	fluorotrichloromethane (CFC-11)
CDIAC	Carbon Dioxide Information Analysis Center (Oak Ridge, Tennessee, U.S.A.)
CEA	Commissariat à l'Energie Atomique (France)
CFC	chlorofluorocarbon (as a family of chemical compounds)
CFC-11	chlorofluorocarbon-11 (CCl ₃ F, fluorotrichloromethane)
CFC-113	chlorofluorocarbon-113 (CCl ₂ FCClF ₂ ; 1,1,2-trichlorotrifluoroethane)
CFC-12	chlorofluorocarbon-12 (CCl ₂ F ₂ , dichlorodifluoromethane)
CH ₃ CCl ₃	methylchloroform (1,1,1-trichloroethane)
CH ₄	methane
CIRES	Cooperative Institute for Research in Environmental Sciences (Boulder, Colorado, U.S.A.)
cm	centimeter
cm ³	cubic centimeter (milliliter)
CMDL	Climate Monitoring and Diagnostics Laboratory (NOAA, Boulder, Colorado, U.S.A.)
CMP	computer model package
CNR	Comitato Nazionale per la Ricerca (ENEA, Rome, Italy)
CNRS	Centre National de la Recherche Scientifique (Paris, France)
CO	carbon monoxide

CO ₂	carbon dioxide
COADS	Comprehensive Ocean-Atmosphere Data Set
CPA	Centrally Planned Asia
CPE	Eastern Europe (also called Centrally Planned Europe)
CRE	Centro Ricerche Energia (ENEA, Rome, Italy)
CRU	Climatic Research Unit (University of East Anglia, Norwich, U.K.)
CSIR	Council for Scientific and Industrial Research (South Africa)
CSIRO	Commonwealth Scientific and Industrial Research Organisation (Aspendale, Australia)
CY	calendar year
D	
D	deuterium (also abbreviated ² D or ² H)
DE08	designation of an ice core drilled in 1987 at Law Dome, Antarctica
DOE	U.S. Department of Energy (Washington, D.C., U.S.A.)
DSIR	Department of Scientific and Industrial Research (Lower Hutt, New Zealand)
E	
EC	electron capture
ECMWF	European Centre for Medium-Range Weather Forecasts (Reading, U.K.)
EEC	European Economic Community
EEP	east equatorial Pacific
ENEA	Energia Nucleare e delle Energie Alternative (Italy)
ENSO	El Niño-Southern Oscillation
ESD	Environmental Sciences Division (Oak Ridge National Laboratory, Oak Ridge, Tennessee, U.S.A.)
F	
FEA	Far East
FID	flame ionization detector
FRG	Federal Republic of Germany
G	
g	gram
GAGE	Global Atmospheric Gases Experiment
GC	gas chromatograph (also, gas chromatography)
GDR	German Democratic Republic
GHz	gigahertz
GISS	Goddard Institute for Space Studies (New York, New York, U.S.A.)
GMCC	Geophysical Monitoring for Climate Change (now CMDL)
H	
H-1301	halon-1301 (CBrF ₃ , bromotrifluoromethane)
H-1211	halon-1211 (CBrClF ₂ , bromochlorodifluoromethane)
HCCD	Historical Canadian Climate Database
HCFC-22	hydrochlorofluorocarbon-22 (CHClF ₂ , chlorodifluoromethane)
HCN	Historical Climatology Network

H ₂ O ₂	hydrogen peroxide
HP	Hewlett Packard (gas chromatograph manufacturer)
I	
IFU	Fraunhofer Institute for Atmospheric Environmental Research (Garmisch-Partenkirchen, Germany)
INSTARR	Institute of Arctic and Alpine Research (Boulder, Colorado, U.S.A.)
IOS	Institute for Ocean Science (Sidney, British Columbia, Canada)
ITCZ	Intertropical Convergence Zone
K	
K	Kelvin
kg	kilogram
km	kilometer
kPa	kilopascal
kyr	kiloyear
L	
L	liter
M	
m	meter
MAT	marine air temperature
mb	millibar
MDE	Middle East
MGO	Main Geophysical Observatory (St. Petersburg, Russia)
min	minute
mL	milliliter
MLO	Mauna Loa Observatory (Hawaii, U.S.A.)
mm	millimeter
MS	mass spectrometry
MSL	mean sea level
MSU	microwave sounding unit
N	
N ₂	nitrogen
NAM	North America
NASA	National Aeronautics and Space Administration (U.S.A.)
NBS	National Bureau of Standards (now NIST)
NCAR	National Center for Atmospheric Research (Boulder, Colorado, U.S.A.)
NCDC	National Climatic Data Center (Asheville, North Carolina, U.S.A.)
NDIR	nondispersive infrared gas analyzer
NDP	numeric data package
NIST	National Institute of Standards and Technology (Gaithersburg, Maryland, U.S.A.)
nm	nanometer
NMC	National Meteorological Center (Camp Springs, Maryland, U.S.A.)

Appendix C

N ₂ O	nitrous oxide
NOAA	National Oceanic and Atmospheric Administration (U.S.A.)
NO _x	oxides of nitrogen [generic: includes NO (nitric oxide) and NO ₂ (nitrogen dioxide)]
NSF	National Science Foundation (U.S.A.)
O	
O ₂	oxygen
O ₃	ozone
¹⁸ O	oxygen-18 (oxygen isotope with an atomic weight of 18)
OCN	Oceania
OGC	Oregon Graduate Center (now OGIST)
OGI	Oregon Graduate Institute (now OGIST)
OGIST	Oregon Graduate Institute of Science and Technology (Portland, Oregon, U.S.A.)
ORNL	Oak Ridge National Laboratory (Oak Ridge, Tennessee, U.S.A.)
P	
P	significance level (statistical)
Pa	pascal
PDB	Pee Dee belemnite (used as an isotopic standard)
ppb	parts per billion (1×10^9)
ppbv	parts per billion (1×10^9) by volume
ppm	parts per million (1×10^6)
ppmv	parts per million (1×10^6) by volume
ppt	parts per trillion (1×10^{12})
PRC	Peoples Republic of China
psi	pounds per square inch
Q	
QBO	quasi-biennial oscillation
R	
R ²	coefficient of determination (statistical)
RAI	Rainfall Anomaly Index
S	
SIO	Scripps Institution of Oceanography (La Jolla, California, U.S.A.)
SOI	Southern Oscillation Index
SPO	South Pole Observatory (Antarctica)
SRM	standard reference material
SST	sea surface temperature
SY	seasonal year

T

TAAF
TIROS

Terres Australes et Antarctiques Françaises (France)
Topographic Infrared Operations Satellite

U

UBA
UCAR
U.K.
U.N.
UNEP
U.S.A.
U.S.S.R.
UV

Umweltbundesamt (Offenbach/Main, Germany)
University Corporation for Atmospheric Research (Boulder, Colorado, U.S.A.)
United Kingdom
United Nations
United Nations Environment Programme
United States of America
Union of Soviet Socialist Republics
ultraviolet

W

WDCGG
WEU
WMO

World Data Center for Greenhouse Gases (WMO, Tokyo)
Western Europe
World Meteorological Organization (Geneva, Switzerland)

Y

yr

year

$\delta^{13}\text{C}$

deviation from standard $^{13}\text{C}:^{12}\text{C}$ ratio

δD

deviation from standard $^2\text{H}:^1\text{H}$ ratio

$\delta^{18}\text{O}$

deviation from standard $^{18}\text{O}:^{16}\text{O}$ ratio

$\Delta^{14}\text{C}$

deviation from standard ^{14}C activity

μm

micrometer

%

percent (per hundred)

‰

per mil (per thousand)

σ

standard deviation (statistical)

Σ

summation

τ

period (of an oscillation)

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	Carbon Dioxide	Methane	Other Trace Gases and Atmospheric Aerosols	CO ₂ Emissions	Temperature	Precipitation
AFRICA	---	---	---	531-33	---	952-62, 964-73
South Africa	---	---	---	566-67	---	---
Cape Point	---	352-56	---	---	---	---
African Regions						
East Africa	---	---	---	---	---	969-70
Eastern and South- eastern Africa	---	---	---	---	---	958-61
Sahel	---	---	---	---	---	966-68
Southwestern Africa	---	---	---	---	---	971-72
West Africa	---	---	---	---	---	954-57
ANTARCTICA						
Amundsen Scott (see South Pole)						
Byrd Station	---	234-38, 239-43	380-84, 385-89	---	---	---
Halley Bay	72-73	304-05	---	---	---	---
Law Dome	---	256-60	391-94	---	---	---
Palmer Station	94-95	328-29	---	---	---	---
Siple Station	11-14	251-54	---	---	---	---
South Pole	17, 24-25, 30, 37-38, 104-05	340-41	465-69, 492-93	---	---	---
Syowa Station	110-11	344-45	---	---	---	---
Vostok	7-10	229-32	---	---	590-602	---
ASIA						
India	---	---	---	550-51	---	---
Iran	---	---	---	574-76	---	---
Japan	---	---	---	543-44	---	---
Syowa Station	110-11	344-45	---	---	---	---
Mongolia						
Ulaan Uul	114-15	---	---	---	---	---
North Korea	---	---	---	572-73	---	---
Peoples Republic of China	---	---	---	540-42	---	---
Qinghai Province	96-97	330-31	---	---	---	---
Republic of Uzbekistan						
Kyzylcha	186-87	---	---	---	---	---
Russia						
Bering Island	182-83	---	---	---	---	---
Kotelny Island	184-85	---	---	---	---	---

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	Carbon Dioxide	Methane	Other Trace Gases and Atmospheric Aerosols	CO ₂ Emissions	Temperature	Precipitation
ASIA						
Russia (continued)						
Station "C"	188-89	---	---	---	---	---
Teriberka Station	190-91	---	---	---	---	---
Vostok	7-10	229-32	---	---	590-602	---
Saudi Arabia	---	---	---	581-83	---	---
South Korea	---	---	---	568-69	---	---
Tae-ahn Peninsula	112-13	346-47	---	---	---	---
Asian Regions						
Centrally Planned Asia	---	---	---	518-19	---	---
East Asia	---	---	---	---	---	911-17
Far East	---	---	---	520-22	---	---
Former U.S.S.R.	---	---	---	537-39	---	906-10
Middle East	---	---	---	525-27	---	---
ATLANTIC OCEAN						
Ascension Island	48-49	280-81	---	---	---	---
Azores	50-51	282-83	---	---	---	---
Bermuda (East)	56-57	288-89	---	---	---	---
Bermuda (West)	58-59	290-91	---	---	---	---
Canary Islands						
Izaña	74-75	306-07	---	---	---	---
Greenland						
Camp Century	---	239-43	385-89	---	---	---
Crête	---	239-43	385-89	---	---	---
Dye 3	---	234-38	380-84	---	---	---
Summit	---	244-49	---	---	---	---
South Georgia Island	---	338-39	---	---	---	---
Station "C"	106-07,188-89	---	---	---	---	---
Station "M"	108-09	342-43	---	---	---	---
Terceira Island (see Azores)						
Caribbean Islands						
Barbados	52-53	284-85	401-04	---	---	---
Ragged Point (see Barbados)						
St. Croix (see Virgin Islands)						
Virgin Islands	116-17	348-49	---	---	---	---
AUSTRALIA						
Albany (South Coast of Western Australia)	---	---	---	570-71	---	918-50
Brownlow Post Office (South Australia)	---	---	---	---	---	941-43
Brownlow Post Office (South Australia)	---	---	---	---	---	929-31

	Carbon Dioxide	Methane	Other Trace Gases and Atmospheric Aerosols	CO ₂ Emissions	Temperature	Precipitation
AUSTRALIA (continued)						
Canary Island (Victoria)	---	---	---	---	---	944-46
Carrick (Tasmania)	---	---	---	---	---	932-34
Dowerin (Western Australia)	---	---	---	---	---	923-25
Gatton-Lawes (Southeastern Queensland)	---	---	---	---	---	926-28
Leura Post Office (Eastern New South Wales)	---	---	---	---	---	920-22
Mount Barker (SW Western Australia)	---	---	---	---	---	938-40
Peak Hill Post Office (Inland New South Wales)	---	---	---	---	---	947-49
Tasmania						
Cape Grim	60-61	292-93	405-08, 445-48	---	---	---
Winton Post Office (Northeastern Australia)	---	---	---	---	---	935-37
CENTRAL AMERICA	---	---	---	528-30	---	---
EUROPE						
Austria						
Vermunt	213-21	---	---	---	---	---
Denmark						
Greenland (see GREENLAND)						
France	---	---	---	559-61	---	---
Amsterdam Island	46-47, 131-34	278-79	---	---	---	---
Germany (see also Pre-1991 FRG & Former GDR)	---	---	---	545-47	---	---
Brotjacklriegel	136-37	---	---	---	---	---
Deuselbach	138-39	---	---	---	---	---
Garmisch-Partenkirchen	148, 150-51	---	---	---	---	---
Osnabrück	157-60	---	---	---	---	---
Schauinsland	140-41, 204-12	---	---	---	---	---
Waldhof	142-43	---	---	---	---	---
Wank Peak	148, 152-53	---	---	---	---	---
Westerland	144-45	---	---	---	---	---
Zugspitze	149, 154-55	---	---	---	---	---
Pre-1991 FRG	---	---	---	549	---	---
Former GDR	---	---	---	548	---	---
Hungary						
K-Pusztá	161-64	---	---	---	---	---

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	Carbon Dioxide	Methane	Other Trace Gases and Atmospheric Aerosols	CO ₂ Emissions	Temperature	Precipitation
EUROPE (continued)						
Ireland						
Adrigole	---	---	398-400	---	---	---
Mace Head	78-79	310-11	413-15	---	---	---
Italy	---	---	---	557-58	---	---
Lampedusa Island	165-68	357-60	---	---	---	---
Mt. Cimone	169-72	---	---	---	---	---
Mediterranean Sea						
Lampedusa Island	165-68	357-60	---	---	---	---
Poland	---	---	---	564-65	---	---
Spain	---	---	---	577-78	---	---
Izaña	74-75	306-07	---	---	---	---
United Kingdom	---	---	---	552-53	---	---
Ascension Island	48-49	280-81	---	---	---	---
Bermuda (East)	56-57	288-89	---	---	---	---
Bermuda (West)	58-59	290-91	---	---	---	---
England and Wales	---	---	---	---	---	975-83
European Regions						
Central Europe	203-21	---	---	---	---	---
Eastern Europe	---	---	---	512-14	---	---
Western Europe	---	---	---	515-17	---	---
GREENLAND						
Camp Century	---	239-43	385-89	---	---	---
Crête	---	239-43	385-89	---	---	---
Dye 3	---	234-38	380-84	---	---	---
Summit	---	244-49	---	---	---	---
INDIAN OCEAN						
Amsterdam Island	46-47, 131-34	278-79	---	---	---	---
Mahé Island (see Seychelles)						
Seychelles	100-01	334-35	---	---	---	---
NEW ZEALAND						
Baring Head	174-78	---	---	---	---	---
Wellington	193-202	---	---	---	---	---
NORTH AMERICA						
Canada	---	---	---	509-11	---	---
British Columbia	---	---	---	554-56	738-41	800-05
Cape St. James	124-25	---	---	---	---	---
Estevan Point	126-27	---	---	---	---	---

	Carbon Dioxide	Methane	Other Trace Gases and Atmospheric Aerosols	CO ₂ Emissions	Temperature	Precipitation
NORTH AMERICA						
Canada (continued)						
Northwest Territories						
Alert	44–45, 122–23	276–77, 366–71	435–38	---	---	---
Mould Bay	84–85	316–17	---	---	---	---
Nova Scotia						
Sable Island	128–29	---	---	---	---	---
Canadian Regions						
Arctic Mountains and Fjords	---	---	---	---	762–63	826–27
Arctic Tundra	---	---	---	---	760–61	824–25
Atlantic Canada	---	---	---	---	742–43	806–07
Great Lakes Basin/St. Lawrence Lowlands	---	---	---	---	744–45	808–09
Mackenzie District	---	---	---	---	758–59	822–23
Northern Canada (55°–70° N)						790–91
Northeastern Forest	---	---	---	---	746–47	810–11
Northwestern Forest	---	---	---	---	748–49	812–13
Pacific Coast	---	---	---	---	754–55	818–19
Prairies	---	---	---	---	750–51	814–15
South British Columbia Mountains	---	---	---	---	752–53	816–17
Yukon/North British Columbia Mountains	---	---	---	---	756–57	820–21
Greenland						
Camp Century	---	239–43	385–89	---	---	---
Crête	---	239–43	385–89	---	---	---
Dye 3	---	234–38	380–84	---	---	---
Summit	---	244–49	---	---	---	---
Mexico	---	---	---	562–63	---	---
United States	---	---	---	534–36	---	---
Alaska						
Barrow	17, 20–21, 29, 31–32, 54–55	286–87	439–44, 486–87	---	---	---
Cold Bay	68–69	300–01	---	---	---	---
Point Barrow (see Barrow)						
Shemya Island	102–03	336–37	---	---	---	---
American Samoa (see Samoa)						
Cape Matatula (see Samoa)						
Colorado						
Niwot Ridge	86–87	318–19	454–58	---	---	---
Florida						
Key Biscayne	76–77	308–09	---	---	---	---
Guam	70–71	302–03	---	---	---	---

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	Carbon Dioxide	Methane	Other Trace Gases and Atmospheric Aerosols	CO ₂ Emissions	Temperature	Precipitation
NORTH AMERICA						
United States (continued)						
Hawaii						
Cape Kumukahi	62–63	294–95	---	---	---	---
Mauna Loa	16, 18–19, 30, 33–34, 80–81	312–13	449–53, 479–82, 488–89	---	---	---
Mariana Islands (see Guam)						
Midway Islands	82–83	314–15	---	---	---	---
Oregon						
Cape Meares	64–65	296–97, 361–65	409–12	---	---	---
Point Matatula (see Samoa)						
Samoa	17, 22–23, 30, 35–36, 98–99	332–33	416–19, 459–64, 490–91	---	---	---
Sand Island (see Midway Islands)						
St. Croix (see Virgin Islands)						
Virgin Islands	116–17	348–49	---	---	---	---
Washington						
Olympic Peninsula	---	320–21	---	---	---	---
U.S. Regions						
Alaska (West of 141° W)	---	---	---	---	---	788–89
California Interior Valleys	---	---	---	---	696–97	845–47
Coastal Northeast	---	---	---	---	732–33	899–901
Coastal Southeast	---	---	---	---	734–35	902–04
Contiguous U.S.	---	---	---	---	688–89	830–35
East Slope North Cascades	---	---	---	---	698–99	848–50
Eastern Prairies	---	---	---	---	722–23	884–86
Great Basin	---	---	---	---	700–01	851–53
Great Lakes	---	---	---	---	720–21	881–83
Gulf Coast	---	---	---	---	718–19	878–80
North Cascades	---	---	---	---	694–95	842–44
North Pacific Coast	---	---	---	---	690–91	836–38
Northern Appalachians	---	---	---	---	724–25	887–89
Northern Piedmont	---	---	---	---	728–29	893–95
Northern Plains	---	---	---	---	712–13	869–71
Northern Rockies	---	---	---	---	704–05	857–59
Northern Steppes	---	---	---	---	708–09	863–65
Southcentral U.S.	---	---	---	---	---	782–83
South Coastal Plain	---	---	---	---	716–17	875–77
South Pacific Coast	---	---	---	---	692–93	839–41
Southern Appalachians	---	---	---	---	726–27	890–92
Southern Desert	---	---	---	---	702–03	854–56
Southern Piedmont	---	---	---	---	730–31	896–98
Southern Plains	---	---	---	---	714–15	872–74
Southern Rockies	---	---	---	---	706–07	860–62
Southern Steppes	---	---	---	---	710–11	866–68

	Carbon Dioxide	Methane	Other Trace Gases and Atmospheric Aerosols	CO ₂ Emissions	Temperature	Precipitation
NORTH AMERICA						
U.S. Regions (continued)						
Southern U.S. (28°–35° N; East of 105° W)	---	---	---	---	---	796–97
Southwestern U.S.	---	---	---	---	---	780–81
U.S.-Canadian Regions						
Northcentral U.S./ Southcentral Canada	---	---	---	---	---	776–77
Northeastern U.S./ Southeastern Canada	---	---	---	---	---	778–79
Northwestern U.S./ Southwestern Canada	---	---	---	---	---	774–75
U.S. and Southern Canada (South of 55° N)	---	---	---	---	---	772–73
U.S. and Canada (35°–45° N)	---	---	---	---	---	794–95
U.S. and Canada (45° N–55° N)	---	---	---	---	---	792–93
PACIFIC OCEAN						
American Samoa (see Samoa)						
Cape Matatula (see Samoa)						
Christmas Island	66–67	298–99	---	---	---	---
Guam	70–71	302–03	---	---	---	---
Hawaii						
Cape Kumukahi	62–63	294–95	---	---	---	---
Mauna Loa	16, 18–19, 30, 33–34, 80–81	312–13	449–53, 479–83, 488–89	---	---	---
Japan	---	---	---	543–44	---	---
Syowa Station	110–11	344–45	---	---	---	---
Kiribati (see Christmas Island)						
Mariana Islands (see Guam)						
Midway Islands	82–83	314–15	---	---	---	---
Oceania	---	---	---	523–24	---	---
Point Matatula (see Samoa)						
Samoa	17, 22–23, 30, 35–36, 98–99	332–33	416–19, 459–64, 490–91	---	---	---

	Carbon Dioxide	Methane	Other Trace Gases and Atmospheric Aerosols	CO ₂ Emissions	Temperature	Precipitation
PACIFIC OCEAN (continued)						
Sand Island (see Midway Islands)						
Shipboard Sites	88-93	322-27	---	---	---	---
SOUTH AMERICA	---	---	---	528-30	---	---
Brazil	---	---	---	579-80	---	---
MISCELLANEOUS REGIONS AND ZONES						
Developing America	---	---	---	528-30	---	---
Equatorial	---	---	---	---	644, 658-59	---
Global	---	262-66, 268-72	424-30, 472-78	501-04, 506-08	603-08, 609-14, 615-20, 629-34, 636-38, 650-51, 673-75, 678-79	---
North Polar	---	---	---	---	641, 652-53	---
North Subtropics	---	---	---	---	643, 656-57	---
North Temperate	---	---	---	---	642, 654-55	---
Northern Hemisphere	---	---	422-30	---	603-08, 609-14, 615, 621-23, 629-34, 639, 668-69, 676, 680-81	---
Oceania	---	---	---	523-24	---	---
South Polar	---	---	---	---	647, 664-65	---
South Subtropics	---	---	---	---	645, 660-61	---
South Temperate	---	---	---	---	646, 662-63	---
Southern Hemisphere	---	---	422-30	---	603-08, 609-14, 615, 624-26, 629-34, 640, 670-71, 677, 682-83	---
Tropical	---	---	---	---	648, 666-67	---