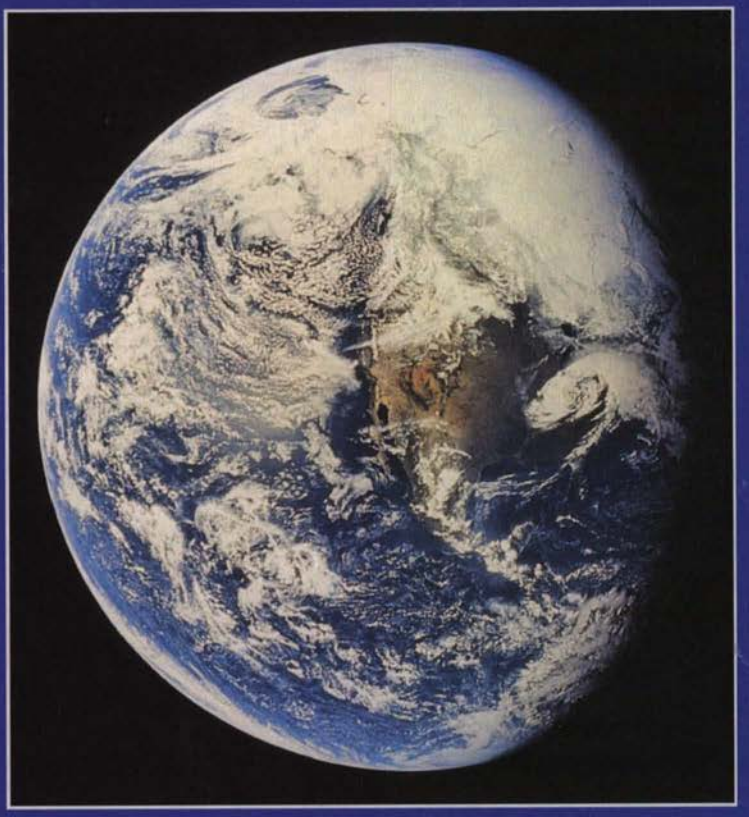
OUR CHANGING PLANET

THE FY 1998
U.S. GLOBAL CHANGE RESEARCH PROGRAM



An Investment in Science for the Nation's Future

A Report by the Subcommittee on Global Change Research,
Committee on Environment and Natural Resources
of the National Science and Technology Council

A Supplement to the President's Fiscal Year 1998 Budget

On the Front Cover

The Earth gleams brightly against the stark black backdrop of space, as photographed by the Apollo 16 astronauts during their Earth-Moon roundtrip. The United States and other parts of North America are clearly visible in this photograph.

Figure courtesy of the National Aeronautics and Space Administration.

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About the National Science and Technology Council

President Clinton established the National Science and Technology Council (NSTC) by Executive Order on November 23, 1993. This cabinet-level council is the principal means for the President to coordinate science, space, and technology policies across the Federal Government. The NSTC acts as a "virtual" agency for science and technology to coordinate the diverse parts of the Federal research and development enterprise. The NSTC is chaired by the President. Membership consists of the Vice President, the Assistant to the President for Science and Technology, Cabinet Secretaries and Agency Heads with significant science and technology responsibilities, and other senior White House officials.

An important objective of the NSTC is the establishment of clear national goals for Federal science and technology investments in areas ranging from information technology and health research, to improving transportation systems and strengthening fundamental research. The Council prepares research and development strategies that are coordinated across Federal agencies to form an investment package that is aimed at accomplishing multiple national goals.

To obtain additional information regarding the NSTC, contact the NSTC Executive Secretariat at 202-456-6100 (voice).

About the Committee on Environment and Natural Resources

The Committee on Environment and Natural Resources (CENR) is one of nine committees under the NSTC, and is charged with improving coordination among Federal agencies involved in environmental and natural resources research and development, establishing a strong link between science and policy, and developing a Federal environment and natural resources research and development strategy that responds to national and international issues.

To obtain additional information about the CENR, contact the CENR Executive Secretary at 202-482-5917 (voice).

About the Office of Science and Technology Policy

The Office of Science and Technology Policy (OSTP) was established by the National Science and Technology Policy, Organization, and Priorities Act of 1976. OSTP's responsibilities include advising the President on policy formulation and budget development on all questions in which science and technology are important elements; articulating the President's science and technology policies and programs; and fostering strong partnerships among Federal, State, and local governments, and the scientific communities in industry and academia.

To obtain additional information regarding the OSTP, contact the OSTP Administrative Office at 202-456-6004 (voice).

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
WASHINGTON, D.C. 20502

Members of Congress:

I am pleased to forward a copy of *Our Changing Planet: The FY 1998 U.S. Global Change Research Program*. This annual report was prepared under the auspices of the President's National Science and Technology Council (NSTC).

The first edition of *Our Changing Planet* was transmitted to Congress as a supplement to the FY 1990 budget. In the eight years since, the U.S. Global Change Research Program (USGCRP) has brought about dramatic improvements in our knowledge of the Earth system. Consider just a few of the major accomplishments. The rate, extent, and mechanisms of stratospheric ozone depletion are largely understood, enabling us to monitor the effectiveness of the remedial actions that this knowledge has stimulated. The rate and extent of South American tropical deforestation have been documented, the other tropical regions of the world are being inventoried, and a series of exciting new interdisciplinary investigations are unraveling the basic processes, causes and effects of land cover change. The onset and effects of El Niño/Southern Oscillation ocean circulation events in the Pacific are being predicted with increasing accuracy, and these science results are being used to create useful information for resource managers around the world.

As the USGCRP continues to pursue the challenge of explaining the physical and chemical processes of global-scale changes, it is increasing its efforts to explain the regional consequences of such changes. Among the fundamental aspects of the results described above are the regional texture and variation of the impacts of, and vulnerabilities to, global change. Regional-scale modeling and investigations are the natural outgrowth of the continued progress in global-scale analysis. Over the next year, the USGCRP will conduct a series of workshops across the U.S. that are focused on identifying and analyzing regional vulnerabilities to climate variability and climate change. This will be an important first step in assessing the vulnerability of the U.S. to global change and developing appropriate research strategies to provide the information needed for decisions on adaptation and mitigation.

The USGCRP was established in 1989, and has been strongly backed by every Administration and Congress since its inception. The FY 1998 Budget Request demonstrates President Clinton's ongoing commitment to the program. The President and the Vice President believe that global change research is one of the foundations of a sustainable future. The Administration looks forward to working with you as we carry on this bipartisan tradition of support for sound science.

I commend the members of the Subcommittee on Global Change Research, the program staff, and all the participants in government, academia, and industry for their continuing efforts.

John H. Gibbons
Director

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Executive Summary

Over the past decade, scientific research has greatly advanced the understanding of global environmental change. Research supported through the U.S. Global Change Research Program (USGCRP) is providing answers to important questions about the Earth system, how it is changing, and the implications of global change for society.

The USGCRP is focusing research on four key areas of Earth system science that are of significant scientific and practical importance. These priority environmental science issues are:

1) **Seasonal to Interannual Climate Variability**—The USGCRP plays a leading role in an ongoing global endeavor to develop and enhance prediction of seasonal and interannual climate variability. These forecasts are used for economic planning and development in climate-sensitive sectors such as agriculture, water supply, and public health.
2) **Climate Change Over Decades to Centuries**—The USGCRP supports research to reduce uncertainties associated with prediction of long-term climate change and is broadening research to understand and assess the impacts of climate change on natural resources, public health, and socio-economic sectors.
3) **Changes in Ozone, UV Radiation, and Atmospheric Chemistry**—Through USGCRP-supported research, emissions of CFCs from human activities have been unambiguously identified as the cause of the Antarctic ozone hole. Projections that large increases in CFC emissions would lead to large losses of stratospheric ozone underlie the agreement to phase out CFC use. Observations of declining CFC growth rates demonstrate the efficacy of the policies adopted to protect the ozone layer.
4) **Changes in Land Cover and in Terrestrial and Aquatic Ecosystems**—The USGCRP supports research to inventory the current land cover of the Earth and to document changes; to improve understanding of the dynamics of land-cover and land-use change and how terrestrial and aquatic ecosystems react to change; and to document and understand chemical, physical, and biological processes in the oceans and their relationship with the carbon cycle and marine life.

To provide the basis for continuing advancement in scientific understanding and leadership in global change research, the USGCRP continues to support a number of integrative and cooperative efforts, which contribute in varying degrees to all of the priority environmental science issues. These efforts include:

- Developing an integrated global observing and monitoring system
- Maintaining full and open access to useful global change data, products, and information services
- Supporting fundamental scientific research needed to gain a predictive understanding of variations and changes in the Earth system
- Enhancing understanding of the human contributions and responses to global change
- Providing strong U.S. leadership through participation in and support for international research cooperation
- Encouraging global change science literacy through global change education and communication.

Over the next decade, global change research can further benefit society by promoting sustainable economic development. Research challenges to accomplish this include:

- Regional-scale estimates of the timing and magnitude of climate change and other aspects of global change
- Regional analyses of the environmental and socio-economic consequences of climate change and other aspects of global change, in the context of other stresses
- Integrated assessments of the implications for society and the environment of climate change and other aspects of global change.

1. Understanding Global Change

The Earth System and Global Change

The Earth is a forever-changing planet. Its orbit around the Sun varies, continents drift, mountains are driven upwards and erode, animal and plant species evolve, and terrestrial and marine ecosystems change. Large changes have generally occurred as the result of natural forces beyond human influence or control.

Humans have become powerful agents of environmental change on global, regional, and local scales. With an increasing world population, an expanding global economy, and the development of new technologies, the human impact on the environment will become even more significant in the future.

The Earth system includes the atmosphere, oceans, land, and all living organisms.

Research supported through the U.S. Global Change Research Program (USGCRP) is documenting environmental change and leading to a better understanding of its significance. For example:

- Research has demonstrated that increased use of fossil fuels since the mid-1800s is changing the composition of the Earth's atmosphere and that this change is now exerting a warming influence on the global climate.

Central Purposes of the U.S. Global Change Research Program

- To observe and document changes in the Earth system
- To understand why these changes are occurring
- To improve predictions of future global change
- To analyze the environmental, socio-economic, and health consequences of global change
- To support state-of-the-science assessments of global environmental change issues

- Research indicates that global-scale variations in climate alter regional patterns of rainfall and temperatures.
- Research has documented that changes in land cover such as the conversion of forest to pasture in the tropics, and changes in land use such as increases in fertilizer applications to croplands worldwide, are contributing to changes in atmospheric composition and may also contribute to climate change on both regional and global scales.
- Research has demonstrated that emissions of chlorofluorocarbons (CFCs) and other chlorine- and bromine-containing gases have led to depletion of stratospheric ozone in both the Southern and Northern Hemispheres that will last for decades and cause adverse impacts on human health and ecological systems.

These and other changes in the Earth system are having profound consequences. Scientific research is the means to develop an understanding of the changes, their causes, and their consequences.

Changes in any single component of the Earth's system will affect the entire system. For example, changes in the tropical Pacific Ocean affect weather in North America and other parts of the world. The complexity of the Earth system and the many feedbacks among its components make understanding and predicting climatic and environmental change and all of its ramifications an exceedingly difficult challenge.

Changes in the global environment are having profound consequences for the natural environment and for society.

Progress Over the Past Decade in Global Change Research

Over the past decade, scientific research has greatly advanced our understanding of global change. The growing understanding that the current and future state of the Earth system is inexorably linked to human activities, and the increasing societal concern about the implications of global environmental change, underscore the need for and importance of these scientific efforts.

Science continues to improve our understanding of global change. Research supported by the USGCRP is providing answers to important questions about the Earth system, how it is changing, and

the implications of global environmental change for society. Following are a few key examples from research that has focused on:

- Ozone depletion
- Seasonal to interannual variations in climate
- Climate forcings
- Climate change over decades to centuries
- Detection and attribution of climate change
- Terrestrial and aquatic ecosystem feedbacks and effects
- Land cover and land use
- Climate impacts on marine ecosystems.

Ozone Depletion

In 1974, research scientists hypothesized that industrial emissions of CFCs could cause depletion of the stratospheric ozone layer, which serves to shield life on Earth from harmful levels of ultraviolet (UV) radiation. In 1985, after extensive study, the scientific community released its first international assessment, predicting only a small thinning of the ozone layer with continued emissions of chlorinated substances.

With the discovery of the Antarctic ozone hole in 1985—a phenomenon resulting in the springtime destruction of more than 50% of the ozone over Antarctica in a period of several weeks—it became clear that the potential danger of ozone depletion was significantly greater than shown in earlier scientific studies. The atmospheric science community rapidly embarked on a series of experimental field campaigns. This work, together with satellite and aircraft observations, laboratory studies, and the development of atmospheric chemistry models, clearly identified human emissions of chlorinated and brominated chemicals (e.g., CFCs and halons) as the causes of stratospheric ozone depletion.

The current and future state of the Earth system is inexorably linked to human activities.

A Successful Partnership Between Science and Policymaking

In 1987, in parallel with scientific developments and in response to the 1985 assessment, the nations of the world entered into a landmark global agreement, the Montreal Protocol on Substances that Deplete the Ozone Layer. The Parties to the Montreal Protocol agreed—on the basis

of scientific predictions—to reduce emissions of the chlorinated and brominated ozone depleting substances (ODSs). Thus was born a new era of cooperation between the science and policy communities.

The Parties to the Montreal Protocol have since periodically requested that the science community provide new assessments of the state of the ozone layer, to be used as the basis for revising the international rules limiting emissions of ODSs. In response, the science community, with U.S. funding increasingly focused through the USGCRP, has engaged in extensive monitoring, and process and modeling studies. These studies have elucidated the causes of the observed global thinning of the ozone layer in increasing detail. At the same time, they have identified many ozone-friendly substitutes for the ODSs.

Stratospheric Ozone: The scientific community mobilized quickly to diagnose and design responses to a major environmental threat.

Based heavily on this research, new assessments were prepared in 1989, 1991, and 1994 by international panels of leading scientists, under the co-chairmanship of USGCRP scientists, and with USGCRP scientists serving prominently as authors and reviewers. These authoritative, internationally recognized documents provided the scientific understanding underlying the subsequent Amendments and Adjustments to the Montreal Protocol, which have proven necessary for the protection of the stratospheric ozone layer.

Based on assumed compliance with the most recent Amendments to the Montreal Protocol, stratospheric chlorine and bromine abundances are expected to peak in the next few years, then slowly decline as international controls on ODSs take effect. All other things being equal, global ozone losses and the Antarctic ozone hole are expected to recover in about 50 years. The ongoing research program has shown that such recovery would have been impossible and that ozone losses would have been so large as to cause very large increases in skin cancer without the controls agreed to in the Montreal Protocol and its Amendments.

Authoritative international assessments were prepared with USGCRP scientists serving prominently as leaders, authors, and reviewers.

Both the ozone layer and the atmospheric abundances of ODSs are monitored globally by USGCRP scientists. Long-term observations have revealed that atmospheric abundances of the ODSs have recently

started to decline as their phase-out takes effect. Simultaneously, the abundances of their substitutes have been increasing. These important observations confirm the effectiveness of the international policy response to this scientifically identified global threat.

Seasonal to Interannual Variations in the Climate

The weather fluctuates day-to-day, even hour-to-hour. Weather forecasters have developed enough understanding about atmospheric behavior to be able to make socio-economically useful predictions about the specific conditions of the atmosphere up to almost a week in advance. Climate—the general patterns of weather in a region averaged over seasons, years, and decades—also exhibits natural variations and fluctuations. Thus, monthly and seasonally averaged temperature, precipitation, sunshine, cloudiness, and wind vary from year to year and decade to decade.

Scientists are seeking to understand how the climate system worked in the past and how it is working now, including the influence of human activities. Improving this understanding is essential to developing the capacity for society to adapt to change and to achieve maximum benefit under the prevailing climatic conditions. Over the past decade, scientists studying the season-to-season and year-to-year fluctuations of the climate have improved their ability to predict rainfall and temperatures up to a year in advance.

Seasonal-to-interannual forecasts are now being done with useful skill and are used by agricultural and water resource planners in some parts of the world, particularly in the tropics.

Even though they are still experimental, these seasonal-to-interannual forecasts are now being made with useful skill and are used by agricultural and water resource planners in some parts of the world, particularly in the tropics, to adjust planting schedules, crop selections, and water releases from dams in order to reduce the economic and social impacts of droughts and floods.

The El Niño-Southern Oscillation

The ability to make seasonal-to-interannual forecasts, particularly for tropical and subtropical regions and for the southern and western

United States, has come from an improved understanding of the irregular cycling of El Niño/Southern Oscillation (ENSO). The ENSO phenomenon involves the warming and cooling of large areas in the tropical Pacific Ocean, with large associated shifts in atmospheric pressure and rainfall in other regions.

The Tropical Ocean/Global Atmosphere (TOGA) program from 1985 to 1995 untangled these complex interrelationships sufficiently to allow prediction of the ENSO cycling under some conditions. With this understanding, scientists have been able to associate changes in ENSO with important consequences in the United States, including:

- Changes in rainfall patterns along the U.S. Pacific Coast—for example, the varying pattern of flood and drought conditions in California
- Wet and dry periods across the southern and central United States—for example, the 1988 Midwest drought
- Other changes—for example, the beginning and end of the drought in the southwestern United States in 1996.

Prediction of ENSO events and their impacts has enabled South American farmers to adjust their crops and planting in ways that have greatly alleviated the impacts of drought and enhanced the abilities to have bountiful harvests during periods of good rains. ENSO variations have also been found to influence outbreaks of some diseases.

Expanding the Scope of Research

Research in this area is now focusing on the following needs:

- To develop more comprehensive prediction systems
- To expand the scope of climate prediction to North America and the rest of the globe
- To improve climate prediction over longer time scales.

In addition, research focuses on understanding how individuals, industries, and resource sectors respond to climate fluctuations. This understanding, coupled with improved knowledge about the climate system, will make it possible to identify options for reducing vulnerability to extreme climate events such as droughts and flooding, and, in some regions, for taking advantage of opportunities provided by rainfall or temperature changes.

Research is now focusing on expanding the scope of climate prediction to North America and the rest of the globe.

Climate Forcings

Human activities have become so pervasive that they are creating changes in the atmosphere and at the land surface that perturb the Earth's natural fluxes of solar and infrared (heat) radiation. These human-induced changes, often called "enhanced radiative forcings," lead to changes in temperature, precipitation, and other climatic variables.

Human activities are creating changes in the atmosphere and at the land surface.

Greenhouse Gases

The most important enhancements of radiative forcings are a result of the emissions of carbon dioxide (CO_2), methane (CH_4), and other greenhouse gases, which have the ability to increase the natural atmospheric trapping of infrared radiation. Emissions from combustion of coal, oil, and natural gas and from deforestation and land cultivation have increased the natural CO_2 concentration by almost 30% over the past 200 years. The atmospheric CO_2 concentration is currently rising at about 0.5% per year due to annual emissions of about 7 GtC (gigatons of carbon—1 GtC equals 1 billion metric tons) as carbon dioxide per year from fossil-fuel combustion and land-clearing activities.

Aerosol Effects on Solar Radiation

It has long been recognized that small particles in the atmosphere (called aerosols) can reflect some solar radiation back to space, thus exerting a cooling influence. However, a relatively new finding is that regional increases in short-lived aerosols resulting from human activities are sufficient to alter the Earth's radiation balance. Emissions of sulfur dioxide from coal combustion, and of other gases from biomass and other burning, cause the atmosphere over and downwind of major industrial regions and regions of tropical deforestation to reflect back to space some of the incoming solar radiation. This exerts a regionally distributed cooling influence.

Emissions of sulfur dioxide from coal combustion exert a cooling influence over much of the Earth.

In many industrialized nations, including the United States, the particle loading from fuel burning is being controlled in order to reduce human health impacts, acid rain, and visibility problems. However, as

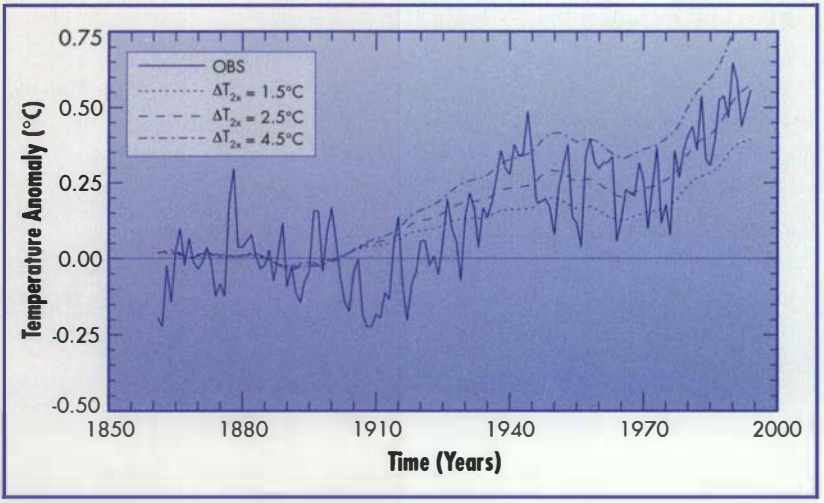


Figure 1: Observations over land and oceans indicate that the global average surface temperature has increased by ~0.5°C (~1°F) since the mid-19th century (annual average temperature departures are shown by the solid, irregular line). The smoother curves show results from simplified climate models that include the effects of the increasing concentrations of greenhouse gases and the changing influences of sulfate aerosols and solar forcing. The central curve is for the IPCC "best estimate" climate sensitivity of 2.5°C for a doubling of the CO_2 concentration; the outer curves are for higher and lower sensitivities. The results suggest that the temperature increase during this period is due mainly to the warming influence of the increased concentrations of CO_2 and other greenhouse gases, but that the global average temperature is also affected by the cooling influence of sulfate aerosols and the cyclic effects of variations in solar radiation. The general agreement of observations and model results suggests that estimates of climate sensitivity are in the range predicted by comprehensive climate models (see Appendix D for further information). Source: T.M.L. Wigley, P.D. Jones, and S.C.B. Raper, "The observed global warming record: What does it tell us?" Proceedings of the National Academy of Sciences, *in press.*

aerosol concentrations are reduced, the global warming they have masked would become apparent.

Climate Change Over Decades to Centuries

Predicting the future influences of human activities on the climate requires an understanding of how natural forces affect the climate. Gaining sufficient understanding to predict future changes requires consideration of the many variables and processes that describe and control how the Earth system behaves, including how human activities may be influencing natural components. Various approaches are used to develop and test prediction capabilities. Confirming that different approaches yield similar predictions can add to confidence in the results.

Paleoclimate Studies

Paleoclimate studies—studies of past variations in the climate—indicate that future warming projected by current climate model simulations would lead to global average temperatures during the next century that have not occurred on the Earth in millions of years. Furthermore, the rate of global warming projected for the next century would be more rapid than any natural climatic change that has occurred during the past 10,000 years.

Paleoclimate studies also indicate that past climate has been quite sensitive to relatively modest changes in the factors governing the climate—for example, changes in atmospheric composition, changes in solar radiation related to the Earth's orbit around the Sun, and the locations and elevations of mountains. In addition, paleoclimate evidence indicates that climate changes of the magnitude forecast for the next century have caused major shifts in the geographical distribution of forests and other vegetation types in the past, implying significant ecological disruption as a consequence of future climate changes.

The rate of global warming expected over the next century would be more rapid than any that has occurred during the past 10,000 years.

Predictive Models

Developing quantitative predictions of how these complex changes might occur in the future requires the use of computer-based climate models that incorporate as much as possible of our theoretical understanding about how the Earth system works. Exploratory global climate models were first developed in the 1960s and started to be used to study human influences on the climate in the 1970s.

Over the past decade, predictive climate models have improved as scientific understanding has advanced and computers have become more powerful. The early climate models (referred to as general circulation models, or GCMs) were only able to calculate the climate change from a large and fixed change (e.g., a doubling) in the atmospheric concentration of CO_2. Because they

Developing predictions of climate change requires the use of computer-based models that incorporate as much as possible of our theoretical understanding of the Earth system.

include the capacity of the oceans to act as a heat sink and thereby slow the rate of temperature increase, current models are now able to simulate more realistically the climatic effects from the gradually increasing atmospheric CO_2 concentration. Capabilities are also being developed to treat other human influences on atmospheric composition, including sulfate aerosols, other greenhouse gases, and changes in land cover.

A climate model that incorporates many of these new capabilities is now available for research and application studies. Developed and maintained at the National Center for Atmospheric Research in Boulder, Colorado, this is the world's first comprehensive and interactive Climate System Model available for widespread use by the scientific community. In FY98, continued enhancements of this model will facilitate a wide range of global change sensitivity studies and predictions by a broad array of USGCRP researchers and scientists throughout the world.

Comparing and Evaluating Models

Because computer models only approximate the real world, it is important to analyze and test their results carefully. This became especially clear when it was recognized that the several different models used by researchers in the United States and around the world were giving different estimates for the most basic model result: How much global warming would result from a doubling of the CO_2 concentration. The model estimates range from about 1.5–4.5°C (about 3–8°F). The reasons for the differences relate primarily to the limited understanding and representation of cloud-radiation feedbacks. Research on these feedbacks is a major focus of the USGCRP effort.

The differences were also an important incentive for the establishment of a series of intercomparison studies, particularly the Atmospheric Model Intercomparison Project. In the future, more powerful predictive models will contain the finer spatial and temporal resolution and the improved representations of climate processes that are needed to represent more completely the many aspects of the hydrologic cycle, including clouds and upper tropospheric water vapor, and processes governing the coupling of the land, ocean, and sea ice with the atmosphere.

Detection and Attribution of Climate Change

Scientists have been searching for several decades for evidence that climate change is occurring and that it is a result of human activities. The

Intergovernmental Panel on Climate Change (IPCC) was created in 1989 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) to assess the state of knowledge of climate change. More than 2,000 scientists from around the world were involved in the IPCC Second Assessment Report, released in December 1995. The Second Assessment Report came to the important conclusion that "the balance of evidence suggests that there is a discernible human influence on global climate."

"The balance of evidence suggests that there is a discernible human influence on global climate."

— Intergovernmental Panel on Climate Change, *Climate Change 1995*

Detection of Climate Change

For some time there has been clear evidence that detectable global warming is occurring:

- Temperature observations taken by ships and land stations confirm that the global average temperature has risen by about 0.3-0.6°C (about 0.5-1.1°F) since the late 19th century. The changes do not occur uniformly over the globe.
- A 700-year temperature history put together from tree rings and other proxy indicators suggests that the current century is warmer than any century in this longer record and that the warming is unusually rapid and prolonged.

A number of additional records also point to long-term global warming:

- Temperatures from deep holes in the ground
- The melting back of mountain glaciers around the world
- The continuing rise in sea level due to warming and from glacial meltback.

The 17-year satellite record of temperature in the lower atmosphere does not directly show a warming trend. However, analyses that take account of several additional factors do suggest that greenhouse gases are exerting a warming influence. Issues relating to the satellite data set are currently being addressed by USGCRP-supported research.

Attribution of the Causes of Climate Change

Distinguishing the clear signal of human activities from the "noise" of natural variability has been a difficult challenge for two reasons. First,

both natural and human influences can cause climate to change. Second, greenhouse gases exert a warming influence while sulfate aerosols exert a cooling influence.

New statistical tests indicate that much of the warming that has been observed can indeed be attributed to human activities. This is because both the *geographical pattern* across the Earth's surface and the *vertical pattern* into the atmosphere of temperature change are what is expected from changes induced by human influences:

- *The Geographical Pattern*: For much of this century, more warming has been occurring in the Southern Hemisphere than in the Northern Hemisphere because of the cooling influence of the greater amount of aerosols in the Northern Hemisphere; in the latter part of this century and into the next century, more equal warming of the hemispheres has occurred and is expected to continue.
- *The Vertical Pattern*: Cooling is occurring in the stratosphere due to ozone depletion and greenhouse gas increases, in contrast to warming in the troposphere (the lower atmosphere and surface) from greenhouse gases.

These patterns are unlike those expected from naturally varying forcing factors, such as solar radiation and volcanic eruptions.

The amount of warming since the 19th century is also in accord with the range of model estimates of the surface warming that is expected from the increases in greenhouse gases and aerosols that have occurred. Inclusion of a more complete set of human influences, including the cooling influences of aerosols and stratospheric ozone depletion, has been important in reconciling observed and predicted changes and in clarifying that it is essential to consider all important factors that can influence the climate, rather than drawing conclusions or making comparisons based on the estimated change from any single factor (like greenhouse gases).

Climatic Extremes

From model predictions about climate change, inferences can be drawn that there will be:

- Increases in the frequency and intensity of floods, droughts, and heat waves
- Changes in the frequency of occurrence of climatic extremes due to increases in greenhouse gas emissions.

Analyses of the climate record are seeking to determine if these inferences are in accord with recent observations.

It is inappropriate to attribute any particular extreme weather event to climate change, but the trends in their occurrence can be examined. While detailed worldwide information is not available to explore this question, analyses of data for the United States during the 20th century show a consistency between inferences drawn from model predictions and observed responses. Such modeled and observed changes include, for example, an increase in intense rainfall events.

Terrestrial and Aquatic Ecosystem Feedbacks and Effects

Changes in the atmospheric composition and climate will have a significant influence on terrestrial and aquatic ecosystems. Because these ecosystems also have a major influence back on the atmosphere and climate, understanding their role in potential positive and/or negative feedbacks is critical. Over the past 10 years, significant advances have been made in understanding terrestrial and aquatic processes and their effects on the climate system.

Significant advances have been made in understanding terrestrial and aquatic processes and their effects on the climate system.

The feedbacks and effects that the land and aquatic environments exert on climate are of two types:

1) *Biogeochemical*: Changes in the distribution and circulation of chemicals such as carbon- and nitrogen-containing compounds between the atmosphere, oceans, biosphere, and soils, resulting in changes in the atmospheric composition of greenhouse gases
2) *Physical*: Changes in land-surface properties such as albedo (the ability to reflect light) and roughness (the ability to alter wind speed and direction), resulting in changes in the Earth's energy balance.

Biogeochemical Cycling

A particular challenge has been to identify where all of the CO_2 being emitted as a result of human activities is going. Natural biological and physical processes, such as photosynthesis and oceanic uptake, are able to limit the annual increase in the atmospheric loading of CO_2 to just under half the annual emissions of CO_2. Together, the land and ocean

components of the climate system must be taking up the half of the CO_2 that does not remain in the atmosphere.

Research over the past decade has helped to clarify the means by which this carbon sequestration on land occurs. Much of the excess carbon from human activities that is being removed from the atmosphere appears to be going into terrestrial systems. Studies suggest that land-surface processes are removing about 2 billion metric tons more of carbon from the atmosphere each year than they release. This net carbon uptake by land ecosystems is related to several processes, including the regrowth of previously deforested areas and to enhanced storage of carbon by plants due to the elevated CO_2 concentration. Previously deforested areas, particularly in the northeastern United States, are showing substantial forest regrowth. For example, areas in New England that were 80% farms 100 years ago are now 80% forest-covered.

A particular challenge has been to identify where all of the CO_2 being emitted as a result of human activities is going.

The role of ocean ecosystems in "pumping" carbon to the deep ocean as dead animals and plants sink to the ocean floor is also important, and would be especially so if the ocean circulation is slowed by global warming. Data collected in a series of ship cruises indicate that about 2 billion metric tons more carbon is being taken up by the oceans than is being released by them through natural processes.

Critical questions remain:

- How long will these elevated removal rates continue? Because it is likely that these mechanisms cannot continue indefinitely, the rate of carbon uptake by the land surface may eventually decrease.
- How will the elevated removal rates be affected by changes in emission rates, land use, and other influences?

Physical Ecosystem Properties

The characteristics of land and ocean surfaces also affect the climate directly. Plants are particularly important in controlling the amount of evaporation and runoff at the surface, thereby influencing the hydrologic cycle. Moreover, by enhancing or reducing evaporation, soils and surface vegetation have an influence on the near-surface temperature.

Shifts in precipitation, whether brought about by seasonal-to-interannual climate fluctuations, volcanic eruptions, or long-term climate

change, will cause shifts in temperature and soil moisture. Depending on their magnitude and timing, persistent changes in precipitation are predicted to cause shifts in ecosystems as well as feedbacks affecting climate.

Interactions Among Feedback Mechanisms

Biological, chemical and physical feedback mechanisms can also interact. For example, climate changes can induce changes in ecosystem structure and function which can alter carbon uptake, which in turn can alter the future climate. New global vegetation models are being developed that can be coupled to climate models to simulate these influences.

In cold land regions, climate change will warm the soils which can lead to the release of methane, a strong greenhouse gas that can thus amplify future climatic warming.

In cold land regions where very large amounts of carbon are currently trapped in frozen soils, climate change will warm the soils which can lead to release of methane, a strong greenhouse gas that could amplify climatic warming. Another possibility is that freshening of the ocean as a result of increased precipitation can slow ocean overturning and the oceanic uptake of carbon, thus creating further climate change. Climatic warming can enhance the release of ozone precursors from the vegetation.

As the atmospheric CO_2 concentration increases, the capacity for plants to take up CO_2 via photosynthesis may increase. This "CO_2 fertilization" effect may act as a negative feedback, thereby reducing the rate of climate change. Conversely, decreases in precipitation in some regions can turn forests to grasslands, thereby leading to release of carbon to the atmosphere.

The "CO_2 fertilization" effect may act as a negative feedback, thereby reducing the rate of climate change.

These and other feedbacks emphasize the need for full treatment of surface processes in climate models.

Land Cover and Land Use

Human activity has altered all but a few of the Earth's landscapes. These changes alter vegetation, change the capacities of landscapes to

cleanse water and the air, affect how animals, plants, and ecosystems can migrate, and alter biological diversity.

The current pattern of global land cover most often reflects past and present land use. Since different land uses and vegetation types (forests, farmlands, grasslands, urban developments, and so forth) have very different capacities to absorb and store carbon, monitoring land cover and land use are critical.

Ground-based research and 20 years of satellite data show that human activity has altered all but a few of the Earth's landscapes.

The larger patterns of land cover are observable and can be monitored from space. From historical archives, including the last 20 years of satellite data, we are building a quantitative assessment of landscape and land-use change. More subtle types of change—for example, those which take place through the intensification of current uses—require additional *in situ* (on site) information.

Mapping and Characterizing Change in the Global Landscape

The USGCRP has supported several current activities to produce and make available global land-cover maps at different spatial resolutions.

The USGCRP supports several current activities to produce and make available global land-cover maps.

These maps provide important foundations for efforts to improve land use. The success of these projects in interpreting land use from satellite data has provided critical information. Products derived from the Advanced Very High-Resolution Radiometer (AVHRR) at 8- and 1-km spatial resolution are already being made available.

The Landsat Pathfinder Humid Tropical Forest project has provided the major foundation of data on tropical and subtropical land-cover conversion. Projects sponsored by U.S. agencies with the goal of measuring the rate of tropical forest loss in South America and Southeast Asia are being coordinated with projects sponsored by Brazilian and European colleagues focused on the Brazilian Amazon and Africa. This coordination includes data exchanges and methods intercomparisons.

Other important regional efforts include the following:

- The EPA/USGS Landsat Pathfinder North American Landscape Characterization data set project, which has documented land

cover in the United States and Central America for three dates in the 1970s, 1980s, and 1990s with Multispectral Scanner (MSS) data

- The multi-agency Multi-Resolution Landscape Characterization (MRLC) project, which provides a consistent Thematic Mapper (TM) data set of the United States for the early 1990s.

Land-Use Change and Habitat Requirements

A major area of emphasis within USGCRP land-management agencies is to combine knowledge of species habitat requirements with measurements of actual land cover, derived from satellite remote sensing, aircraft, and field surveys, to assess the likelihood that sufficient habitat will remain for broad assemblages of species with similar requirements. This analysis program draws on the results of basic biological research, land-use and planning information, and simple modeling to provide direct guidance to managers and policymakers faced with difficult trade-offs over the uses of land.

Analysis of land-use change and habitat requirements provides direct guidance to managers and policymakers faced with difficult trade-offs.

Climate Impacts on Marine Ecosystems

Climate change can influence marine ecosystems in many ways. Because humans derive about 20% of their food protein from fish and other ocean and freshwater products, understanding the potential for climate change to alter marine ecosystems is important.

Fisheries' yields depend on many direct and indirect effects of climate on the oceans.

Fisheries' yields depend on many effects of climate on the oceans. These effects include, for example, atmospheric and oceanic temperatures and temperature changes, precipitation, runoff, salinity, primary production, and ice dynamics. Due to this complexity of effects, predicting the responses to global change of marine animal populations—both the resource fisheries and the prey upon which they feed—is a difficult challenge for research.

Global Warming and Ocean Circulation Dynamics

Future global warming will not be uniform over the Earth's surface. Large-scale ocean currents, such as the Gulf Stream, are driven by heat, by freshwater runoff cycles, and by winds.

Changes in atmospheric circulation caused by changes in the Earth's heat budget may eventually cause changes in these major ocean currents. Scientists know that during past major climate changes, the locations of major ocean currents were significantly different from their present positions. Future greenhouse-induced changes might produce similar shifts in ocean currents, displacing species accordingly. If currents shift, entirely different ecosystems may result.

Some of the most productive of all the world's oceans and the locations for many of the world's most economically valuable fisheries are regions of ocean upwelling (displacement of warm surface water from along a shore by colder water brought up from the subsurface), such as those off the Pacific coasts of North and South America, off the Atlantic coasts of Canada and Africa, and off the coasts of Somalia and the Arabian Peninsula. A climate-driven change in worldwide ocean circulation, which may occur as freshwater increases in the polar regions from enhanced rainfall, would greatly affect marine fish populations and the people who depend upon them for food and their livelihoods. For example, the Georges Bank region off the northeastern United States has the potential for major disruption if ocean flows are changed.

Future greenhouse-induced changes might produce shifts in ocean currents, displacing species and resulting in entirely different ecosystems.

Marine Ecosystem Productivity

Changes in ocean temperature, salinity, and other physical properties can cause a shift in the distribution of populations of primary producers and plankton. These shifts would be expected to cascade throughout the food web, ultimately altering population stability in economically important fish species. The U.S. sardine fishery, and that of the achoveta off the coast of Peru, are excellent examples.

Sardine catches in the United States peaked at more than 700,000 tons in 1936, but drastically declined to a sustained collapse in the 1950s, 1960s, and 1970s. Similar changes occurred elsewhere in the

Pacific. Then large increases in catches started in the late 1970s. The nearly simultaneous and cyclic rise and fall of sardine catches in these regions may be linked to global- and decadal-scale alterations in climate patterns.

U.S. researchers are studying how the global El Niño/Southern Oscillation climate phenomenon is responsible for changes in the large-scale distribution of marine life and how this interacts with the human harvesting of fisheries resources. For example, the anchovy fishery off the west coast of South America was severely impacted by the onset of an El Niño event, which wiped out the stocks weakened by overharvesting.

The nearly simultaneous and cyclic rise and fall of sardine catches may be linked to alterations in climate patterns.

2. Highlights of Recent and Current Research

The USGCRP Focus: Four Key Global Change Issues

The United States, through the U.S. Global Change Research Program, supports research needed to characterize and understand global environmental change and to provide answers to important questions about the Earth system, how it is changing, and the implications of global change for society and the natural systems on which society depends.

The USGCRP is focusing research efforts on four areas of Earth system science.

The underlying premise of the USGCRP is that the development of an appropriate relationship between human society and the global environment is inextricably linked to an improved understanding of the systems that are undergoing change in response to natural and human-influenced processes.

In response to the development of scientific understanding and research capabilities, the USGCRP is focusing research efforts on four areas of Earth system science that are of significant scientific and practical importance:

1) **Seasonal to Interannual Climate Variability**, with the goal of obtaining a predictive understanding and the skills to produce forecasts of short-term climate fluctuations and to apply these predictions to problems of social and economic development in the United States and abroad.
2) **Climate Change over Decades to Centuries**, with the goal of understanding, predicting, and assessing changes in the climate and the global environment that will result from the influences of projected changes in population, energy use, land cover, and other natural and human-induced factors, and providing the scientific information needed by society to address these changes.
3) **Changes in Ozone, UV Radiation, and Atmospheric Chemistry**, with the goal of understanding and characterizing the chemical changes in the global atmosphere and their consequences for human well-being.

4) **Changes in Land Cover and in Terrestrial and Aquatic Ecosystems**, with the goal of providing a stronger scientific basis for understanding, predicting, assessing, and responding to the causes and consequences of changes in terrestrial and aquatic ecosystems resulting from human-induced and natural influences.

Progress toward the *Seasonal to Interannual Climate Variability* goal will provide improved predictions that can, among other direct benefits, help farmers maintain their agricultural productivity in spite of extreme climatic events such as droughts and floods; help water resource managers to ensure reliable water deliveries, limit flood damage, and maintain optimal reservoir levels; help in planning fishery harvests; and help foresters allocate resources effectively to safeguard forests (and the public) from major fires during droughts.

The USGCRP plays a leading role in an ongoing global endeavor to develop and enhance prediction of seasonal and interannual climate variability. These forecasts are used for economic planning and development in climate-sensitive sectors such as agriculture, water supply, and public health.

In FY98 and over the next several years, the USGCRP will build on its initial successes and support research activities geared to achieve the following objectives:

- Improve skills in predicting climate fluctuation, particularly over the United States
- Monitor the tropical Pacific Ocean in order to better determine its influence on climate, and to improve predictions
- Map global precipitation and its relationship to climate fluctuations
- Incorporate field data into models in order to improve forecasts of climate variability
- Assess human vulnerability to climate variations and identify options for adaptation based on improved information from predictions
- Establish a network of research centers to improve forecast model development and diagnostics, and the application of predictive information to socio-economic planning processes.

Progress toward the *Climate Change over Decades to Centuries* goal is providing information needed by decisionmakers considering adaptive or mitigative responses to the projected changes in climate and the

associated environmental and societal impacts. The information will also assist planners and managers with responsibilities for the design of infrastructure and other major facilities, sustained management of natural resource-based systems, and long-term planning in the financial sector.

The USGCRP supports research to reduce uncertainties associated with prediction of long-term climate change and is broadening research to understand and assess the impacts of climate change on natural resources, public health, and socio-economic sectors.

In FY98 and over the next several years, the USGCRP will continue to address significant uncertainties through support for research activities oriented toward the following key objectives:

- Quantify the natural and human-induced factors that change atmospheric composition and radiation
- Characterize natural climate variability and the factors contributing to decadal and longer period climate fluctuations
- Improve quantitative representations of climate system mechanisms and feedback processes
- Improve scenario-driven predictions of climate change and identification of the human-induced component in the recent climate record
- Develop improved measures of the sensitivity, vulnerability, and adaptability of natural systems and project the consequences of climate change and long-term variations of the climate
- Develop improved measures of the sensitivity, vulnerability, and adaptability of socio-economic systems, and project the societal implications of climate change and long-term natural variability.

Progress toward the *Changes in Ozone, UV Radiation, and Atmospheric Chemistry* goal will provide information to assist policymakers in protecting human health, preserving the cleansing and shielding qualities of the atmosphere, and ensuring that new chemical compounds released into the atmosphere do not lead to adverse consequences from changes in atmospheric composition.

The USGCRP's atmospheric chemistry research has the following objectives:

- Monitor atmospheric chemical composition trends and the human-influenced emissions that cause them
- Understand the stratospheric ozone variations during the coming most-vulnerable decade

Through USGCRP-supported research, emissions of CFCs from human activities have been unambiguously identified as the cause of the Antarctic ozone hole. Projections that large increases in CFC emissions would lead to large losses of stratospheric ozone underlie the agreement to phase out CFC use. Observations of declining CFC growth rates demonstrate the efficacy of the policies adopted to protect the ozone layer.

- Monitor changes in surface UV radiation, and quantify exposure and consequences to the biosphere and human health
- Develop a predictive understanding of the chemistry of the global troposphere
- Characterize the radiative links between atmospheric chemistry and climate change
- Assess the scientific understanding of the future of the ozone layer and of the role of human-influenced chemistry in the radiative forcing of climate change.

Progress toward the *Changes in Land Cover and in Terrestrial and Aquatic Ecosystems* goal will provide a stronger scientific basis for developing environmental and natural resource practices that are environmentally sound and practical, and that will ensure ecosystems can be managed to yield sustainable benefits to humankind.

Achieving the goal of research on changes in land cover and in terrestrial and aquatic ecosystems will require meeting several key objectives:

- Document the current patterns and past changes in global land cover
- Understand natural and human-induced influences that lead to changes in land cover, land use, coastal alterations, and terrestrial and aquatic ecosystems
- Predict the extent and consequences of changes in land-cover, land-use, and ecosystem processes, especially as

The USGCRP supports research to inventory the current land cover of the Earth and to document changes; to improve understanding of the dynamics of land-cover and land-use change and how terrestrial ecosystems react to change; and to document and understand chemical, physical, and biological processes on the land and in the oceans and their relationship to elemental cycles and living organisms.

they relate to the sustainability of natural resources and economic development
- Quantify exchanges of trace gases between the atmosphere and the terrestrial biosphere, with particular emphasis on the processes controlling carbon sources and sinks
- Observe and document the current patterns and past changes in chemical, physical, and biological activity in the oceans, especially those that are relevant to understanding the exchange of carbon dioxide with the atmosphere
- Understand and analyze the chemical, physical, and biological processes that regulate ocean uptake and release of atmospheric carbon dioxide and that control biological productivity in the oceans, and develop the predictive capabilities needed to ensure the sustainability of marine resources.

Seasonal to Interannual Climate Variability

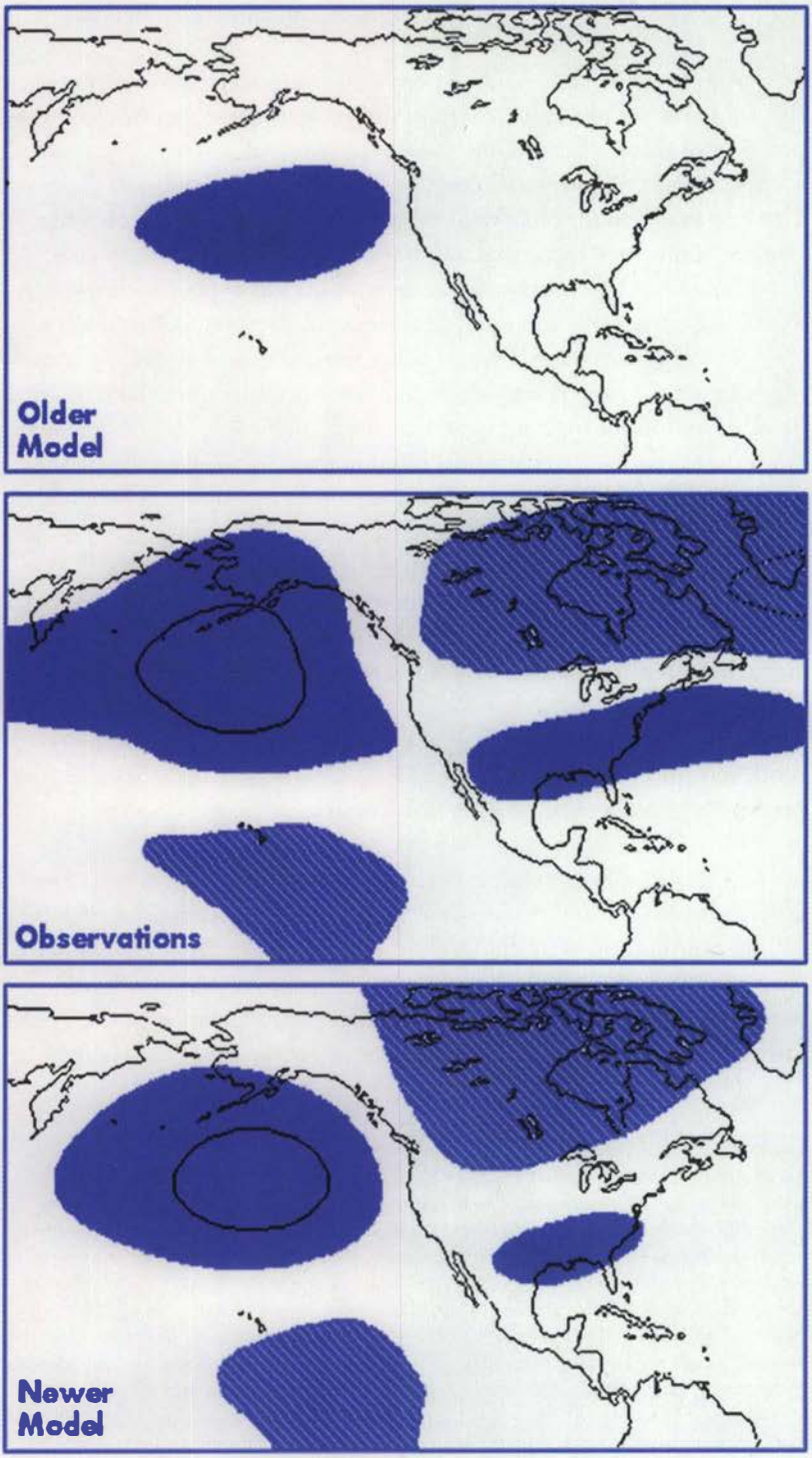
USGCRP-sponsored research continues to achieve results that are directed toward better understanding seasonal to interannual climate variability.

Improved Prediction of El Niño Events

A number of forecasting methods based on numerical models successfully predicted the end of the prolonged El Niño conditons of 1991–95 and their replacement by colder-than-normal conditions in the eastern Pacific in 1996. This change contributed to the drought in the southwestern United States, then the heavy winter precipitation in the West. Predictions of year-to-year climate fluctuation are now being made

Understanding Year-to-Year Climate Fluctuations: Forecasts and Applications

The goal of the seasonal to interannual climate variability component of the USGCRP is to obtain a predictive understanding and the skills to produce forecasts of short-term climate fluctuations and to apply these predictions to problems of social and economic development in the United States and abroad.


Older
Model
Observations
Newer
Model

with longer lead times than previously—more than a year in some cases.

Additionally, studies have been initiated to determine why the 1990s have experienced prolonged multi-year El Niño conditions, in contrast to the mostly single-year events of the 1970s and 1980s. Circumstances such as these are causing scientists to look into the modulation of El Niño by longer time-scale processes.

Satellite and ocean buoy measurements permit extension of our knowledge of changing ocean conditions to the entire tropical Pacific and to higher latitudes.

To improve predictability, a major effort is being mounted to use more complex and sophisticated numerical models to represent the complete scope of interactions between atmosphere and ocean, and to extend the models to include the interaction of the atmosphere with land surfaces, vegetation, and hydrology.

The array of observing instruments in the tropical Pacific Ocean, initiated as part of the Tropical Ocean-Global Atmosphere (TOGA) program, has been augmented by the addition of satellite remotely sensed sea-level elevation and ocean-surface stress generated by winds. These measurements permit extension of our knowledge of changing ocean conditions to the entire tropical Pacific and to higher latitudes and are providing a basis for improved predictions of El Niño occurrences.

Improved Mapping of Global Precipitation Patterns

Precipitation is among the most important climate variables in socio-economic terms because it affects water management and agriculture and causes floods and droughts. The prelude to prediction is the accurate

Figure 2: New model simulations suggest that seasonal mean fluctuations in the climate of North American regions may be predictable during some seasons, especially during El Niño years. The bottom panel shows a 3-month retrospective forecast for the winter of 1988–89, made with a more recent improved climate model assuming that we know global sea-surface temperatures. The model forecasted quite accurately the large-scale shift in the structure of the atmospheric circulation that developed as a result of departures of ocean surface temperatures from their normal conditions. The top panel shows results from a model of 10 years ago, which did not show skill in forecasting this seasonal climate fluctuation. An improved ability to predict the upper atmospheric structure would allow forecasters to adjust their predictions of the track of the jet stream, thus improving predictions of whether winters in particular regions would be warmer or colder, and wetter or drier, than usual (see Appendix D for further information). Source: Center for Ocean-Land-Atmosphere Studies, Calverton, MD.

observation of precipitation patterns and analysis to relate them to other climate variables. An excellent measure of success for climate prediction on seasonal to interannual time scales will be an improved ability to predict the amount and distribution of precipitation.

The USGCRP continues to merge *in situ* (on site) and satellite data to produce the best possible depiction of precipitation patterns. The Tropical Rainfall Measuring Mission (TRMM), a joint U.S.-Japan satellite mission, scheduled for launch in 1997, will provide high-quality remotely sensed observations of precipitation for the entire region between 35°N and 35°S latitudes. It will also provide a basis for accurate estimates of how the rainfall associated with the El Niño and other tropical variations affects the global atmospheric circulation and generates anomalous climatic conditions in far-removed regions of the world.

The USGCRP continues to merge *in situ* and satellite data to produce the best possible depiction of precipitation patterns.

Climate Variability in North America

A 5-year (October 1995 – September 2000) enhanced observing period of the GEWEX Continental-Scale International Project (GCIP) is in progress. GCIP is gathering field data and producing model outputs that will be used to develop improved regional atmospheric, hydrologic, and coupled land-atmosphere models. During the next 2 years, GCIP will focus on three important research priorities: 1) Improving the representation of cold season processes in land-surface schemes for climate models; 2) implementing studies to link Mississippi Basin precipitation patterns to larger external processes during the warm season; and 3) developing links with water resource agencies and implementing projects that apply the results of improved precipitation and soil moisture predictions to hydrologic applications.

One purpose of these studies is to ascertain to what extent year-to-year variability in summer precipitation over North America is predictable.

A Pan-American Climate Studies (PACS) special study has also begun. A primary focus of PACS is improved understanding of the processes at work in the development and decay of the North American monsoon, which is an important annual event (but one that

varies significantly from year to year) in Central America, Mexico, and the U.S. Southwest.

A purpose shared by both GCIP and PACS is to ascertain to what extent year-to-year variability in summer precipitation over North America is predictable. An initial phase of determining year-to-year variability in summer precipitation in North America involves completion of a thorough observational site census.

Applications of Improved El Niño Predictions

A start-up grant for an International Research Institute (IRI) for climate prediction was issued in 1996, and steps are being taken to develop international support for the initiative, which will include a multinational network of research centers and forecast information applications activities. These efforts are intended to:

- Develop and issue experimental seasonal-to-interannual climate predictions based on global and regional modeling of ocean-atmosphere-land surface processes
- Disseminate forecast guidance to nations and regions that are particularly affected by climate variability associated with El Niño
- Tailor global and regional predictions to specific local conditions and needs.

Researchers are investigating how improved predictions can be used in management decisions across a range of economic sectors. For example, a methodology for analyzing the value of El Niño forecasts for salmon fisheries management in the U.S. Pacific Northwest has been developed. Through analysis of relevant physical, biological, economic, and management considerations, options for more efficient fisheries management as a function of possible El Niño effects can be provided. Another USGCRP study has analyzed how improved climate forecasts would affect the agricultural sector nationally and how forecasts could be used to determine likely crop yields and reduce growing costs. The coupling of climate variations to the occurrence and spread of vector-borne diseases is also being examined.

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Climate Change Over Decades to Centuries

A better understanding of the science of climate change is critical to determining an appropriate global mitigation and adaptation policy. Currently, the international community is grappling with the development of such a response strategy, seeking to balance mitigation and adaptation, appropriate action by all nations, and action within a time frame that is scientifically justified and politically and economically feasible.

The United Nations Framework Convention on Climate Change represented the first international policy agreement to address the climate problem. Largely based on the scientific assessments of the Intergovernmental Panel on Climate Change in its first assessment (released in 1990), the Convention was signed into law by the United States and more than 160 other countries starting in 1992. Based on improvements in our understanding of the science of climate change as reflected in the IPCC Second Assessment Report (released in 1995), the community of nations is seeking to strengthen the treaty.

USGCRP-sponsored research continues to advance understanding of climate change processes, prediction of future climate change, and assessment of its implications for society.

Climate Change Processes

Emissions of greenhouse gases continue to rise and, consequently, so do their atmospheric concentrations (with the exception of halocarbons, which are now controlled by the Montreal Protocol on ozone depletion). Halting the rise in the atmospheric carbon dioxide concentration would require significant cutbacks in emissions over the next century. Research

PREDICTING CLIMATE CHANGE AND UNDERSTANDING ITS IMPLICATIONS FOR SOCIETY AND THE ENVIRONMENT

The goal of the climate change component of the USGCRP is to understand, predict, and assess changes in the climate and the global environment that will result from the influences of projected changes in population, energy use, land cover, and other natural and human-induced factors, and to provide the scientific information needed by society to address these changes.

on the carbon cycle is aimed at helping to determine rates and magnitudes of changes in the concentrations of CO_2 and other greenhouse gases in the atmosphere. As one example, studies indicate that forests are taking up about one-third of the carbon dioxide emissions, especially in regions where forest regrowth is occurring, such as the mid-latitudes of the Northern Hemisphere. It is not yet clear, however, how long this might continue.

Studies indicate that emissions of greenhouse gases continue to rise and, consequently, so do their atmospheric concentrations.

Current research, including simultaneous measurements above and below the clouds, is seeking to reconcile theoretical understanding with empirical observations of the absorption of solar radiation in cloudy skies.

New attention is also being given to the couplings among various feedback mechanisms. For example, new observations are planned in high latitudes to address the question: As temperatures rise, to what extent might the formation of low-level stratus clouds moderate the thinning and melting of sea ice in the polar regions? This is important because climate changes in the polar regions play an important role in determining the strength of the deep-ocean circulation, which in turn has a strong influence on mid-latitude climates, including those of North America and Europe.

Predictive Models of Climate Change

Research on past changes in climate is useful in considering the degree of confidence to have in model-derived predictions of climate change. All model simulations of climate changes in the geologic past suggest that the climate system is relatively sensitive to various forcings. Climate models have predicted that temperatures in tropical land areas cooled significantly during the glacial maximum of the last Ice Age, about 20,000 years ago. Recent paleoclimatic research findings are generally consistent with these model predictions.

Significantly improved computer models are becoming available to simulate the global climate and predict future change.

Significantly improved computer models are becoming available to simulate the global climate and predict future change. A new

high-resolution ocean model is simulating ocean currents in the Arctic realistically for the first time. This new model and an associated global ocean model are being coupled to the improved, high-resolution atmospheric model at the National Center for Atmospheric Research. These coupled models will play an important role in simulating climate changes of the recent past and the next century, by including a more complete representation of the relevant climate forcing effects.

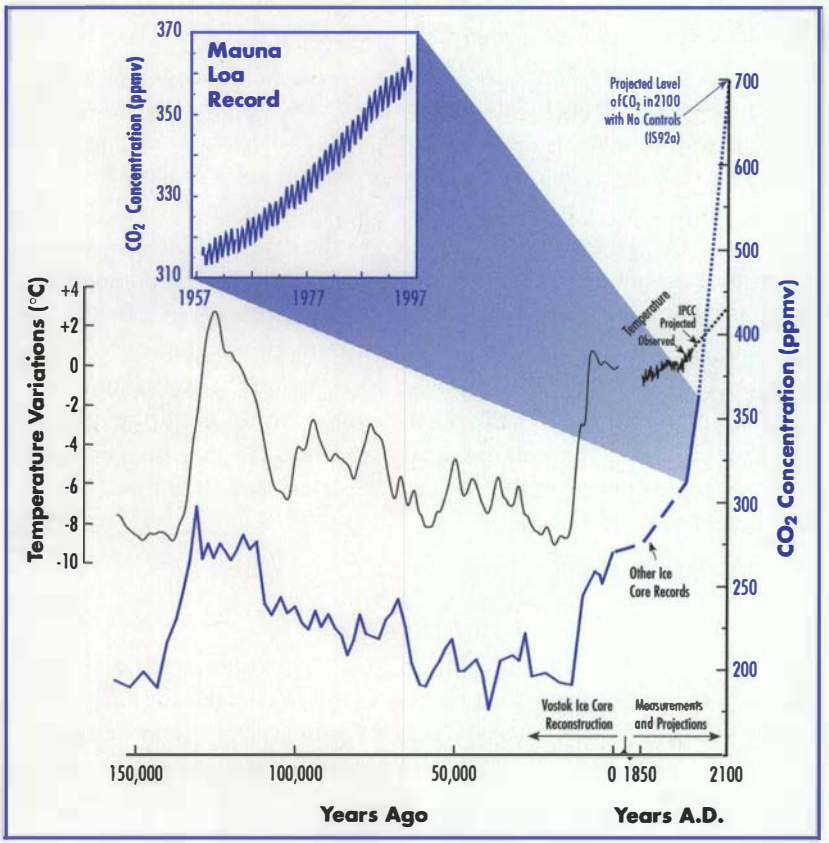


Figure 3: Observations from 150,000 years ago to the present (from ice cores and instrumental observations, including the 40-year Mauna Loa record) suggest a close linkage between carbon dioxide concentrations and temperature, with rising CO_2 contributing to rising temperatures. A central scenario (IS92a) of global CO_2 emissions used in the 1995 IPCC climate change assessment, projected to the year 2100, will lead to a sharply higher CO_2 concentration in the atmosphere, which evidence from past geological periods and from climate models suggests will drive temperatures upward (see Appendix D for further information). Source: The figure was provided by the Carbon Dioxide Analysis and Information Center at the Oak Ridge National Laboratory (ORNL), Oak Ridge, TN, funded by the Department of Energy, using data sets from the Mauna Loa record of C.D. Keeling and the Vostok ice core records of J. Jouzel and J.M. Barnola that are archived at ORNL.

Understanding the Implications of Climate Change

New ocean models will also provide improved estimates of the potential rise in sea level due to global warming. Research suggests that rising sea level will have important effects on coastal wetlands and communities. A rising sea level will amplify the impacts of hurricane-induced storm surges, as recently experienced in the Chesapeake Bay region. Improving models of vegetation will also provide estimates of shifts in vegetation, soil moisture, and runoff, allowing more complete studies of the consequences of long-term climate change.

Ongoing development and testing of integrated climate assessment models include improving the ability of these models to simulate the impacts of climate change on society. A particular challenge is how to model the impacts of global climate change down to regional geographic scales, as well as how to model the impacts on various natural resources and sectors of the economy, including public health. An international assessment of the social dimensions of climate change is currently being completed and will provide new insights into the importance of global change for society.

New ocean models will also provide improved estimates of the potential rise in sea level due to global warming.

Changes in Ozone, UV Radiation, and Atmospheric Chemistry

USGCRP-sponsored research continues to advance understanding of the causes, magnitude, and consequences of changes in stratospheric ozone, UV radiation, and atmospheric chemistry.

Atmospheric Trends in Ozone-Depleting Chemicals

Satellite monitoring of trends in chlorine and fluorine levels in the stratosphere has demonstrated unambiguously that emissions of the chlorofluorocarbons (CFCs) and the hydrochlorofluorocarbons (HCFCs) from human activities are responsible for the observed five-fold increase in ozone-depleting chlorine above its natural background level in the stratosphere. These measurements, which account for the chlorine mass balance to within a few percent, are essential to understanding the full suite of chlorine sources in the stratosphere.

Understanding Atmospheric Chemistry and its Links to Human Well-Being

The goal of the atmospheric chemistry component of the USGCRP is to understand and characterize the chemical changes in the global atmosphere and their consequences for human well-being.

The measurements disprove any residual speculations that increases in stratospheric chlorine could be attributable to natural sources. When combined with recent observations of the first decreases in chlorine abundances in the troposphere, these observations further strengthen confidence that international decisions to phase out CFCs under the Montreal Protocol will lead, over time, to rehabilitation of the stratospheric ozone layer.

These observations further strengthen confidence that international decisions to phase out CFCs under the Montreal Protocol will lead, over time, to rehabilitation of the stratospheric ozone layer.

The Ozone Depletion Link to Climate Change

Model simulations have shown that observed latitudinal patterns of lower stratospheric cooling during the last decade are consistent with those expected from observed depletion of lower stratospheric ozone. Because of the connection between ozone depletion and emissions of halocarbons from human activities, the depletion of ozone combined with its "fingerprint" on global lower stratospheric temperatures is a strong component of the "discernible human influence on global climate" reported in the recent *Climate Change 1995* assessment of the Intergovernmental Panel on Climate Change.

One outcome of the anticipated rehabilitation of the ozone layer over the coming decades may be a clearer unmasking of enhanced greenhouse warming.

The magnitude of the cooling induced by ozone depletion during the past decade greatly exceeds the lower stratospheric radiative cooling calculated to have resulted from the combined emissions of all of the other greenhouse gases since preindustrial times. The cooling induced by ozone depletion partially offsets the global warming of the

troposphere that results from the greenhouse effect. With the anticipated rehabilitation of the ozone layer over the coming decades, this cooling offset will diminish, raising the possibility that one outcome will be a clearer unmasking of enhanced greenhouse warming.

Observed Increases in Ground-Level Ultraviolet Radiation

Satellite observations of global ozone depletion gathered with the Total Ozone Mapping Spectrometer (TOMS) instrument, combined with measured changes in clouds and aerosols, have been used to infer increases in ground-level ultraviolet (UV-B) radiation. Poleward of about 40° latitude, statistically significant increases are calculated for the period between 1979 and 1992. The largest calculated increases in ground-level UV-B occurred at higher latitudes in winter and spring, with the most important increases occurring at the shorter, more damaging wavelengths.

At 45°N latitude (e.g., Portland, Minneapolis, Montreal, southern France, northern Italy), springtime exposure to DNA-damaging and erythemal (sunburn-inducing) radiation has increased.

For example, at 45°N latitude (e.g., Portland, Oregon; Minneapolis; Montreal; southern France; northern Italy; Bosnia), springtime exposure to DNA-damaging and erythemal (sunburn-inducing) radiation is calculated to have increased by 8.6% and 5.1% per decade, respectively, for the past 2 decades. Over highly populated areas at 55°N latitude (e.g., the United Kingdom, Scandinavia, Russia), springtime increases have been even larger, and the year-round average exposure has increased by 6.8% and 4.3% per decade. These observations quantify the previously estimated increases in ground-level UV-B associated with stratospheric ozone depletion, underscoring the importance of measures taken under the Montreal Protocol to protect the ozone layer.

Over highly populated areas at 55°N latitude (e.g., the United Kingdom, Scandinavia, Russia), springtime increases have been even larger.

Effects of UV Radiation on Human Health

Since UV radiation is a human carcinogen, a primary focus of research is to discover how it initiates or promotes cancer. Scientists have recently

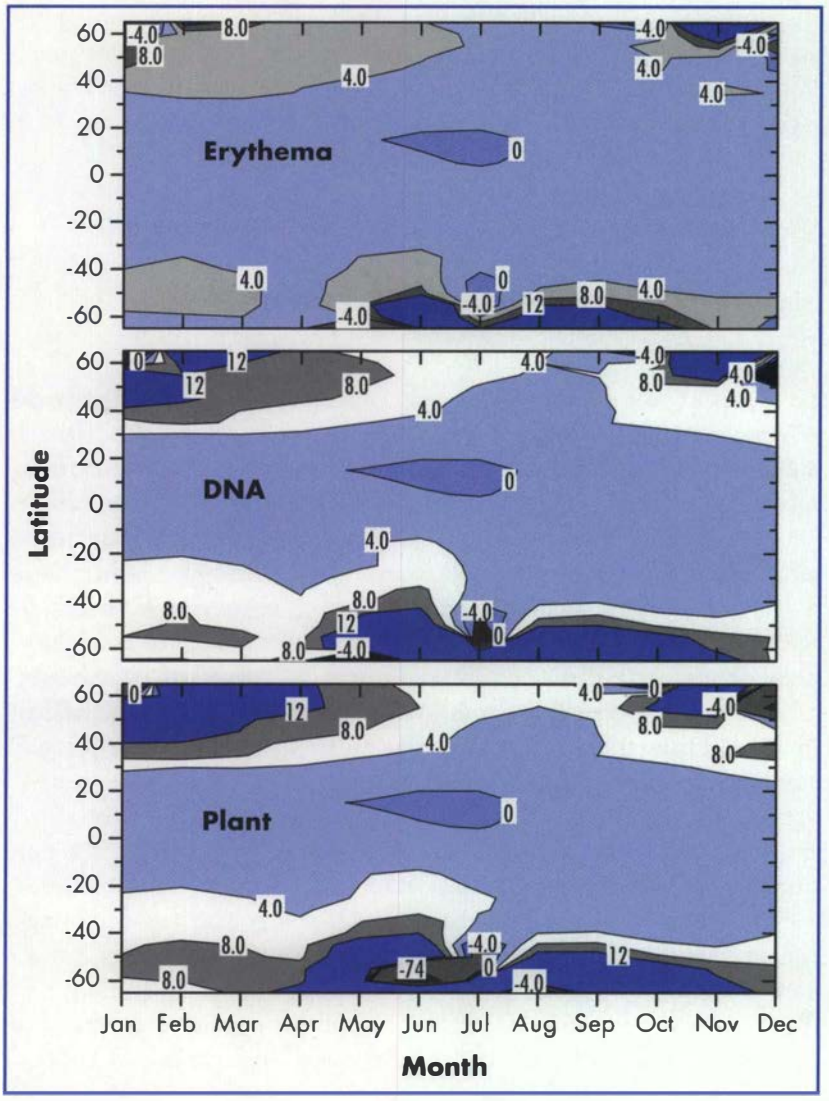


Figure 4: Stratospheric ozone depletion is allowing increased amounts of ultraviolet (UV) radiation to reach people, plants, and animals. Increased exposure of the skin (or erythema) leads to increased incidence of skin cancer (top panel). Increased exposure of DNA leads to genetic damage (middle panel). Increased exposure of plants can alter plant flowering and survival (bottom panel). Currently, the significant increases in exposure (shown here in percentage change per decade) are occurring in mid- and high latitudes (see Appendix D for further information). Source: J.R. Herman, P.K. Bhartia, J. Ziemke, Z. Ahmad, and D. Larko, 1996: "UV-B increases (1979–1992) from decreases in total ozone," Geophysical Research Letters, **23**, *21107-21120.*

found evidence that a particular gene stands guard against the most common skin cancer, basal cell carcinoma, and that damage to the gene leads to skin cancer. Some of the mutations in this gene can be caused by UV exposure, which is known to promote basal cell carcinoma.

Other research results have provided new and important information related to the signaling pathway of UV-B, offering an explanation for why individuals with different pigmentary characteristics have different levels of risk for developing sun-induced skin cancers. In addition, UV radiation from sunlight has been implicated in the high incidence of skin cancer found in patients receiving azathioprine for treatment of rheumatoid arthritis.

Researchers have developed a novel and uniquely sensitive technique to map UV effects and their repair rates at the DNA sequence level in human genes.

Researchers have developed a novel and uniquely sensitive technique, the Ligation-Mediated Polymerase Chain Reaction, to map UV effects and their repair rates at the DNA sequence level in human genes. Using this methodology, they have found that repair rates can vary dramatically with sequence position. Slow repair contributes significantly to the chance for mutation in a cancer-relevant gene. This new technology has provided insights that will aid in understanding the mechanism of cancer development resulting from increased exposure to UV radiation.

Changes in Land Cover and in Terrestrial and Aquatic Ecosystems

USGCRP-sponsored research continues to advance understanding of the causes, magnitude, and consequences of changes in land cover and in terrestrial and aquatic ecosystems.

Global Ecosystems and the Dynamics of Sustainability

The goal of the land cover and ecosystems component of the USGCRP is to provide a stronger scientific basis for environmental and natural resource practices that are environmentally sound, practical, and that will yield sustainable benefits to humankind.

Terrestrial Ecosystems and the Carbon Cycle

Measurement and analysis of changes in the atmospheric concentration of oxygen and the ratio of ^{13}C to ^{12}C in atmospheric carbon dioxide support the hypothesis that, in the 1990s, terrestrial ecosystems of the mid-latitudes of the Northern Hemisphere have functioned as a significant "carbon sink," sequestering up to about a third of the carbon from fossil fuel emissions. Without this sink, the rate of CO_2 accumulation in the atmosphere would have been even greater.

Periodic measurements are now being taken that will lead to improved estimates of the effects of year-to-year climate variability on carbon exchange between land ecosystems and the atmosphere. This information can be used to develop and test process-based ecosystem models that are important components of the larger Earth system models. These models are critical research tools in global change science and assessment.

New land-cover data for South America, Southeast Asia, and the conterminous United States, developed from Landsat products, will facilitate better estimates of rates of deforestation and of the flux of carbon to the atmosphere associated with forest clearing. The land-cover data for the conterminous United States, which have a 1-km resolution, are an important information base for resource managers working on regional-scale planning.

New land-cover data for South America, Southeast Asia, and the United States will improve estimates of deforestation rates.

Ecosystem Response to Increasing Atmospheric CO_2

With continued use of fossil fuels, atmospheric CO_2 concentrations will continue to rise substantially over at least the next century. A long history of CO_2-enhancement studies in greenhouses, open-top chambers, and other carefully controlled growing conditions has already led to substantial understanding of the basic physiological responses governing carbon fixation in high-CO_2 atmospheres.

There are still relatively few data on how entire ecosystems respond to increases in CO_2.

However, there are still relatively few data on how entire ecosystems respond to increases in CO_2. A network of field experiments using

Free Air CO_2 Enrichment (FACE) technology has now been implemented to evaluate responses of terrestrial plants and ecosystems at elevated concentrations of atmospheric CO_2 expected in future decades. Initial data from crop and forest experiments suggest increased growth and net carbon sequestration in perennial ecosystems when plants are grown in the field at elevated CO_2 concentrations. These long-term experiments will continue to lay the scientific foundation for understanding the consequences of future emissions of CO_2 from combustion of fossil fuels.

A network of stations to measure the uptake and release of CO_2 will be expanded to include a representative set of native ecosystems and a variety of land-use and land-cover types. The expanded network of measurements will be coordinated with research on processes and with studies of climatic and human factors that influence terrestrial systems.

This research will be used to refine scientific understanding of the processes that determine net carbon uptake by plants and soils and to improve the accuracy of predictions of future atmospheric CO_2 concentrations. The results will help to provide the scientific basis for consideration of options for stabilizing atmospheric CO_2 concentrations.

Climate Change Impacts on Terrestrial Ecosystems

Large-scale ecosystem modeling efforts are making important progress. The models can be used to simulate a range of ecological responses to changes in climate and the chemical composition of the atmosphere, including changes in the distribution of terrestrial plant communities across the globe as climate changes (see data product on back cover).

Research suggests that fire in mountain regions is likely to be increased not only by global warming but also by increased climatic variability. Analysis of the Colorado Rocky Mountains Front Range demonstrates that, over the past 400 years, fire occurrence has been extremely sensitive to climatic variability.

Fire occurrence in the Colorado Rocky Mountains Front Range has been extremely sensitive to climatic variability.

One of the expected consequences of global warming is rising sea level. The loss of coastal wetlands in the southeastern United States has been accelerated by sea-level rise during the past 50 years. Researchers

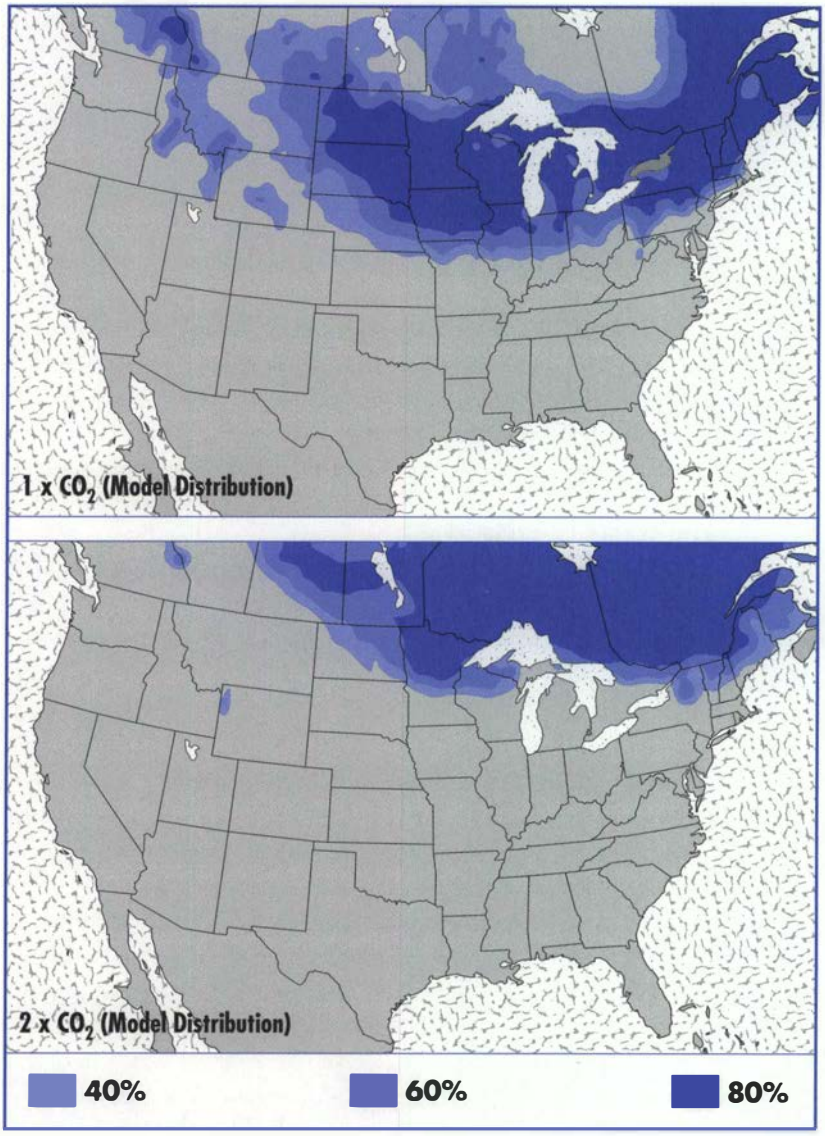


Figure 5: Global climate change will cause rising temperature, changes in precipitation, and shifts in vegetation. These changes will cause shifts in the habitats suitable for various plants and animals. Based on simulations with an observationally based model that closely matches the current summertime distribution of bobolinks, the shifts in climatic conditions that would result from a doubling of the atmospheric CO_2 concentration are predicted to cause this migratory North American songbird to relocate northward (percentages are of abundance relative to the maximum density of bobolinks). Such poleward shifts are indicative of how many landscapes and species will be affected by and respond to global warming (see Appendix D for further information). Source: Redrawn from article by S.H. Schneider and T.L. Root entitled "Climate Change," appearing in Status and Trends of the Nation's Biological Resources, *edited by M.J. Mac, P.A. Opler, C. E. Puckett-Haecker, and P.D. Doran, U.S. Dept. of the Interior, 1997.*

are seeking a better understanding of the implications of continued sea-level rise for a range of wetlands ecosystems:

- Forested wetlands at low elevations are among the coastal plant communities considered most vulnerable to losses due to sea-level rise. Research indicates that large-scale shifts and/or losses in wetland forest communities will occur over the next 50 years if sea-level rise continues its current amplified trajectory.
- Research indicates that, at projected levels of sea-level rise over the next century, major portions of the coastal zone of northwestern Florida will be converted from coastal salt and freshwater marsh to open water, approaching the scale of marsh loss that has been experienced in Louisiana.

Marine Ecosystems

Recent studies in the tropical Pacific Ocean indicate that iron, which is relatively abundant in waters near land, may be the limiting nutrient in determining primary production of marine life in the blue waters of the central ocean basins. In a series of field experiments involving controlled additions of iron salts to surface waters, scientists documented dramatic plankton blooms and concomitant drawdown of other excess nutrients. These results are encouraging studies of factors controlling primary production, carbon cycling, and ocean-climate impacts elsewhere in the world ocean.

Scientists are studying the implications of decadal-scale climate-related events for marine resource populations.

Recent modeling studies have shown that unusual physical conditions along the break in the Georges Bank shelf off the northeastern U.S. coast during the 1950s and 1960s can be traced to changes in the cold Labrador Current. Scientists are evaluating the impact of such decadal-scale climate-related events on the dynamics of planktonic animal populations, which in turn influence marine resource populations.

3. Integrating Activities and Perspectives

To provide the basis for continuing advancement in scientific understanding and to fulfill the U.S. commitment to international leadership in global change research, the USGCRP supports a number of integrative and cooperative efforts, which contribute in varying degrees to all of the priority environmental science issues discussed in Chapter 2:

- Observing and monitoring global change
- Global change data, products, and information services
- Earth system science
- Human contributions and responses to global change
- International research cooperation
- Global change education and communication.

Observing and Monitoring Global Change

Observations of the global environment are critical for documenting global change and for providing the basis for how and why changes are occurring. To advance our understanding of the Earth system and our ability to predict how it will change in the future requires detailed knowledge of the behavior and state of the atmosphere, the land and its vegetative cover, the oceans, and the polar regions.

Systematic monitoring and observation on scales from regional to global requires not only satellite-based observations, but also a wealth of diverse, detailed observations from *in situ* (on site) measurements. A strong infrastructure of surface observation sites is essential for research and for resource management and planning.

Moving Toward an Integrated Global Observing and Monitoring System

The goal of the USGCRP observation and monitoring program is to ensure the availability of a long-term, high-quality observational record of the state of the Earth system, its natural variability, and changes that are occurring over extended time scales.

Only with information from this full range of observational efforts will a capability be developed to document and understand global change, to determine and understand its consequences for humans and ecosystems, and to plan and evaluate measures to aid in adaptation to and mitigation of change.

Only with information from a full range of observational efforts will a capability be developed to document and understand global change and its consequences for humans and ecosystems.

Current Developments

Global Observing System

Over the past year, the USGCRP has intensified planning activities in support of international efforts to design and implement a global observing system. This system will build upon the present system of meteorological satellites and surface networks. Existing meteorological satellite and surface systems, with some adjustments in procedures and instruments, can provide much of the information that is needed. USGCRP efforts are focused on determining how best to augment available observation capabilities, on developing the tools for cost-effectively making new measurements, and on assembling and processing observations taken in the past for use in global change studies.

Tropical Rainfall Measuring Mission

NASA is on schedule for a 1997 launch of the Tropical Rainfall Measuring Mission (TRMM), a cooperative program with Japan, to get the first direct measurements of rainfall in regions of the world where convective precipitation is most frequent and intense.

NASA is on schedule for a 1997 launch of the Tropical Rainfall Measuring Mission.

Landsat and the Earth Observing System

The Landsat and Earth Observing System (EOS) satellite programs are also moving along on schedule, with important launches scheduled for

Measurements

Measurements	Seasonal to Interannual Climate Variability	Climate Change Over Decades to Centuries	Changes in Ozone, UV Radiation, and Atmospheric Chemistry	Changes in Land Cover and in Terrestrial and Aquatic Ecosystems
Atmosphere Set				
Aerosol Properties (natural and human-induced)	✘	✘	✘	
Atmospheric Humidity	✘	✘	✘	✘
Atmospheric Temperature	✘	✘	✘	✘
Cloud Amounts, Types, and Properties	✘	✘	✔	
Lightning	✔	✔	✔	
Precipitation	✘	✘	✔	✘
Radiative Energy Fluxes	✘	✘	✔	✔
Stratospheric Chemistry	✔	✔	✘	
Tropospheric Chemistry	✔	✘	✘	✔
Solar Radiation Set				
Total Solar Irradiance	✔	✘		
Ultraviolet Spectral Irradiance	✔	✔	✘	✔
Land Set				
Fire Occurrence	✔	✔	✔	✘
Land Cover and Land Use Change	✔	✔	✔	✘
Surface Temperature	✘	✘	✔	✘
Surface Wetness	✘	✔		✘
Vegetation Dynamics	✔	✔		✘
Volcanic Effects (on surface)	✘	✔	✘	✔
Ocean Set				
Ocean Surface Topography	✘	✘		✔
Phytoplankton and Dissolved Organic Matter	✔	✔	✔	✘
Surface Temperature	✘	✘		✔
Surface Wind Field	✘	✔		
Cryosphere Set				
Land Ice	✔	✘		✔
Sea Ice	✘	✘		
Snow Cover	✘	✘		✔

KEY

✘ Essential Contribution

✔ Supporting Contribution

1998. EOS will provide data sets of global measurements related to the atmosphere, solar radiation, the land surface, the oceans, and the cryosphere. The table on the previous page summarizes the EOS contributions to USGCRP research goals. The table lists the various sets of measurements to be taken by the EOS series of satellites and their applicability to research on key global change environmental science issues.

NASA Scatterometer

The NASA Scatterometer (NSCAT) was successfully launched on the Japanese Advanced Earth Observing Satellite (ADEOS) in August 1996.

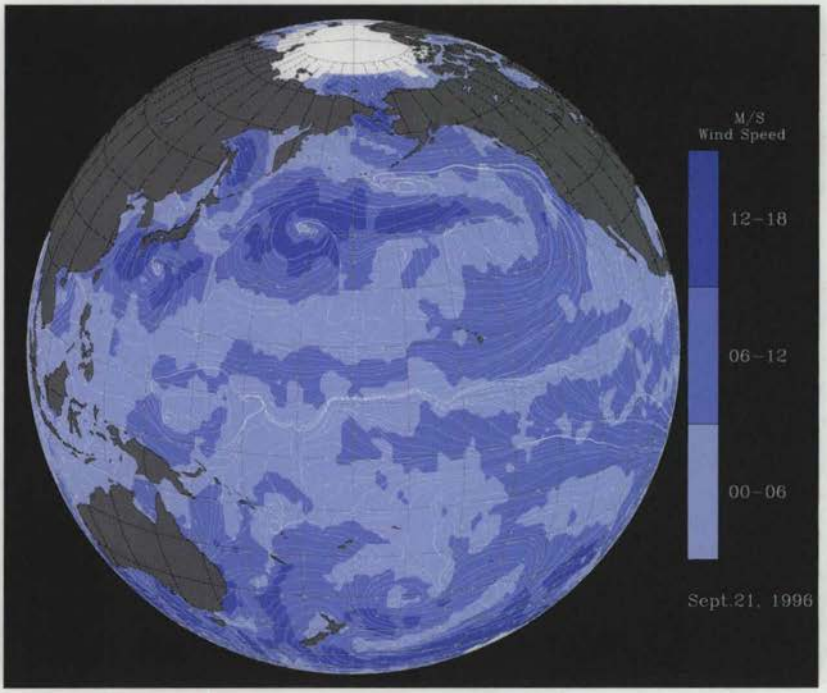


Figure 6: Data from the recently launched NASA scatterometer (NSCAT) instrument aboard Japan's Advanced Earth Observing Satellite (ADEOS) can be used to estimate wind speed and direction over the oceans, where surface observations have previously been very sparse. The blue shading shows wind speed and the arrows show wind direction for September 21, 1996, at noon Greenwich time. Having this information on a regular basis will improve forecasts of the weather, of severe storms, and of the slowly changing ocean conditions that play a major role in determining how the seasonal climate will vary in the tropics and over North America. In this figure, two typhoons are present in the western Pacific Ocean and other features such as the trade winds are shown (see Appendix D for further information). Source: Figure provided by W.T. Liu and W. Tang of the NASA Jet Propulsion Laboratory.

The six NSCAT antennas scan two 600-km bands of the ocean, providing data on surface wind speed and direction at 25-km resolution under both clear and cloudy conditions. Winds drive ocean current, which transports the heat stored in the ocean. By redistributing the heat in both atmosphere and ocean, winds play a crucial role in moderating the world's climate. With its repeated global coverage, NSCAT is the only means of measuring ocean surface winds at the temporal and spatial scales adequate for the study of global change, while also providing spatial resolution adequate for investigation of hurricanes and storms.

With two more NASA Scatterometers to be launched on ADEOS-II and ADEOS-III in 1999 and 2002, continuous global wind measurements will be realized for at least a decade. This will allow studies linking seasonal, interannual, and decadal variabilities, and enhance understanding of how long-term and global changes are manifested in local and short-term weather and natural hazards.

Tropical Ocean Array

NOAA support for the Tropical Ocean Array (TOA) of ocean buoys in the mid-Pacific, deployed and maintained in cooperation with other nations of the Pacific Rim, is ensuring real-time observations of surface and upper ocean temperatures and ocean surface conditions. These data are needed in order to "initialize" the models that are being used to predict upcoming fluctuations of the seasonal climate, including droughts and flooding rains in regions of the United States.

Observations of Changing Atmospheric Composition

NOAA observations of atmospheric composition are providing several interesting findings. The atmospheric concentrations of key chlorofluorocarbons (CFCs) are now starting to drop, which should lead to the start of the recovery of the stratospheric ozone layer over the next decade. The annual increase in the atmospheric concentration of carbon dioxide, which dropped following the

The annual increase in the atmospheric concentration of carbon dioxide, which dropped following the Mount Pinatubo volcanic eruption, is again at significant levels.

Mount Pinatubo volcanic eruption, is again at significant levels. Studies of changes in the isotopic ratios of CO_2 suggest that the changes in climate resulting from the eruption (i.e., cooling and shifted precipitation patterns) may have had an influence in slowing the rate of rise in its concentration. Understanding these changes may help in estimating future biogeochemical feedbacks involving carbon stored in the soils and vegetation.

Global Positioning System/Meteorology (GPSMet)

NSF, NOAA, NASA, and the Federal Aviation Administration (FAA) combined with industrial partners Orbital Sciences Corporation and Allen Osborne Associates to support the 1995 launch of a proof-of-concept version of a GPSMet satellite, which is able to provide about 500 measurements daily of the temperature profile of the atmosphere. Initial results compare well with measurements by weather balloons from 40 km down to ~5 km above the surface, thereby potentially extending the information provided by the balloon measurements well up into the stratosphere and out over the world's oceans.

The expanded record from this satellite and follow-ons being planned will provide much more consistent and extensive global coverage to much higher altitudes than is currently available. This will lead to improved forecasts of the weather and seasonal climate fluctuations.

Extending Accurate Records into the Past

NOAA and NASA are also making significant progress in assembling and reprocessing observations over the past 30 years into completely self-consistent data sets of lower and upper atmospheric behavior. These reanalyses of past data are extending accurate records back into the past using the best analysis techniques and understanding now available. Since there have been some quite significant climate fluctuations and changes over the past several decades, these data sets will be essential in testing computer models of the atmosphere.

These data sets of observations over the past 30 years will be essential in testing computer models of the atmosphere.

Global Change Data, Products, and Information Services

Data and information on global change are needed by users for a wide range of purposes, including:

- Scientific research to investigate Earth system processes and to monitor, document, understand, and predict global and regional changes in climate, atmospheric chemistry, and ecosystems
- Provision of information on global change and the progress of the USGCRP to policymakers, educators, the communications media, and the public.

Data and information to meet these needs cover the physical, chemical, biological, and social sciences. Important basic data and derived data products include everything from temperature and pressure in the atmosphere, to current and salinity in the oceans, to vegetation and population on land. The spatial scales range from local observations to globally integrated patterns. The temporal scales range from instantaneous observations to multi-century trends, both past and future. The spectrum of data sources includes:

- Observations taken by satellites, aircraft, ships, surface stations, and field personnel
- Simulations by models
- Data and information produced by research studies.

Global Change Data and Information System (GCDIS)

The USGCRP has endorsed the concept of a distributed (decentralized) database. The Federal agencies involved in the USGCRP have cooperated to establish the Global Change Data and Information System. GCDIS builds upon the mission resources and responsibilities of each agency and links the data and information services of the agencies to

Meeting User Needs for Full and Open Access to Useful Products and Services

The goal of the data, products, and information services element of the USGCRP is to provide to all users ready and affordable access to the full spectrum of global change data, products, and information in useful forms.

each other and to users. In addition to GCDIS, an associated Global Change Research Information Office (GCRIO) was established in 1993, to provide a USGCRP information resource service both nationally and internationally.

Policy Statements on Data Management for Global Change Research were issued in 1991, by the President's Office of Science and Technology Policy. Detailed GCDIS plans were published in Program and Implementation Plans (in 1992 and 1994, respectively), which were endorsed by the President's Science and Technology Adviser. GCDIS now includes more than 70 data center, library, and information service nodes in seven Federal agencies. Both GCDIS and GCRIO can be accessed on the Internet by web browsers and gopher as well as by phone, fax, e-mail, and postal mail (see Appendix E for contact information).

New Challenges

New challenges facing the Global Change Data and Information System include:

- Providing a major increase in GCDIS coverage to meet expanding USGCRP needs for data and information from the biological, economic, and social sciences, and for regional- and local-scale data.
- Expanding full and open data and information availability nationally and internationally in the rapidly changing technological and policy environment.

GCDIS faces the challenge of expanding full and open data and information availability nationally and internationally in the rapidly changing technological and policy environment.

Earth System Science

Global environmental changes are the result of a complex interplay among a number of natural and human systems. The totality of those systems has come to be called the Earth system. From its inception, the USGCRP has been driven by the philosophy that a holistic view of the Earth system is essential to develop answers to fundamentally important questions about environmental change and its impacts and consequences.

Policy Statements on Data Management for Global Change Research

- The U.S. Global Change Research Program requires an early and continuing commitment to the establishment, maintenance, validation, description, accessibility, and distribution of high-quality, long-term data sets.
- Full and open sharing of the full suite of global data sets for all global change researchers is a fundamental objective.
- Preservation of all data needed for long-term global change research is required. For each and every global change data parameter, there should be at least one explicitly designated archive. Procedures and criteria for setting priorities for data acquisition, retention, and purging should be developed by participating agencies, both nationally and internationally. A clearinghouse process should be established to prevent the purging and loss of important data sets.
- Data archives must include easily accessible information about the data holdings, including quality assessments, supporting ancillary information, and guidance and aids for locating and obtaining the data.
- National and international standards should be used to the greatest extent possible for media and for processing and communication of global data sets.
- Data should be provided at the lowest possible cost to global change researchers in the interest of full and open access to data. This cost should, as a first principle, be no more than the marginal cost of filling a specific user request. Agencies should act to streamline administrative arrangements for exchanging data among researchers.
- For those programs in which selected principal investigators have initial periods of exclusive data use, data should be made openly available as soon as they become widely useful. In each case, the funding agency should explicitly define the duration of any exclusive-use period.

Toward a Predictive Understanding of Variations and Changes in the Earth System

The goal of the Earth system science component of the USGCRP is to support the long-term, integrated, and exploratory research needed to gain a predictive understanding of the interactions among the physical, chemical, geological, biological, and solar processes that determine the functioning of the Earth system and its trends and fluctuations on global and regional scales.

Earth System Science refers to the many linkages and relationships among the Earth's air, water, land, ice, plants, and animals, including humans. Of necessity, Earth system science requires a broad range of studies that involve observations, analyses, theory, modeling, and assessment. The scope of these studies ranges from regional to global and encompasses phenomena and processes within the atmosphere, land, oceans, and biosphere.

Earth system science is a paradigm for integrating diverse sets of knowledge developed within the elements of the USGCRP, to derive a view of the Earth's environment as a whole. The integration, testing, and application of existing and new knowledge produced by the full suite of USGCRP programs is proceeding by means of fully coupled and interactive Earth system models.

Earth System Science is a paradigm for integrating diverse sets of knowledge to derive a view of the Earth's environment as a whole.

Human Contributions and Responses to Global Change

From its inception, the USGCRP has considered people to be an integral component of the integrated Earth system. As a result, USGCRP agencies have developed a complementary set of programs designed to improve knowledge of the ways that humans contribute and respond to global change.

Human contributions and responses research within the USGCRP focuses on three major forms of interaction:

- Human contributions to climate change
- Responses to the consequences of climate change
- Proactive strategies for dealing with global change.

Human Contributions to Global Change

This line of research focuses on the ways that human activities contribute to changes in other components of the Earth system. Research on human contributions is critical for understanding the complex dynamics that result in longer term climate change, changes in atmospheric chemistry, and changes in land cover and ecosystems.

USGCRP research examining the dynamics of land-use change in tropical forests, for example, has highlighted the complex interplay among factors as diverse as soil quality, the presence of roadways, fluctuations in world markets for various commodities, and legal systems that influence land ownership. Given the presence of these and other variables, predicting future rates of deforestation and reforestation cannot be done through simple extrapolation of past trends.

Responses to the Consequences of Global Change

A second major line of research focuses on the consequences of natural and human-induced change for the health and well-being of humans and their institutions. As climate fluctuates and changes, as the composition of gases in the atmosphere is altered, and as land cover and ecosystems are transformed, the impacts of changing environmental conditions on humans can be dramatic and diverse.

Research examining the ways that humans respond to environmental change has shown that farmers have adapted practices to a diversity of climates around the globe and to considerable short- and medium-term climate variability. The record of adaptation in farming suggests considerable potential to adapt to long-term climate change through changes in crops and cultivars raised, through altered tillage, irrigation, and harvesting practices, and through changes in planting

Toward an Understanding of the Human Dimensions

The goal of this component of the USGCRP is to identify, understand, and analyze how human activities contribute to changes in natural systems, how the consequences of natural and human-induced change affect the health and well-being of humans and their institutions, and how humans could potentially respond to problems associated with environmental change.

schedules. Successful adaptations by farmers could well offset much of the deleterious impacts on global food production associated with a doubling of carbon dioxide in the atmosphere. However, the opportunities for and costs and effectiveness of adaptation strategies vary by location, with the implication that the consequences for agriculture will be highly variable across areas.

Successful adaptation is facilitated by the ability to accurately anticipate or predict future changes at regional or local scales, an ability that is currently weak with regard to long-term climate change. For shorter term fluctuations, such as weather patterns associated with the El Niño Southern Oscillation, USGCRP research has shown that advances in the ability to predict these events can significantly enhance the ability of farmers, forest managers, fishers, and others to adapt successfully to variable climatic conditions. An important question to investigate is whether and how long-term climate change may affect the ability to predict short-term fluctuations and the ability to adapt successfully to these fluctuations.

Successful adaptations by farmers could well offset much of the deleterious impacts of long-term climatic change on global food production. However, success will vary by location and some locations may experience adverse effects.

Proactive Strategies for Dealing with Global Change

The third major line of research also focuses on responses; but, rather than identifying the ways that humans react to change already underway, it concentrates on the proactive ways that people and institutions anticipate and develop strategies for dealing with different facets of global change. Among the kinds of USGCRP research related to this theme are projects that analyze the strategies that resource managers employ to deal with changing environmental conditions.

For example, research on water management approaches involves modeling and analysis of regional hydrology, water markets, and ecosystem dynamics. One computer-assisted management system that will be tested in California soon is aimed at increasing the flexibility of

A new management system soon will be tested in California to increase the flexibility of water managers to deal with changing water quality, supply, and demand.

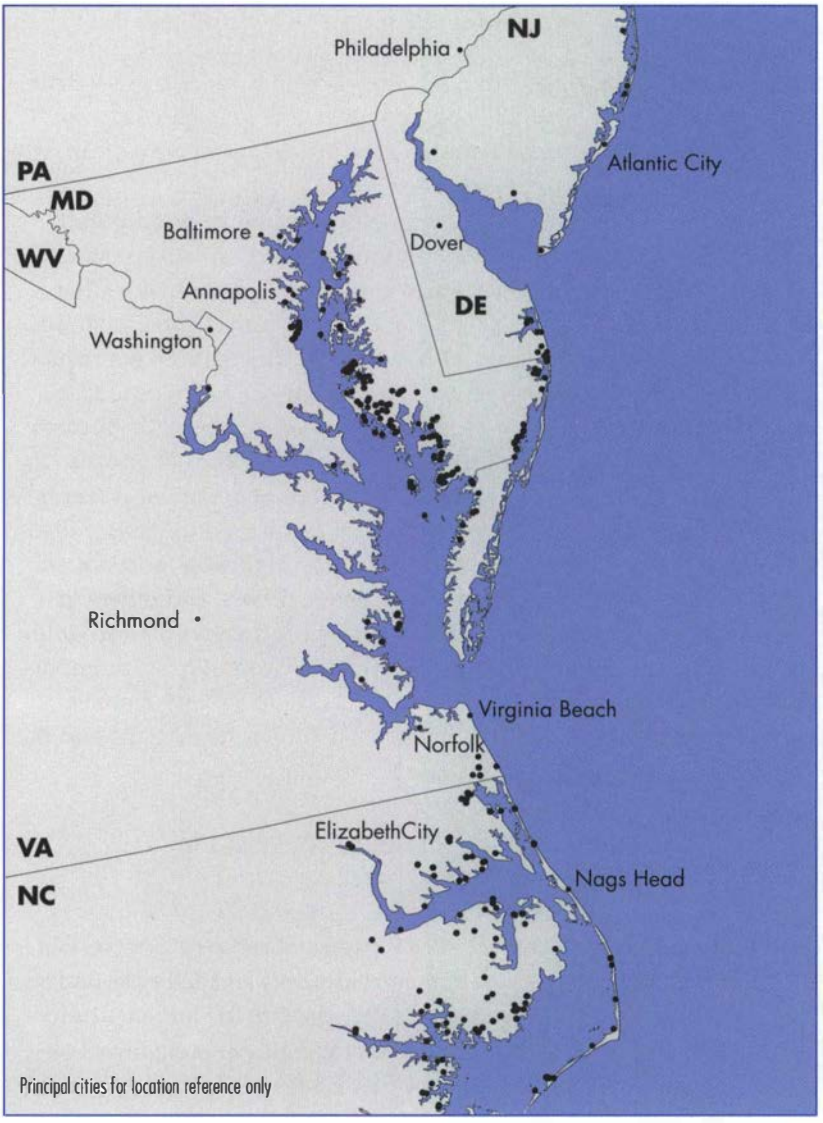


Figure 7: Over the past 100 years, sea level has risen about 0.3 m (~12 in) in the U.S. Mid-Atlantic region. About half of this change has been due to worldwide sea-level rise and about half has been due to other factors. Climate change is projected to cause the rate of global sea-level rise to increase, implying an overall rise of ~0.65 m (~26 in) by 2100 in the Mid-Atlantic region. The dots on this map show populated places, primarily in low-lying coastal areas (elevations of 1 m or less), that have homes and/or municipal infrastructure that may be increasingly exposed to ocean influences, particularly during storms and high tides (see Appendix D for further information). Source: Department of the Interior, U. S. Geological Survey.

water managers to deal with changing water quality, supply, and demand.

Integrated Assessment Methods and Models

In addition to examining these separate dimensions of human and environmental interaction, researchers focusing on human contributions and responses to global change also have recognized the need for improving models and other representations of the complex feedbacks among human and natural systems over time. Progress has been made, for example, in the development and refinement of methods for integrated assessment.

As a demonstration of this progress, various types of climate models have been linked with models that replicate economic activity and the propensity of different populations to favor various strategies for dealing with environmental problems. Through integration and refinement of these types of models, decisionmakers and citizens can:

- Better determine how future human activities will impact the environment
- Explore the possible impacts and efficacy of different response strategies.

International Research Cooperation

The United States—through its scientists, scientific research institutions, and Federal agencies—strongly supports and participates in international efforts that bring research scientists and their institutions and programs together in internationally coordinated research programs through multilateral organizations and bilateral arrangements.

The U.S. Commitment to Leadership and Coordination

The goal of the international research cooperation component of the USGCRP is to support and assist the program and its participating scientists and their interactions with related international research, observing, and assessment activities and in the full and open international sharing of data and research findings.

Only through such coordinated efforts can the critical mass of scientists, scientific and financial resources, and management support be aggregated to achieve the objectives of global change research and assessment.

The Major International Science Programs

The core of the international efforts in this area are the three major international programs developed by the research community to address scientific questions related to global change:

- *World Climate Research Programme (WCRP)*: The WCRP, jointly sponsored by the International Council of Scientific Unions (ICSU) and the World Meteorological Organization (WMO), seeks to lay the scientific foundation for predicting the response of the Earth's climate to natural and human influences. The United States will co-sponsor with WMO and ICSU a major scientific conference on the WCRP in mid-1997, to review scientific progress to date.
- *International Geosphere-Biosphere Programme (IGBP)*: The ICSU-sponsored IGBP is focused on acquiring basic scientific knowledge about the interactive processes of biology and chemistry of the Earth as they relate to global change. Priority is given to research on key interactions and significant changes on time scales of decades to centuries that most affect the biosphere, that are most susceptible to human perturbations, and that will most likely lead to a practical, predictive capability.
- *International Human Dimensions Programme (IHDP)*: The IHDP was initiated under the aegis of the International Social Science Council (ISSC), and ICSU has recently become a co-sponsor. The IHDP Secretariat is currently setting up its office in Bonn, Germany.

These programs and a wide range of bilateral and multilateral research activities have identified many of the key scientific problems that need to be addressed on the global scale; have developed the scientific rationale and plans to resolve these questions; and provide an international framework within which national research programs such as the USGCRP can both address national research objectives and work with other nations to gain knowledge from coordinated programs that are seeking to resolve global- and regional-scale scientific questions.

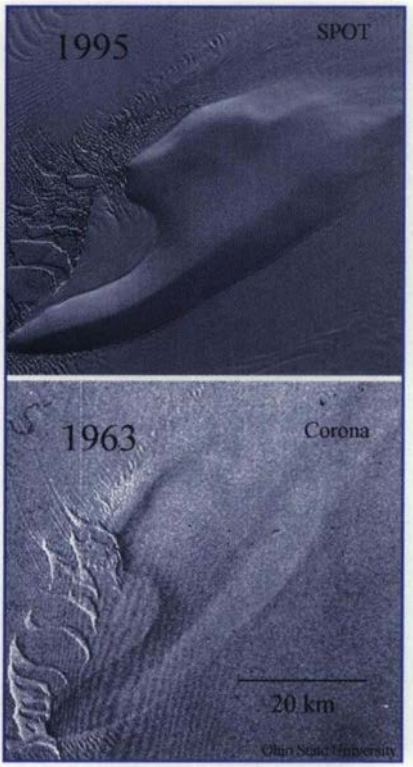


Figure 8: The Crary Ice Rise is the result of an ice-capped island that causes the ice to rise nearly 50 m above the surrounding 400-m-thick Ross Ice Shelf in Antarctica. The rise rests in the downstream ice flow from two of the ice streams that create the Ross Ice Shelf, which floats on the Ross Sea in the region of West Antarctica generally south of New Zealand. Recent research suggests that the area just downstream of the ice rise is thinning by about 1 m/yr, while other areas are thickening. Comparison of formerly classified photographs taken by DOD's Corona satellite in 1963 with images from France's SPOT satellite taken in 1995, along with recent studies, suggest that natural variations or cycles in the two converging ice streams feeding this region may be contributing to the current cracking that is observed in the ice shelf, rather than human influences acting alone or even being a dominant factor (see Appendix D for further information). Source: Byrd Polar Research Center at Ohio State University, Columbus, OH, and the MEDEA initiative to declassify previously classified photographs and other intelligence-derived information about the environment.

Support for International Scientific Assessments of Global Change

The Intergovernmental Panel on Climate Change (IPCC)

The United States has joined with other nations in supporting the IPCC as the vehicle for organizing state-of-the-science climate change assessments. The IPCC was jointly established by the World Meteorological Organization and the United Nations Environment Programme in 1988, in order to: 1) Assess available scientific information on climate change; 2) assess the environmental and socio-economic impacts of climate change; and 3) formulate response strategies.

The IPCC's comprehensive Second Assessment Report was published in 1996. A number of U.S. scientists served as lead authors for chapters of the Second Assessment Report and many U.S. scientists served as co-authors, contributors, and reviewers.

A Third Assessment Report is being planned by the IPCC for publication in 2001. The United States continues to co-chair IPCC Working

Group II and the USGCRP supports the Working Group II Technical Support Unit. The new IPCC chair-elect is also from the United States. The Working Group II co-chairs and Technical Support Unit oversaw the preparation of the IPCC Technical Paper on *Technologies, Policies and Measures for Mitigating Climate Change*, which was published in November 1996.

The IPCC is currently preparing four special reports in response to requests from the Conference of Parties (COP) to the U.N. Framework Convention on Climate Change:

- Special Report on the Regional Impacts of Climate Change (1997)
- Special Report on Atmospheric Effects of Aviation (1998)
- Special Report on Technology Transfer (1999)
- Special Report on Emissions Scenarios (1999).

In addition, the IPCC is convening a number of workshops at the request of the COP.

International Ozone Assessment

The United States served as a leader in the preparation of the 1994 international *Scientific Assessment of Ozone Depletion*, which continued an international series started in the 1980s. The ozone assessments have provided crucial scientific information for the Montreal Protocol on Substances that Deplete the Ozone Layer and its subsequent amendments and adjustments. As a follow-up to the overall assessment, a special assessment on the atmospheric effects of aircraft is currently underway under the leadership of NASA. It is expected that a report on subsonic aircraft will be completed in 1997, and that the final planned assessment of the impacts of supersonic aircraft will be completed in 1998.

Regional Efforts in Global Change Research and Related Capacity-Building

Inter-American Institute for Global Change Research (IAI)

The IAI was established under an agreement between the United States and 16 Western Hemisphere nations to promote optimal use of available resources for global change research and to augment the scientific capacity of the region. The IAI Directorate, located in Brazil, was opened in 1996. The IAI has issued two calls for scientific proposals, and grants are currently being awarded. The results of these

awarded proposals will serve as the first examples of IAI-fostered regional cooperation. Additional calls for scientific proposals will be announced in early and mid-1997. Scientific data and information provided by IAI researchers will be managed as a common resource for the region and should provide baseline information for use in regional planning.

The Global Change System for Analysis, Research, and Training (START)

The United States continues to provide leadership and funding support for the joint IGBP/IHDP/WCRP START program, which reflects the U.S. commitment to build capacities for global change research in the developing world. START regional research networks promote focused research and training on regional issues of global relevance, integrate and synthesize results, and provide input to decisionmakers at national and regional levels.

START networks in Asia and Africa have initiated studies on land-use and land-cover change, climate variability and agriculture, and regional modeling of climate and biospheric changes. START regional centers have been established in Beijing, Bangkok, New Delhi, and Nairobi.

U.S. Country Studies Program (USCSP)

The United States initiated the Country Studies Program (USCSP) in 1992 to help developing countries meet their commitments under the Framework Convention on Climate Change, and to contribute to meeting the obligation of the industrialized countries under the Climate Convention to provide additional resources for technical assistance.

This program, a joint initiative of 10 Federal agencies, is making USGCRP research and related capabilities available to other nations to enable them to improve their understanding of climate change, strengthen their participation in the IPCC process, and assist in the development of their national communications as called for under the Climate Convention. The USCSP has assisted 55 developing countries and countries with economies in transition around the world, providing training and analytical support to more than 1,000 analysts in these countries.

Global Change Education and Communication

Global change education and communication seeks to provide useful information on the results of scientific research. In addition, it is an effort to help lay the foundation for the understanding that is needed in order to interpret and apply scientific findings. The application of knowledge from research and assessments to the challenges faced by society calls for a broad-based public understanding of global change.

Highlights of Current Developments

Global Change Educational Materials

A number of new global change educational resources have been released recently or will be available later in 1997:

- A video highlighting the Global Change Data and Information System (GCDIS) has been produced and widely distributed in the education community.
- The fourth monograph in the series *Reports to The Nation on Our Changing Planet* will be available early in the fall of 1997. This publication, *Our Changing Climate*, will be designed to educate students and non-technical readers. A CD-ROM dealing with the subjects of the monograph series will be released in 1997.
- Since 1995, five issues of *Consequences* magazine, published with support from USGCRP agencies, have been produced and distributed as a public service to provide reliable assessments of practical concerns related to the national and international consequences of changes in the global environment.
- With guidance from the Association of Science and Technology Centers, a global change traveling exhibit will start a tour of the United States in 1997.

Encouraging Global Change Science Literacy

The goal of the education and communication component of the USGCRP is to increase public awareness of the Earth system and how it is changing and to promote global change education.

Global Change Research Information Office (GCRIO)

The U.S. Global Change Research Information Office (GCRIO) World Wide Web site provides access to a number of on-line environmental educational resources (http://www.gcrio.org/educ.html):

- The GCRIO Earth Education Site (EES) consists of searchable databases that describe national, regional, and local environmental educational programs, resources, and events. These databases give a teacher, student, or administration the ability to quickly identify items that are relevant to a particular subject category and grade level.
- GCRIO is developing a number of on-line lesson plans that exploit the data access, visualization, and decision-support tools developed by the Consortium for International Earth Science Information Network (CIESIN). The initial lesson plan deals with biodiversity within the context of international treaties.
- GCRIO maintains a number of links to environmentally relevant World Wide Web sites, environmental education mailing lists, and information on fellowships, grants, and other funding opportunities.

The U.S. Global Change Research Information Office (GCRIO) World Wide Web site provides access to a number of on-line environmental educational resources.

USGCRP Seminar Series

The USGCRP Seminar Series is continuing on Capitol Hill in Washington, DC, in 1997. Each month's session offers a presentation and discussion of a topic drawn from the latest scientific studies of the global environment and its interaction with societal activities and the economy. The format is designed to encourage consideration of important research findings in the context of the issues facing decisionmakers. The topics and speakers are selected for their potential interest to a wide audience, both governmental and nongovernmental.

The Seminar Series is designed to encourage consideration of important research findings in the context of the issues facing decisionmakers.

Thus far in FY97, seminar topics have included:

- The Ecological Effects of Global Warming on North American Birds and Butterflies
- Sustainable Water Resources in the Next Century, with Special Reference to Global Climate Change and the Western U.S.
- The Economics of Climate Change Impacts and Mitigation: The Importance of Values and Assumptions
- Food, Agriculture, and Climate Change: The U.S. and International Outlook
- Assessing U.S. Regional Climate Impacts Using Global-Scale General Circulation Models
- Ecological and Climatic Consequences of Human -Induced Changes in the Global Nitrogen Balance
- The Role of Energy Technologies in Determining the Long-Term Costs for Stabilizing the Carbon Dioxide Concentration.

For information on this series, contact the USGCRP Coordination Office (see Appendix E for contact information).

4. New Research Challenges for the USGCRP

For the past decade, much of the research supported by the USGCRP has focused on the causes and rates of climate change, with an emphasis on understanding what is occurring at the global scale. This research has made valuable contributions to understanding of the Earth's climate system and was central to the development of one of the most important findings in the 1995 international scientific assessment by the Intergovernmental Panel on Climate Change, that "the balance of evidence suggests that there is a discernible human influence on global climate."

As the USGCRP prepares to enter its second decade, it is essential that the program continue to deepen and extend scientific understanding by maintaining a very strong research base. At the same time, the program must actively build links to applications of research that can enable society to benefit from the understanding and capabilities that are being developed.

The program must actively build links between global change research and applications that can benefit society.

In setting out the challenges for the USGCRP over the next decade, there are a number of opportunities to enhance the role of global change research in providing insights that can be used to benefit society in ways that will promote sustainable development. Some of the key research challenges for the next decade include enhancing efforts to develop:

- *Regional-scale estimates* of the timing and magnitude of climate change and other aspects of global change
- *Regional analyses of the environmental and socio-economic consequences* of climate change and other aspects of global change, in the context of other stresses
- *Integrated assessments of the implications* for society and the environment of climate change and other aspects of global change.

Regional-Scale Estimates

The Earth system is governed by fundamental physical laws that determine its large-scale characteristics. For this reason, and based on

Key Research Challenges for the Next Decade

- Regional-scale estimates of the timing and magnitude of global change
- Regional analyses of the environmental and socio-economic consequences of global change, in the context of other stresses
- Integrated assessments of the implications for society and the environment of global change

understanding gained from observations of past changes in the system, we are becoming better able to predict the large, global-scale behavior of the Earth system.

The primary computer models of global climate, called general circulation models (GCMs), predict a variety of climatic variables, such as temperature, precipitation, winds, snow accumulation, and soil moisture, on spatial scales of several hundred kilometers—that is, with areas the size of Colorado represented by a single point. While the GCMs provide useful coarse-scale predictions at the sub-continental level, predictions at the regional scale are considered unreliable.

An important USGCRP priority is to improve capabilities for refining large-scale estimates of climate and the global environment and providing the needed finer scale estimates. To be of greatest use for work on the ecological, economic, and social consequences of climate change and to make the results more usable for application studies, models must be strengthened to the point where they can simulate accurately primary processes governing the Earth system on scales of tens of kilometers, rather than hundreds of kilometers. Thus, as the basis for subsequent studies of the consequences of global change, capabilities must be developed to represent such features as changes in the lengths of the seasons, the pattern of changes from mountain to coastal regions, and the evolution of changes from decade to decade.

To be of greatest use for work on the consequences of global change and in application studies, models must be strengthened to the point where they can simulate accurately primary processes governing the Earth system on scales of tens of kilometers.

A range of approaches needs to be considered in order to provide the needed regionally resolved results. Together, these "downscaling" techniques need to be used to improve estimates of changes in drought

and flood occurrence, in hurricanes and winter storms, and in extreme highs and lows of temperature—each focused on changes in particular parts of the country.

Currently there are both theoretical and practical challenges to developing such "regionally resolved" estimates of global climate change. The theoretical challenges to the downscaling involve a range of issues, including how to deal with cloud physics and how to represent the effects of highly variable topography on climate. The practical challenges are focused on the need for enhanced computer power and full utilization of computer resources that are available.

"Downscaling" techniques need to be used to improve estimates of changes in drought and flood occurrence, in hurricanes and winter storms, and in extreme highs and lows of temperature.

Regional Analyses of Consequences

Policymakers, resource managers, and the public need to know what the consequences of global change will be for their regions, and understand the environmental and socio-economic significance of these consequences:

- Predictions that less rainfall will occur in a particular season or in future decades must be translated, for example, into estimates of changes in water availability, water quality, and fire frequency in the southwestern United States.
- Predictions of sea-level rise from global warming must be translated, for example, into information needed to minimize damages from storm surges in coastal regions of the country.
- Predictions of stratospheric ozone depletion must be translated, for example, into guidance for how people in the southeastern United States can avoid exposures that increase skin cancer rates.
- Predictions of changes in vegetation must be analyzed to determine, for example, how changes in forests and grasslands will affect the ability to produce timber and food in the northeastern and northwestern United States.

A key priority is to improve understanding of the potential connections between climate change and the frequency and magnitude of

extreme weather events and other disturbances. Some of the regionally specific questions for the United States include:

- Will the frequency and severity of wildfires increase in the Southwest?
- Will the frequency and severity of droughts change in the Great Plains?
- Will the number and extent of severe floods increase in the upper Mississippi Basin?
- Will the Atlantic and Gulf coastal regions be subject to more frequent and severe tropical storms and hurricanes?

Disturbances such as fire, drought, floods, and strong winds can, in turn, affect the structure and function of the land and water ecosystems on which society depends. These changes, brought about also by the wide range of other local and regional stresses, will affect the products and services that support economic systems and can lead to changes in plant productivity, nutrient cycles, and species composition.

Scientists do not yet have the capacity to predict these changes with confidence. To do so will require the study of complex interactions among ecological processes through long-term monitoring activities, large-scale field experiments and manipulations, and intensified analysis and simulation modeling efforts.

A key priority is to improve understanding of the potential connections between climate change and the frequency and magnitude of extreme weather events and other disturbances.

One of the great new challenges will be to understand how the population dynamics of plants, animals, and microbes are linked to biogeochemical processes. This understanding is needed in order to forecast how climate change will affect the extent and distribution of the Earth's vegetative cover and its associated animal and microbial species.

Another major new challenge will be to consider the regional consequences of global change in the context of other regional pressures on ecosystems. Each region has its own set of pressures that will act with global change to affect its ecosystems. In the northeastern United States, for example, climate change must be considered along with tropospheric ozone and urban expansion as shapers of ecosystems. Both ozone and urban expansion are also pressures on the ecosystems of southern

Another major new challenge will be to consider the regional consequences of global change in the context of other regional pressures on ecosystems.

California, but so too are a suite of pressures related to water use, such as water diversion and salinization of irrigated croplands.

Information on these regional impacts of global-scale change will be essential to policymakers and planners. An enhanced USGCRP research effort on these consequence areas is vital for providing the needed information.

Assessing the Consequences of Global Change

"...stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened, and to enable economic development to proceed in a sustainable manner."

– Ultimate Objective of the UN Framework Convention on Climate Change (Article 2)

The nations of the word have set as a long-term goal the stabilization of atmospheric concentrations of greenhouse gases (GHGs) at a level that will avoid "dangerous anthropogenic interference in the climate system." But what is that level? The judgment of what may be "dangerous" is not a scientific one, as it involves political and ethical value judgments. However, to make this judgement, research must provide policymakers with an understanding of the consequences of different atmospheric concentrations of GHGs for natural ecosystems, food production, and sustainable economic development.

Intensified emphasis on consequences research is needed to build on current knowledge and to improve understanding of the potential impacts of different magnitudes and rates of climate change on, for example, forests, water resources, food and fiber, human infrastructure, human health, and biodiversity:

- *Forests*: Will changes in climate outpace the speed at which forest species grow, reproduce, and reestablish themselves? What fraction of the existing forested areas of the world will undergo major changes in vegetation? How will changes in climate affect the viability of forestry activities, for example in the Southeast or the Pacific Northwest of the United States? Can strategies be developed to assist the migration of individual and perhaps even groups of species?

Assessing the Consequences of Global Change (cont.)

- *Water Resources*: How will changes in temperature and precipitation, along with potentially non-linear changes in evapotranspiration and soil moisture, affect runoff? How might changes in the seasonal distribution of river flow and water supply affect agriculture and hydroelectric power? Which regions of the United States are most vulnerable to water supply and water quality problems, and what prospective adaptation measures can help reduce the vulnerability of these regions to shortages?
- *Food and Fiber*: Taking into account the beneficial effects of carbon dioxide fertilization, changes in agricultural pests, and possible effects of changing climatic variability, how will food and fiber production be affected in different regions and globally? Where are the optimal regions for growing different crops likely to shift, and how will this affect the farming communities and industries that are currently producing these crops? Internationally, where are the greatest risks of hunger and famine? What information, technologies, and other resources can be provided to assist farmers in adapting to potential changes?
- *Human Infrastructure*: Climate change and rises in sea level clearly will increase the vulnerability of some coastal populations to flooding and erosional land loss. How will changes in the coastal margins affect commercial fisheries production? What are the threats to different coastal regions in the United States and internationally? What strategies can be developed to cope with changes in sea level? How vulnerable is the U.S. financial and insurance system to potential increased losses in coastal areas from changes in the severity and frequency of floods and storms?
- *Human Health*: Climate change has been projected to have wide-ranging impacts on human health. What is the potential public health risk from the interaction of increasingly intense and long heat waves with existing air-quality problems in major urban areas? Are there colder regions in which temperature increases could result in fewer cold-related deaths. What is the relative

Assessing the Consequences of Global Change (cont.)

magnitude of these effects? What is the potential in the United States for increases in the transmission of vector-borne infectious diseases (e.g., malaria, dengue, yellow fever, and some viral encephalitis) resulting from extensions of the geographical range and season for vector organisms such as rodents and insects?

- *Biodiversity and Ecosystem Dynamics*: Vital ecological functions and processes ultimately depend on a diversity of organisms interacting in an ecosystem. Biodiversity found in natural ecosystems also is the source of new chemicals, products, pharmaceuticals, and genes useful for improving agricultural and forestry species. Will changes in climate cause displacement or extinction of species? Will these changes be localized or worldwide? Can species redistribute themselves fast enough to accommodate climate change? Will changes in species composition lead to alterations in ecosystem structure and function?

As future climate extends beyond the boundaries of empirical knowledge from the documented impacts of climate variation in the past, surprises and unanticipated changes will become more likely. Research on the potential consequences of different atmospheric concentrations of greenhouse gases can assist in identifying and preparing for such events.

Integrated Assessment

Changes in the global environment are the subject of wide-ranging debates, intense international negotiations, and policy decisions that have the potential to reach into many aspects of society. Perhaps most far-reaching in their potential implications are the negotiations under the Framework Convention on Climate Change (FCCC).

In general, integrated assessments of global change should be based on the best possible understanding of:

- How the global environment will change due to natural and human events

- How these changes will lead to consequences for food production, water resources, human health, communities, and critical natural systems such as forests, grasslands, and fisheries
- How environmental, ecological, and resource changes will affect society and lead society to further affect these systems.

For example, there is a pressing need to support the FCCC negotiations with careful analyses that focus on predictions of causes and effects of climate change through efforts that bring together the physical and biological sciences, economics, and the social sciences.

Thus, in the analysis of climate change, forecasts of greenhouse gases and atmospheric aerosols, which are integral to climate analyses, must consider the forces of population, economic growth, and technology that drive and control emissions. In turn, assessments of possible ecological and socio-economic impacts, and the analyses of alternative strategies for adaptation and mitigation, need to be based on careful climate science that takes into account its own uncertainties.

This challenge of integrated assessment of climate change is beginning to be approached through a coupled-model framework. The models vary in their approach, ranging from those that emphasize detail on the physical and biogeochemical aspects to those that emphasize detail on the behavioral and economic aspects. Integrated assessment models for the analysis of climate change often include an economic model for analyses of emissions of greenhouse gases and aerosol precursors, atmospheric chemistry and general circulation models, and models of natural and managed ecosystems for analyses of the consequences of climate change. At present, models describing complex nonmarket societal decisions are generally not included. The existing integrated assessment models all run at the global scale, but also are regionally resolved.

Integrated assessment models can be used now to study the significance of technology development in moving toward a more sustainable use of environmental resources.

Integrated assessment models can be used now to provide indications of many important relationships, including, for example, the significance of technology development in moving toward a more sustainable use of environmental resources, and the combined importance of population growth and energy demand as driving forces leading to global environmental change.

While including many factors of importance, these models are limited by uncertainties in the predicted impacts of global change on

unmanaged ecosystems and their consequences, and by the inability to forecast technological changes and responses to policies. As a result, these models cannot yet be used in comprehensive cost-benefit or risk assessment analyses.

The optimum design of integrated assessment models would permit them to address both policy issues and some important questions in global change science. Some of the policy questions being addressed with integrated assessment models include:

- How effective would specific policy measures be in alleviating relevant environmental and economic concerns?
- How costly are they?
- What are their distributional implications by nation, region, and economic sector?
- Given the current level of understanding of these phenomena, what are the advantages and risks of waiting for better scientific information and observational evidence before taking stronger policy measures?

Over the next 10 years, research needs to be enhanced so that these evaluation frameworks can be used to improve the texture and richness of the integrated assessments that are being carried out.

The Need for Communication

As the USGCRP addresses these new research challenges, it will generate scientific knowledge needed to develop a sustainable future for our nation and the world. Rigorous scientific research will provide an indispensable contribution to society in meeting the challenge of sustainable development.

Conducting research is of vital importance to society, but it is not sufficient by itself. Scientists must also communicate clearly and responsibly with the public. Communications, often in the form of consensus assessments of what is known and uncertain, must convey scientists' best understanding of how the Earth's life support system works, how its behavior affects human activities, and how the Earth system can be affected by human activities.

Scientists must communicate clearly and responsibly with the public.

The communication must also be a dialogue, in which the presentation of scientific information is appropriate to the knowledge and concerns of the recipients, and in which those expressed concerns in

turn feed back into the research enterprise, by helping to clarify the critical societal needs that research must help to address.

Epilogue: The Fundamental Rationale

Almost a decade ago, the first edition of *Our Changing Planet* ended with the following insight:

> *"In the coming decades, global change may well represent the most significant societal, environmental, and economic challenges facing this nation and the world. The national goal of developing a predictive understanding of global change is, in its truest sense, science in the service of mankind."*

The fundamental rationale for the USGCRP articulated in 1989 is the same now as it was then.

APPENDIX A

THE PROPOSED USGCRP BUDGET FOR FY98

The proposed FY98 USGCRP budget totals $1.878 billion. After adjusting so that comparable programs are included in the compilation (see discussion below), the FY98 request is an increase of $68 million (3.8%) from the estimated FY97 budget.

As outlined in this edition and in the FY97 edition of *Our Changing Planet*, the USGCRP budget supports scientific research on key global change environmental issues, including seasonal to interannual climate variability; climate change over decades to centuries; changes in ozone, UV radiation, and atmospheric chemistry; and changes in land cover and in terrestrial and aquatic ecosystems.

The USGCRP budget supports global change research integrating activities, including observing and monitoring global change; global change data, products, and information services; research on Earth system science and on human contributions and responses to global change; international research cooperation; and global change education and communication.

The figures and tables in Appendix A provide the following:

- USGCRP budgets for FY96-FY98 by Federal agency
- USGCRP budgets for FY96-FY98 by Budget Function
- USGCRP activities on global change environmental science issues by agency, indicating which agencies make a "broad-based" scientific contribution in each area and which agencies participate by making a more "focused" contribution
- USGCRP activities on issues central to program integration by agency, indicating which agencies make a "broad-based" scientific contribution in each area and which agencies participate by making a more "focused" contribution.

For comparison with USGCRP budgets in years prior to FY98, two changes in the presentation of the USGCRP budget by agency should be noted:

1) The FY98 USGCRP budget request of $1.878 billion in this edition of *Our Changing Planet* is identical to that identified for global change research in the President's FY98 Budget.

This differs somewhat from the USGCRP budget presented in previous editions in which there typically were some differences (explained in each edition) with the numbers presented in the President's Budget for the same year.

In general, the changes in this edition involve reclassifying as part of the USGCRP certain programs and activities in some agencies that were not previously included in the USGCRP budget as presented in *Our Changing Planet*.

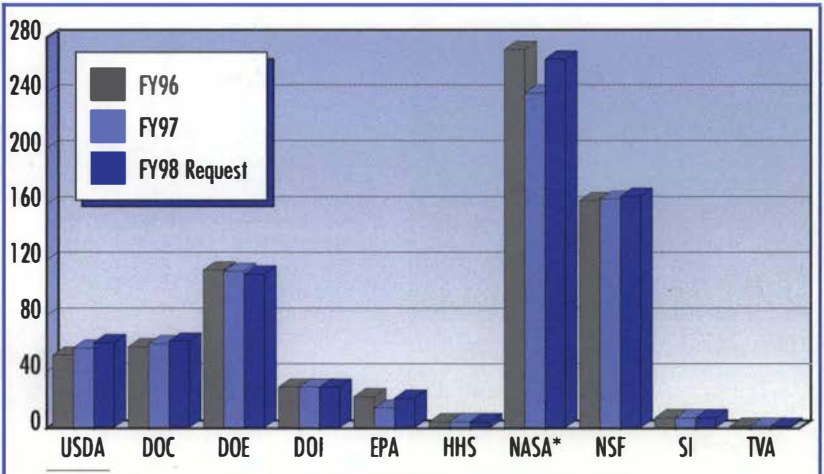
The FY96 and FY97 budget figures in this edition of *Our Changing Planet* have been adjusted so that comparable programs are included throughout the compilation presented here for FY96, FY97, and FY98. The result is to make the USGCRP budget totals for FY96 and FY97 somewhat higher than those presented in previous editions.

2) In this edition of *Our Changing Planet*, the USGCRP budget is presented in two broad components: Scientific Research, and Space-Based Observation Programs. This change is intended to make clearer the portion of the USGCRP budget that supports scientific research by individual investigators and small groups, as compared with the portion that supports NASA's Mission to Planet Earth program components relating directly to space missions—particularly the Earth Observing System series of satellites and data information systems, which provide data in support of the research activities.

Of the total USGCRP FY98 budget request, 61% supports Space-Based Observation Programs while 39% supports Scientific Research. The FY98 request for $1.153 billion for Space-Based Observation Programs is a 2.8% increase from the FY97 budget; the $725 million request for Scientific research is a 5.4% increase from FY97.

FY96–FY98 USGCRP Budget by Agency

(Dollars in Millions)



*Includes only the NASA USGCRP-related scientific research budget (see footnote b below).

Agency	FY96	FY97	FY98 Request
Scientific Research[a]			
Department of Agriculture (USDA)	52	57	61
Department of Commerce (DOC/NOAA, DOC/NIST)	58	60	62
Department of Energy (DOE)	113	112	110
Department of Health and Human Services (HHS)	4	4	4
Department of the Interior (DOI)	29	29	29
Environmental Protection Agency (EPA)	22	14	21
National Aeronautics and Space Administration (NASA)	271	240	264
National Science Foundation (NSF)	163	164	166
Smithsonian Institution (SI)	7	7	7
Tennessee Valley Authority (TVA)	1	1	1
Scientific Research Subtotal	**720**	**688**	**725**
Space-Based Observation Programs			
National Aeronautics and Space Administration (NASA)[b]	1090	1122	1153
U.S. Global Change Research Program Total[c]	**1810**	**1810**	**1878**

[a]The Department of Defense (DOD), as part of its defense mission, supports research that is nevertheless relevant to the global change research activities of the civilian agencies. In past years, this has been reflected in the budget tables published in *Our Changing Planet*. The DOD budget for defense-related research that nevertheless contributes to USGCRP activities follows: $6M (FY96), $9.8M (FY97), and $5.7M (FY98 request).

[b]The NASA budget totals in this line include funding for all Mission to Planet Earth (MTPE) program components relating directly to space missions. In addition to these activities, a few additional programs that have not been included in the USGCRP budget as published in the FY97 and earlier editions of *Our Changing Planet* are now considered by NASA as supporting global change research. These budget items include Launch Services and the transfer of related Technology Applications Research from NASA's Office of Space Access and Technology into MTPE.

[c]The USGCRP budget totals for FY96, FY97, and the FY98 request reported here include NASA MTPE budget components that were not included in the USGCRP budget as published in FY97 and earlier editions of *Our Changing Planet* (discussed in previous note). As a result, the USGCRP budget for these years in this table appears correspondingly higher.

Global Change Environmental Science Issues

USGCRP Program Thrusts

	Seasonal to Interannual Climate Variability	Climate Change over Decades to Centuries	Changes in Ozone, UV Radiation, and Atmospheric Chemistry	Changes in Land Cover and in Terrestrial and Aquatic Ecosystems
Department of Agriculture	●	●	●	●
Department of Commerce				
National Oceanic and Atmospheric Administration	●	●	●	●
National Institute of Standards and Technology			●	
Department of Defense	*		*	
Department of Energy	●	●	●	●
Department of Health and Human Services				
National Institutes of Health			●	
Department of the Interior	●	●		●
Environmental Protection Agency		●	●	●
National Aeronautics and Space Administration	●	●	●	●
National Science Foundation	●	●	●	●
Smithsonian Institution		●	●	●
Tennessee Valley Authority		●		

KEY

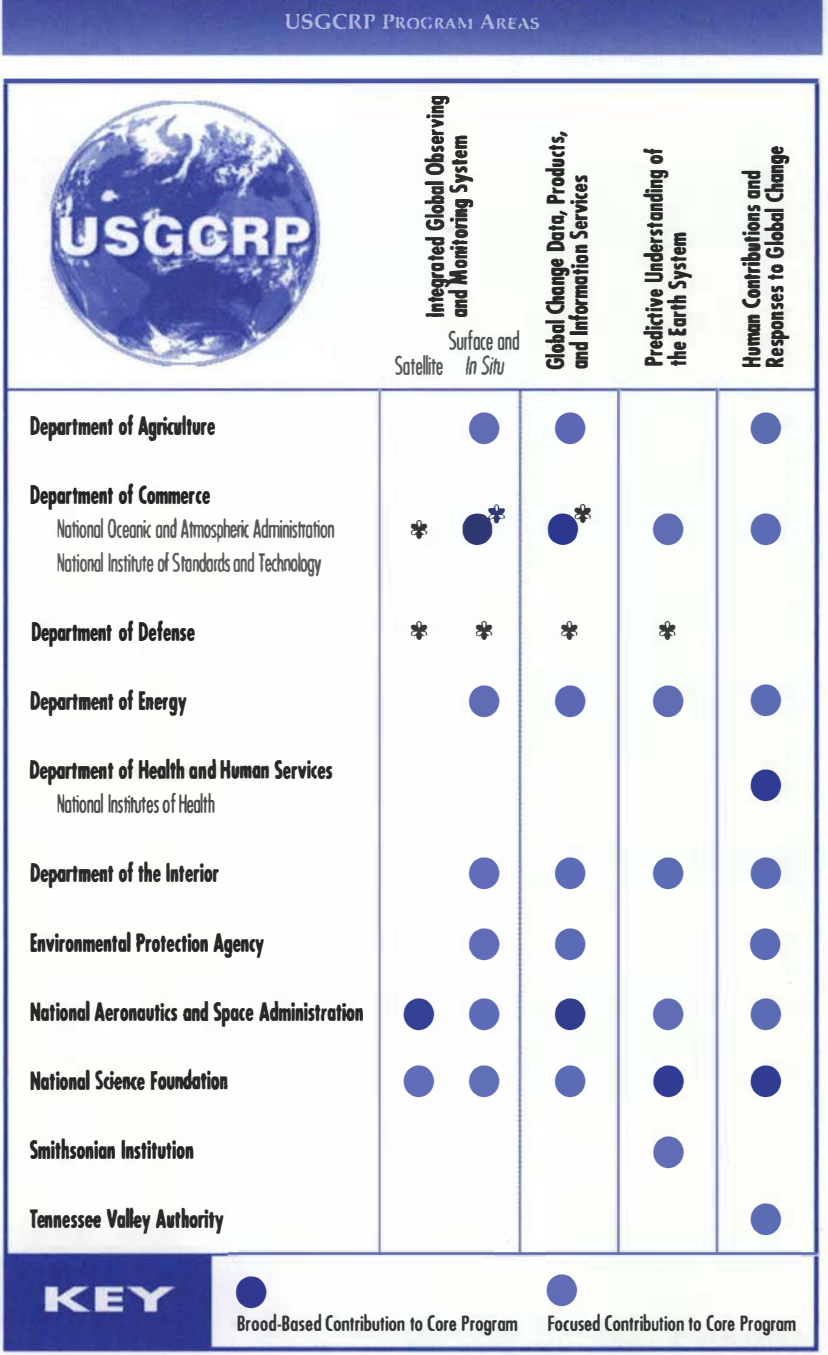
● Broad-Based Contribution to Core Program

● Focused Contribution to Core Program

*Because DOD research activities are conducted for defense-related mission purposes, they are not included in the USGCRP budget. However, these activities nevertheless contribute to USGCRP goals, as noted in this chart.

Issues Central to Program Integration

USGCRP Program Areas



*Research activities, including some satellite and observing activities, that are conducted primarily in support of other mission-related responsibilities are not included in the USGCRP budget. However, since those activities nevertheless contribute to USGCRP goals, they are identified in this chart.

FY96–FY98 USGCRP Budget by Budget Function

(dollars in millions)

Budget Function	Budget Function #	FY96	FY97	FY98 Request
General Science, Space, and Technology	250			
National Aeronautics and Space Administration (NASA)		1361	1362	1417
National Science Foundation (NSF)		163	164	166
Energy	270			
Department of Energy (DOE)		113	112	110
Tennessee Valley Authority (TVA)		1	1	1
Natural Resources and Environment	300			
Department of Agriculture (USDA/FS and NRCS)		16	20	22
Department of Commerce (DOC/NOAA and NIST)		58	60	62
Department of the Interior (DOI)		29	29	29
Environmental Protection Agency (EPA)		22	14	21
Agriculture	350			
Department of Agriculture (USDA/ARS, ERS, and CSREES)		36	37	40
Smithsonian Institution	503			
Smithsonian Institution (SI)		7	7	7
Health	550			
Department of Health and Human Services (HHS)		4	4	4
Total		**1810**	**1810**	**1878**

APPENDIX B

FY96-FY98 USGCRP BUDGET BY AGENCY AND PROGRAM

The allocation of resources to specific programs within agencies that is reflected in these tables for FY97 appropriated funds and the FY98 budget request serve as estimates only, and are subject to change based on decisions on scientific and programmatic priorities among USGCRP agencies, their advisory bodies, and the input of the national and international scientific communities.

These budgets are for programs designated by participating agencies for inclusion in the USGCRP. The budget pages for individual agencies that follow include a listing of these programs, as well as a general description of each agency's "Areas of Global Change Research." For each agency, a "FY98 Program Highlights" section briefly outlines some of the key USGCRP-related activities proposed for the coming year. In addition, the agencies conduct a broad range of "Related Research," as indicated, funding for which is not included as part of the USGCRP budget because the research is conducted primarily for other purposes.

Each agency budget page also includes a "Mapping of Budget Request to Appropriations Legislation." These entries point to the locations in the various Appropriations Bills (and, in some cases, Appropriations Committee reports) of funding for USGCRP activities. Note that it is common for global change research to be funded within Appropriations accounts that also include funding for other activities, so that Appropriations bills and committee reports do not necessarily designate funding specifically for global change research. Thus, the actual funding level for global change research activities must be determined, in part, by decisions within agencies about how to allocate appropriated funds. It should also be noted that USGCRP activities are funded by seven different Appropriations Bills, as well as by a varying number of Budget Authorization Bills. Thus, the relationship between the USGCRP budget and the Appropriations process is complex and not easily summarized.

Department of Agriculture

Areas of Global Change Research. Research sponsored by USDA focuses on understanding terrestrial systems and the effects of global change (including water balance, atmospheric deposition, vegetative quality, and UV-B radiation) on food and fiber production in agricultural, forest, and range ecosystems. It includes research on interactions between terrestrial ecosystems and the atmosphere; the contributions of agricultural sources of methyl bromide to stratospheric ozone depletion, and possible alternatives and substitutes for this fumigant; methane generation and nitrous oxide release; soil properties, including moisture, erosion, organic matter, nutrient fluxes, and microbes; relationship of global change to forest and range fires, insects, and plant pathogens; agricultural management systems; and validation of satellite measurements.

USDA	Program Title	FY96	FY97	FY98 Request*
ARS	Agriculture and Rangeland Global Change	11.7	11.6	10.8
ERS	Economics of Global Change and Agriculture	0.8	0.8	0.8
FS	Forest Global Change	15.0	19.0	21.0
CSREES	Improved Response Models	8.0	8.0	11.8
ARS	Methyl Bromide Research	13.7	14.6	14.6
NRCS	Soil Carbon Studies	1.5	1.5	1.5
CSREES	UV-B Monitoring Network	1.6	1.6	1.6
	Total	**52.3**	**57.1**	
	President's Request	63.7	56.7	**61.0**

*Column does not sum to total, pending Agency's final allocation.

ARS Agricultural Research Service
CSREES Cooperative State Research, Education, and Extension Service
ERS Economic Research Service
FS Forest Service
NRCS Natural Resources Conservation Service

FY98 Program Highlights. The goals of the ARS global change research program are to document and mitigate impacts of global change on agricultural and rangeland ecosystems, to assess agriculture's role as a contributor to the causes of global change, and to provide policymakers and agricultural producers with sound scientific information upon which to base wise decisions. In FY98, the research will continue to focus on four broad areas: 1) Experimental determinations of the direct effects of rising atmospheric CO_2 levels, increasing temperatures, and their interaction with the physiology and performance of crop plants and with ecosystem processes that control productivity of grazing lands; 2) carbon and nitrogen cycling and fluxes between the terrestrial surface and the atmosphere, including sequestration of carbon in soils and vegetation; 3) changes in hydrological processes associated with climate change that may impact water quality, efficiency of use by crops, and availability for industry, urban use, and irrigated agriculture; and 4) the development of a suite of simulation models with required inputs for predicting responses of crops, watersheds, and managed ecosystems to global change.

CSREES is responsible for administration of USDA extramural research in partnership with the Land Grant University System. A major component of the Agency's FY98 global change research is continued development of a UV-B Monitoring Network. The purpose of the network is to provide USDA with information necessary to determine whether changing levels of UV-B have an effect on food and fiber production in the United States. Attention will be given to development of data products required

by the agricultural community to assess the impact of UV radiation on plant and animal productivity. CSREES will continue to support laboratory research on the mechanisms of damage to plants and animals from exposure to increased UV-B radiation, field research on the response of biological systems to increased UV-B radiation, and the development of improved procedures for determining the effects of increased UV-B exposure on biological systems of agricultural importance. CSREES's National Research Initiative Competitive Grants program also supports fundamental and mission-linked research, which is designed to increase our understanding of the possible impacts of global environmental change on the sustainability of agriculture and forestry. Research is supported from the molecular to the ecosystem level for projects that will reduce uncertainty regarding the effects of possible changes in temperature and precipitation patterns, rising carbon dioxide levels, and altered radiation (including UV-B) on crop productivity, natural resources, hydrological processes, and water availability. Integrative projects are also supported which develop models and long-term databases that can be used to interpret the findings from individual studies.

In FY98, ERS will continue efforts to improve understanding of the economics of global change and agriculture. Global modeling and analysis will focus on agricultural links to biodiversity, land-use change, and the ability to satisfy increased demands for agricultural goods and services while minimizing damage to the world's natural resources. Farm-level analysis will focus on the role of learning in adaptation.

Forest Service global change research seeks to establish a sound scientific basis for making regional, national, and international resource management and policy decisions in the context of global change issues. Studies are currently being conducted to determine how atmospheric changes and potential climatic change may affect forest productivity, forest health, and species distributions. Ecosystem-scale experiments involving increased CO_2 and other environmental factors have begun at several sites representing major U.S. forest types. As the uncertainty in model predictions is reduced, analysts may begin to describe likely socio-economic effects of global change on forests in the various regions of the United States. For example, the Mapped Atmosphere-Plant-Soil System simulates ecosystem distribution and function under current and potential future climates. Forests in the coterminous United States could experience partial decline or massive dieback over as much as 40–85% of their distribution.

NRCS provides technical and financial assistance in conjunction with conservation partners to managers of privately owned lands for the conservation and wise use of natural resources. In the context of global change, impacts affecting nutrient cycling, animal waste management, air quality, hydric soil environments, soil carbon sequestration and dynamics, and the extent and role of permafrost-affected soils are studied as part of terrestrial ecosystem dynamics.

Related Research. In addition to focused USGCRP research, the USDA sponsors significant research contributing to the assessment of global change effects on the agricultural food and fiber production systems and the forest and forest ecosystems of the U.S. and worldwide. Programs include long-term studies addressing the structure, function, and management of forest and grassland ecosystems; research in applied sciences, including soils, climate, food and fiber crops, pest management, forest fish and wildlife, and social sciences; implementation of ecosystem management on the national forests and grasslands; and human interaction with natural resources.

Mapping of Budget Request to Appropriations Legislation. In the Agriculture, Rural Development, Food and Drug Administration, and Related Agencies Appropriations Bill, USGCRP activities are funded under Title I–Agricultural Programs, within the Agricultural Research Service (ARS), Cooperative State Research, Education, and Extension Service (CSREES) Research and Education Activities, and Economic Research Service (ERS) accounts; and under Title II--Conservation Programs, within the Natural Resources Conservation Service (NRCS) Conservation Operations account. In the Interior and Related Agencies Appropriations Bill, USDA USGCRP activities are funded in the USDA Forest Service (FS) section under Title II–Related Agencies, within the FS Forest Research account.

Department of Commerce/National Oceanic and Atmospheric Administration and National Institute of Standards and Technology

Areas of Global Change Research. NOAA maintains a balanced program of observations, analytical studies, climate prediction, and information management through ongoing efforts in operational *in situ* and satellite observations with an emphasis on oceanic and atmospheric dynamics (including sea level), circulation, and chemistry; focused research on ocean-atmosphere-land interactions, the global hydrological cycle, the role of ocean circulation and biogeochemical dynamics in climate change, atmospheric trace gas/climate interactions, and the response of marine ecosystems and living resources to climate change and related stress; improvements in climate modeling, prediction, and information management capabilities; projection and assessment of seasonal to interannual and decadal to centennial environmental change; global change economics and human dimensions research; and archiving, management, and dissemination of data and information useful for global change research. NIST research focuses on physical properties of CFC alternatives and on engineering system design of systems utilizing CFC alternatives.

DOC	Program Title	FY96	FY97	FY98 Request
NIST	Ozone and UV Radiation: Chemically Induced Changes	0.9	1.0	1.0
NOAA	Aerosols	1.1	1.2	1.2
NOAA	Atmospheric Chemistry Project	6.4	6.8	7.0
NOAA	Climate Change Data and Detection	3.9	4.2	4.3
NOAA	Climate Dynamics and Experimental Prediction	13.9	13.3	13.7
NOAA	Climate Observations	8.0	10.0	10.3
NOAA	Climate Variability	11.6	10.7	11.1
NOAA	Economics and Human Dimensions of Climate Fluctuations	1.3	1.4	1.4
NOAA	Global Energy and Water Cycle Experiment	4.6	5.0	5.2
NOAA	Marine Ecosystem Response	0.4	0.0	0.0
NOAA	Ocean-Atmosphere Carbon Exchange Study	2.4	2.7	2.8
NOAA	Paleoclimatology	3.9	4.0	4.1
	Total	**58.4**	**60.3**	
	President's Request	89.6	70.9	**62.3**

NIST National Institute of Standards and Technology
NOAA National Oceanic and Atmospheric Administration

FY98 Program Highlights. Reduction of the uncertainty surrounding climate variations that occur on timescales of seasons to centuries, in particular the rate and magnitude of change, enhances the capacity of climate-sensitive sectors such as agriculture, fisheries, reinsurance, water management, and human health to plan for and adjust to fluctuations in rainfall and temperature patterns. In FY98, NOAA will continue to advance the scientific understanding essential for the development of sound policies through several activity streams, including 1) understanding and predicting climate variability on seasonal to interannual time scales and 2) understanding and assessing decadal and longer climate variability.

NOAA's research elements are designed to generate a predictive understanding of the integrated Earth system: 1) Climate Dynamics and Experimental Prediction;

2) Global Ocean-Atmosphere-Land System (GOALS); 3) Atlantic Climate Change Program (ACCP); 4) Global Continental-Scale International Project of the Global Energy and Water Cycle Experiment (GCIP/GEWEX); 5) Climate Observations; 6) Climate Change Data and Detection; 7) Economics and Human Dimensions of Climate Fluctuations; 8) Atmospheric Chemistry; 9) Ocean-Atmosphere Carbon Exchange Study; 10) Paleoclimatology; and 11) Aerosols.

In partnership with other agencies and countries, NOAA will continue to advance activities associated with the "International Forum on Forecasting El Niño: Launching an International Research Institute," held November 6-8, 1995, in Washington, D.C. The Forum called for the establishment of an International Research Institute (IRI) for climate prediction to extend technical capacity in fields relevant to climate forecasting and to foster the creation of a worldwide network with "end-to-end" capabilities in climate science and applications in support of sustainable economic growth. The development of the multinational network of research and applications activities associated with the IRI is a critical component of NOAA's global change program, providing an integrating point for the observations, modeling, assessment, and process studies and social science research conducted under the stewardship of the Climate and Global Change program.

Related Research. In addition to focused USGCRP research, NOAA contributing programs include advance short-term weather forecasting and warning services; prediction and observation systems in support of weather and seasonal to interannual climate forecasts; facilitating the dissemination of global change information; and strengthening facets of environmental technology. NIST also has ongoing programs in atmospheric chemistry.

Mapping of Budget Request to Appropriations Legislation. In the Departments of Commerce, Justice, and State, the Judiciary, and Related Agencies Appropriations Bill, NOAA and NIST USGCRP activities are funded under Title II–Department of Commerce and Related Agencies, within the NOAA Operations, Research, and Facilities and NIST Scientific and Technical Research and Services accounts. In Appropriations Committee reports, funding for NOAA's USGCRP activities is included as part of the Climate and Air Quality Research budget within Oceanic and Atmospheric Research.

Department of Defense

Areas of Global Change Research. DOD provides unique capabilities and programs that concurrently satisfy Defense mission requirements and stated USGCRP goals. DOD funding is planned and programmed on the basis of meeting national security research requirements; but, because the research results nevertheless contribute to understanding of global change, the associated research amounts are shown below. Four research themes that capitalize on DOD capabilities have historically been associated with USGCRP goals: Boundary Layer Dynamics (BLD), High Latitude Dynamics (HLD), Ocean Measurements (OM), and Regional Resolving Models (RRM).

DOD	Program Title	FY96	FY97	FY98 Request
ONR	BLD/Marine Aerosols	1.0	1.0	1.0
ONR	BLD/Ocean Ecological Dynamics	1.0	0.5	0.0
ONR	HLD/Arctic Acoustic Properties	0.0	3.0*	0.0
ONR	HLD/Arctic Ice Dynamics	2.0	1.0	0.5
ONR	HLD/Arctic Marine Sediments	0.3	0.2	0.0
CRREL	HLD/Impact of Climate Change on Energy Fluxes	0.1	0.1	0.0
ONR	HLD/SCICEX Submarine Data Collection	0.0	0.5	0.7
ONR	OM/Coastal Remote Sensing	0.0	0.0	1.0
ONR	OM/North Pacific Acoustic Laboratory	0.0	2.0*	1.0
CRREL	RRM/Coupled Hydrologic and Thermal Models	0.2	0.1	0.0
ONR	RRM/Coupled Ocean-Atmosphere Models	1.4	1.4	1.5
	Total	**6.0**	**9.8**	
	President's Request	6.4	5.9	**5.7**

*Funded above FY97 budget request (Congressional add-on).

CRREL Cold Regions Research and Engineering Laboratory
ONR Office of Naval Research

FY98 Program Highlights. Fundamental research sponsored in DOD is specifically tailored to Defense mission requirements, but may concurrently address issues significant to the USGCRP. For FY98, an Arctic ice camp associated with the ongoing interagency, interdisciplinary Surface Heat Budget of the Arctic (SHEBA) project is proposed. A joint program with NSF using a specially configured submarine to collect *in situ* data under the Arctic ice canopy (SCICEX) will continue in FY98. In-house and extramural investigators addressing marine aerosol dynamics in the open ocean and the littoral atmospheric boundary layer will be supported. Long baseline acoustic thermometry methods will be employed to establish real-time monitoring of North Pacific Ocean temperature structure via the North Pacific Acoustic Laboratory project. The Naval Oceanographic Modeling Program (NOMP) will continue development of Coupled Ocean-Atmosphere models at regional spatial scales in FY98; these regional models could serve as stable modules for global general circulation models. All data and results from these Defense research efforts are routinely made available to the civil science community.

Related Research. DOD-sponsored research, not shown in the table above, also contributes to observing, understanding, and predicting processes related to seasonal to interannual global change. Associated programs include observing and monitoring unique middle and upper atmosphere phenomena; fundamental research in physical

and biological oceanography; terrestrial and sea ice modeling; solar influences; global cloud specification/modeling; and a unique program to review classified data sets that could be made available to the research community.

Mapping of Budget Request to Appropriations Legislation. In the Department of Defense Appropriations Bill, research associated with the USGCRP is funded under Title IV–Research, Development, Test, and Evaluation. In Appropriations Committee reports, nearly all funding is included within the budget for Defense Research Sciences.

Department of Energy

Areas of Global Change Research. Research by DOE's Office of Health and Environmental Research addresses the impacts of energy production and use on the global Earth system primarily through studies of climate response. It includes research in climate modeling, atmospheric chemistry and transport, atmospheric properties and processes affecting the Earth's radiant energy balance, carbon sources and sinks, consequences of atmospheric and climatic change for vegetation and ecosystems, critical data needs for global change research and for early detection of climatic change, and funding for education and training of scientists and researchers in global change. The DOE Policy Office supports studies that assist in interpretation of research results.

DOE	Program Title	FY96	FY97	FY98 Request
OHER	Atmospheric Chemistry and Carbon Cycle	25.6	26.0	24.0
OHER	Climate and Hydrology	64.5	63.7	62.3
OHER	Ecological Processes	13.2	11.0	12.0
OHER	Human Interactions	9.5	9.0	9.2
OHER	Small Business Innovative Research/Technology Transfer	0.0	2.6	2.6
	Total	**112.8**	**112.3**	
	President's Request	122.8	112.4	**110.1**

OHER Office of Health and Environmental Research

FY98 Program Highlights. To support its global change research efforts, the Biological and Enviromental Research program (BER) of the DOE Office of Health and Environmental Research utilizes the unique multidisciplinary capabilities and facilities of the DOE National Laboratories and supports biological and environmental research projects and research infrastructure at National Laboratories, universities, and other research institutions. In support of the USGCRP, the BER program includes activities in four key areas:

1) *Climate and Hydrology*: The Atmospheric Radiation Measurement (ARM) program, developed in recognition that the effect of clouds on the Earth's radiative energy balance is a major source of uncertainty in climate models, focuses on the improvement of climate prediction by providing data and improved parameterizations of clouds and their interactions with solar and terrestrial radiation through ground-based, airborne (crewed and uncrewed), and satellite platforms. In FY98, key activities of the ARM program are the further development and utilization of measurement capabilities at the Tropical Western Pacific site, the initial conduct of intensive observational periods on the North Slope of Alaska, and uncrewed aerial vehicle (UAV) flights over the Southern Great Plains site.

   Climate modeling, with an emphasis on the Computer Hardware, Advanced Mathematical and Model Physics (CHAMMP) program, expands the current theoretical basis of climate dynamics and continuously optimizes computer models (from all agencies) for climate prediction and assessment of climate change. The Program on Climate Model Diagnosis and Intercomparison (PCMDI) develops and implements improved methods and tools for the diagnosis, testing, and intercomparison of general circulation models (GCMs). Key FY98 activities of the CHAMMP program will center on improvements in

GCM parameterizations for cloud liquid water structure and resultant radiation fields at tropical, arctic, and mid-latitudes.

2) *Atmospheric Chemistry and Carbon Cycling*: The Atmospheric Science Program develops a comprehensive understanding of the atmospheric processes that control the transport, transformation, and fate of energy-related air pollutants.

   The Terrestrial Carbon Processes (TCP) program focuses on improvement of the understanding of the biophysical processes in terrestrial ecosystems that affect the emission of CO_2 to the atmosphere and the removal of CO_2 from the atmosphere. In FY98, the TCP program and the National Institute for Global Environmental Change (NIGEC) will implement the AmeriFlux network to measure the net exchange of CO_2 between the atmosphere and terrestrial biosphere in major terrestrial ecosystems in North America.

3) *Ecological Processes*: The Program on Ecosystem Research (PER) focuses on improvement of the understanding of the consequences of atmospheric and climatic changes for terrestrial ecosystems and resources. The vegetation subprogram of TCP investigates the response of terrestrial vegetation to elevated CO_2 and altered climate variables. In FY98, PER, NIGEC, and the TCP program will support experimental and modeling studies to improve understanding of the response of terrestrial ecosystems to human-induced changes in atmospheric composition and climate. The research includes Free-Air-Carbon-Exchange (FACE) experiments to examine the response of terrestrial vegetation to changes in atmospheric composition and a major field experiment to examine the response of a southern deciduous forest ecosystem to reduced and enhanced precipitation.

4) *Human Dimensions*: The Integrated Assessments (IA) program analyzes climate change from cause through impacts, with an orientation toward developing policy options by methodological development and by the prediction of technology innovation and diffusion. NIGEC supports research to develop and improve models used to assess the regional economic and social consequences of climate change due to alterations in water, agricultural, and forestry resources. A combined education and research program for minority colleges and universities focuses on developing collaborative global change research ties between minority colleges and universities and ongoing global change research programs at the DOE laboratories, thereby diversifying and increasing America's scientific workforce in global change research.

   The Carbon Dioxide Information Analysis Center (CDIAC), a component of the U.S. Global Change Data and Information System (GCDIS), provides access to current global-change information and quality-assured and fully documented numeric data, technical publications, newsletters, and research summaries.

The National Institute for Global Environmental Change is a Congressionally-mandated institution operated by the University of California. The six regional centers support research at universities and nonprofit research institutions on all four programmatic areas of DOE's global change research priorities, with emphasis on improving understanding of the regional consequences of atmospheric and climatic change on terrestrial ecosystems and resources.

Related Research. DOE supports research on technologies and strategies to mitigate the increases in CO_2 and other energy-related greenhouse gases and plays a major role in implementing the President's Climate Change Action Plan to reduce greenhouse emissions through changes in energy supply and improvements in energy efficiency and conservation. In addition, DOE conducts research related to energy issues, including studies of chemical processes in the atmosphere related to energy

production and use; atmospheric studies of the lower atmospheric boundary layer; solid Earth processes related to the formation of energy resources and possible changes in surface interactions; long-term solar interaction with the Earth; basic research in plant and microbial biology; technologies to improve energy conservation and use efficiency and alternative energy technologies to reduce or replace carbon-based fuels for energy production; and international environmental policy studies.

Mapping of Budget Request to Appropriations Legislation. In the Energy and Water Development Appropriations Bill, DOE USGCRP activities are funded under Title III–Department of Energy, within the Energy Supply, Research, and Development Activities account. In Appropriations Committee reports, funding for DOE's USGCRP programs is included within the budget for Biological and Environmental Research.

Areas of Global Change Research. National Institutes of Health funding supports research on health effects of CFC replacement chemicals and ultraviolet radiation, including studies in metabolism and toxicity of HCFCs and halogenated hydrocarbons; effects of UV exposure on the pathogenesis of disease and on target organs, especially skin and eyes; repair of solar UV radiation-related DNA damage in human cells; and effects of shorter wavelength UV radiation on photosensitivity in people who use many commonly prescribed drugs.

HHS	Program Title	FY96	FY97	FY98 Request
NIH	Human Health Effects of Exposure to UV Radiation	3.9	4.1	4.3
	Total	**3.9**	**4.1**	
	President's Request	4.0	4.0	**4.3**

NIH National Institutes of Health

FY98 Program Highlights. Research conducted by NIH that is relevant to global change has been an important component of the NIH research agenda for a long time. The potential for increased human exposure to UV radiation, air pollution, infectious diseases, or agricultural chemicals resulting from ozone depletion or climate change serves to heighten the NIH commitment to this broad range of health research, from exploring the biological mechanisms of how disease is initiated and promoted to finding new treatments and technologies to care for people who are ill.

This research could help to reduce the substantial burden on individuals and society imposed by cancer and the need for cataract surgery. From 1973 to 1993, the age-adjusted rate for melanoma in the United States increased from 5.7 to 12.2 per 100,000. More than 1.5 million cataract and more than 800,000 nonmelanoma skin surgeries are performed annually.

Highlights of the FY98 research program include studies to determine how UV radiation-induced immunosuppression and genetic damage contribute to skin cancer in humans and experimental animals; to understand the roles of DNA repair and mutant frequency in cancer susceptibility to UV exposure; and to understand the photobiological mechanisms involved in aging caused by chronic UV damage. Other research projects include the testing of antimalarial drugs in order to determine whether the cutaneous and ocular side effects associated with their use are light-induced, and studies of the photochemistry of all light-absorbing components of the eye in order to determine whether long-term exposure to light contributes to the deterioration of clarity of the lens and functioning of the retina.

Related Research. In addition to research that is designated as part of the USGCRP, NIH conducts research related to other impacts of global change on human health, including the effects of environmental and occupational exposures to air pollution, agricultural chemicals, and materials used in alternative or new technologies to mitigate or adapt to climate change. Exposures of special concern for FY98 include those that contribute to the greatly increased incidence of childhood asthma and that disrupt the normal functioning of the endocrine system. Renewed concern about emerging and reemerging infectious diseases has prompted increased attention to a variety of diseases whose incidence would be affected by environmental

change. NIH provides significant resources for research on and development of vaccines and treatment for cholera and vector-borne diseases, such as encephalitis, malaria, dengue, and Lyme disease.

Mapping of Budget Request to Appropriations Legislation. In the Departments of Labor, Health and Human Services, and Education and Related Agencies Appropriations Bill, USGCRP activities are funded under the NIH section of Title II–Department of Health and Human Services, within the National Institute of Environmental Health Sciences account.

Department of the Interior

Areas of Global Change Research. DOI programs include studies of past climates, from which understanding of current changes can be drawn; interaction and sensitivity of hydrologic and ecological systems with climate at local, landscape, and regional levels, including the ecological linkage between environmental factors, climate change, terrestrial and aquatic ecosystems, and the associated biological resources; arid, polar, and coastal regions and systems; impacts of sea-level change on coastal wetland and forest ecosystems, and the influence of climate on the ecological status and nutrient limits of large reservoir systems and associated fisheries; volcano-atmosphere interactions; methane hydrates; changing land surface characteristics; ocean heat fluxes; assessments of the impacts of global change and the social, environmental, and economic consequences for human activities, water resources, coastal wetlands, biological species, ecological systems, and land management; carbon cycle variation; and archiving and distribution of space- and land-based Earth science data.

DOI	Program Title	FY96	FY97	FY98 Request
USGS*	Global Change Research	28.5	28.5	28.5
	Total	**28.5**	**28.5**	
	President's Request	30.0	28.5	**28.5**

*DOI budget information has been consolidated as a result of the merging of the USGS and National Biological Service.

USGS U.S. Geological Survey

FY98 Program Highlights. One of the significant DOI research activities in FY98 will investigate the importance of the land surface in biogeochemical issues such as the global carbon budget. The USGS Mississippi Basin Carbon Project conducts research on the carbon budget in soils and sediments of the Mississippi River Basin. The project focuses on the effects of land-use change on carbon storage and transport, nutrient cycles, and erosion and sedimentation throughout the Mississippi River Basin. Particular emphasis is placed on understanding the interactions among changes in erosion, sedimentation, and soil dynamics. Two hypotheses are being examined: (1) That significant amounts of carbon are buried in terrestrial environments during the deposition of sediments, caused largely by human acceleration of erosion and modifications of hydrologic systems and nutrient supplies; and (2) that the burial of this carbon is accompanied by enhancement of ongoing processes that deliver photosynthetically fixed carbon to soils and terrestrial sediments.

Another significant DOI FY98 activity will be the continued development of detailed records of past climates and climate variability with emphasis on terrestrial records from North America. Long climate records from the coast of western North America will be completed during FY97, and studies of records from the Great Salt Lake will be initiated. These records are part of a transect of climate records that are being developed for the western United States that will provide information on regional trends and patterns in climate variability on millennial to glacial-interglacial times scales. During FY98, work will continue on summarizing information on the conditions in North America during the last interglacial. Work will center on the record of dust deposition as preserved in soils and loess deposits.

Related Research. In addition to focused USGCRP research, DOI sponsors contributing research programs addressing the collection, maintenance, analysis, and interpretation of short- and long-term land, water, biological, and other geological and biological processes and resources through dispersed observing networks; research in land use and land cover, including creation of maps and digital data products; and inventorying and monitoring of biological habitats, resources, and diversity.

Mapping of Budget Request to Appropriations Legislation. In the Interior and Related Agencies Appropriations Bill, DOI USGCRP activities are funded under Title I–Department of the Interior. Funding for U.S. Geological Survey USGCRP programs is included within the USGS Survey, Investigations, and Research account.

Environmental Protection Agency

Areas of Global Change Research. Understanding the regional ecological vulnerabilities to climate change is EPA's primary goal for the Global Climate Change Program. EPA's research aims to address key scientific questions concerning factors affecting the ecological vulnerability of freshwater, coastal, and terrestrial ecosystems to climate change; to examine the human health risks associated with the ecological impacts of climate change; to examine the socio-economic effects of climate change and adaptations to mitigate those effects; and to provide EPA and other stakeholders with technical information needed to understand the costs and performance of risk management options. Stresses associated with climate change are considered in the context of other stressors on ecosystems. Through both extramural funds and intramural activities, EPA supports research on coastal ecosystem vulnerabilities; sentinels or indicators of climate change; regional scenarios of climate projected from GCMs; factors controlling the nutrient and carbon cycles; watershed process models; integrated assessment models; multiple stressor experiments; direct and indirect impacts of climate change on human health; specific climate change mitigation technologies; and the potential for ecosystems to adapt to climate change.

EPA	Program Title	FY96*	FY97	FY98 Request
ORD	Terrestrial Carbon Flux Tracking	1.9	0.0	0.0
ORD	Developing Predictive Models	2.0	1.8	0.0
ORD	Regional Vulnerabilities	11.9	9.7	17.8
ORD	Integrated Assessment Research	1.7	1.3	3.3
ORD	Stratospheric Ozone Depletion	3.5	1.3	0.0
	Total	**22.0**	**14.2**	
	President's Request	23.4	13.7	**21.1**

*Column does not sum to total, pending Agency's program reclassification.

ORD Office of Research and Development

FY98 Program Highlights. Under the Global Change Research Program, EPA conducts research to understand the factors controlling sensitivity or vulnerability of ecosystems to global change. EPA's ecosystem vulnerabilities program fills a critical gap in scientific knowledge and will help to provide the scientific basis to assess, evaluate, predict, and respond to the causes and consequences of global change on a regional scale.

In FY98, EPA will focus on the the following regional vulnerabilities research areas: 1) Regional assessments of the potential ecological risks of climate change for coastal, freshwater, and terrestrial ecosystems in different regions throughout the United States, extending the analysis to include the implications for human health; 2) understanding further the microbial, biological, chemical, and physical processes that control nutrient cycles, carbon storage, and biosphere-atmosphere gas exchange; 3) understanding the vulnerability of watersheds to significant impairment of ecological processes by characterizing landscape-level stressors and exposures at watershed scales; and 4) understanding ecological impacts at the regional level and health effects of potential changes in disease vectors.

EPA's UV-B radiation research will evaluate the biological effects of UV-B radiation, such as the effects on amphibians. EPA will also enhance research in the development of

ecosystem indicators as sentinels of change. The focus will be on terrestrial, aquatic, and coastal indicators that can detect and/or quantify the effects of climate change.

Related Research. In addition to the focused USGCRP research activities, EPA conducts contributing research to characterize and understand risks to ecosystems; develop a national, multi-scale, integrated environmental status and trends program; and understand and predict ecosystem exposures, responses, and vulnerabilities to high-risk chemicals and non-chemical stressors at multiple levels of biological organization and geographic scales.

Mapping of Budget Request to Appropriations Legislation. In the Departments of Veterans Affairs and Housing and Urban Development, and Independent Agencies Appropriations Bill, Environmental Protection Agency USGCRP activities are funded under the EPA section of Title III–Independent Agencies, within the Science and Technology account.

National Aeronautics and Space Administration

Areas of Global Change Research. NASA research efforts in global change involve space-based studies of the Earth as an integrated system, including research and satellite programs studying atmospheric ozone, ocean surface winds, tropical precipitation, and the Earth's upper atmosphere. The space-based activity complements ongoing ground-based research programs in the observation, understanding, and modeling of radiation, climate dynamics, and hydrology; ecosystem dynamics and biogeochemical cycles; atmospheric chemistry; solid Earth science; and the processing, archiving, retrieval, dissemination, and use of global change data. The focus is Earth system science, which involves interdisciplinary research and coupled modeling. Development of algorithms for retrieval of the information content of space-based, remotely sensed observations is carried out as part of the flight mission.

FY98 Program Highlights. The overall goal of the Mission to Planet Earth (MTPE) program is to understand the Earth system and the effects of natural and human-induced changes on the global environment. To preserve and improve the Earth's environment for future generations, policies and decisions worldwide should have the strongest possible scientific basis. The vantage point of space provides information that is obtainable in no other way about the Earth's land, atmosphere, ice, oceans, and biota, as well as the impact of humans on the Earth system.

The science and observations of NASA's MTPE program are becoming increasingly important as the demand for economic progress by the growing global population drives policies that encourage natural resource depletion and rapidly increasing emissions of environmental pollutants. In addition, remote sensing has the potential to improve dramatically crop and forest yield predictions, seasonal and interannual climate forecasts, urban planning, mineral exploration, and many other activities of socio-economic importance. In concert with the global change research community, the MTPE program is utilizing space to lead the development of knowledge required to support the complex national and international policy decisions that lie ahead.

In order to make it more readily understandable, this edition of *Our Changing Planet* divides the MTPE budget into two main components: (1) Scientific research costs; and (2) the costs associated with satellite, aircraft, and balloon measurements, operations and data processing and distribution (including mission costs such as launch, flight, instrument and technology development, fabrication assembly, integration, and testing, as well as mission operation support).

Scientific Research Costs: The scientific research component of the MTPE budget is supported by an integrated science plan that relates research plans to space observations, and fully integrates the Earth Observing System (EOS) and non-EOS science. EOS is a program of multiple spacecraft and interdisciplinary science investigations designed to provide a 15-year data set of key parameters needed in order to understand global climate change. The major themes of NASA's MTPE Science Research Plan are consistent with the USGCRP. They are Land-Cover and Land-Use Change Research, Seasonal to Interannual Climate Variability and Prediction, Natural Hazards Research and Applications, Long-Term Climate–Natural Variability and Change Research, and Atmospheric Ozone Research.

Against the backdrop of the overall MTPE effort to better understand the state and health of the Earth's life-support systems, these five research focus areas target specific research issues important to national and international environmental and economic security. For example, an important priority is to provide an accurate assessment of the extent and health of the world's forests, grasslands, and agricultural

NASA	Program Title	FY96	FY97	FY98 Request
MTPE	Airborne Science Program	27.3	19.0	18.7
MTPE	Applications Research Program	1.0	2.0	2.0
MTPE	Atmospheric Chemical Modeling	6.1	6.5	6.5
MTPE	Atmospheric Dynamics and Remote Sensing	5.5	5.3	5.3
MTPE	Biological Oceanography	5.0	6.4	6.4
MTPE	Ecological Processes	16.1	15.8	15.8
MTPE	EOS Science	56.5	37.5	56.4
MTPE	Geodynamics and Geopotential Fields	17.4	13.9	13.9
MTPE	Geology	4.8	4.3	4.3
MTPE	Global Data Integration and Validation	2.4	2.4	2.4
MTPE	Global Modeling and Analysis Program	4.4	4.6	4.6
MTPE	GLOBE	5.1	5.0	5.0
MTPE	Interdisciplinary Research and Analysis	28.9	10.4	17.9
MTPE	Land Cover and Use Change	1.4	6.0	5.0
MTPE	Land Surface Hydrology	2.7	2.9	2.9
MTPE	Mission Analysis Program	28.5	31.2	30.7
MTPE	Natural Hazards Program	0.3	3.8	3.8
MTPE	Ocean Color Data Purchase/SeaWiFS	2.3	5.1	5.1
MTPE	Pathfinder Science Studies	6.3	6.6	7.0
MTPE	Physical Oceanography and Ocean Modeling	7.2	7.4	7.4
MTPE	Polar Programs	5.1	4.5	4.5
MTPE	Radiation Science Program	6.5	6.6	6.6
MTPE	Stratospheric Chemistry	17.3	17.3	17.3
MTPE	Tropical Rainfall Measurement Science	6.1	6.1	0.0
MTPE	Tropospheric Chemistry	6.8	7.8	8.8
MTPE	Uncrewed Aerial Vehicle Science	0.0	2.0	5.5
NASA Global Change Science Program		271.0	240.4	263.8
MTPE	Advanced Geostationary Studies	0.0	1.0	3.0
MTPE	Commercial Remote Sensing	17.0	16.0	16.0
MTPE	Construction of Facilities	17.0	0.0	0.0
MTPE	Data Purchase	0.0	50.0	0.0
MTPE	Earth Systems Science Pathfinder	1.0	19.4	29.4
MTPE	EOS Data and Information Systems	240.9	248.0	237.7
MTPE	EOS Flight Development	408.5	427.4	535.9
MTPE	EOS Special Spacecraft	60.5	83.1	91.7
MTPE	HPCC Earth Remote Sensing	26.1	28.3	18.3
MTPE	Information Systems	9.6	8.5	4.3
MTPE	LANDSAT	85.2	76.2	52.1
MTPE	Launch Services	107.1	84.7	121.9
MTPE	Lewis & Clark Land Imaging Spacecraft	42.6	5.0	5.0
MTPE	Light SAR	0.0	12.0	0.0
MTPE	Mission Operations	37.8	41.2	31.6
MTPE	NASA Scatterometer	3.2	0.0	0.0
MTPE	Payloads and Instrument Development	4.8	2.1	0.6
MTPE	Total Ozone Mapping Spectrometer	3.0	1.0	5.7
MTPE	Tropical Rainfall Measuring Mission	25.5	17.7	0.0
NASA Global Change Hardware Development		1089.9	1121.6	1153.2
	Total	**1360.8**	**1362.0**	
	President's Request	1341.1	1402.1	**1417.0**

resources. In a time of rapid, and often unrecorded, land-use change, observations from space are the only source of objective information on the human use of land. A closely related priority is to improve understanding and prediction of seasonal to interannual climate variation. Reducing uncertainties in climate predictions out to a season or a year in advance can help improve dramatically the efficiency of water use for agriculture and hydropower, as well as improve contingency planning for energy demand and in other economic sectors.

In addition, the MTPE natural hazards research priority emphasizes the use of remote-sensing observations for the characterization and mitigation of drought and flood impacts. There is increasing evidence that predictions of extreme weather events can be improved by understanding their links to interannual climate phenomena, such as the El Niño events. The MTPE Science Plan also calls for special attention to measuring and modeling the relative influence of forcing factors in long-term climate change, including clouds, aerosols, and greenhouse gases, in order to improve the understanding and prediction of climate on time scales of decades to centuries. A continuing priority area for MTPE is to understand the causes and consequences of changes in atmospheric ozone. Research to resolve questions related to stratospheric ozone depletion continues to make great progress, and increased emphasis is now being focused on the changing composition of the lower atmosphere, which is especially sensitive to the unprecedented growth of pollutant emissions in East Asia and other rapidly developing regions.

Costs Associated with Satellite, Aircraft, and Balloon Measurements, Operations and Data Processing and Distribution: The Earth Observing System is a program of multiple spacecraft (the AM, PM, and CHEM series, Landsat 7, and others) and interdisciplinary science investigations to provide a 15-year data set of key parameters needed to gain a fuller understanding of global climate change. The first EOS satellite launches begin in 1998.

Preceding EOS are a number of individual satellite and Shuttle-based missions which are helping to reveal the basic processes of atmospheric chemistry (Upper Atmosphere Research Satellite—UARS/1991), ozone distribution and depletion (Total Ozone Mapping Spectrometer—TOMS/1978, 1991, 1996, and 2000), ocean topography and circulation (TOPEX/Poseidon/1992), ocean winds (NASA Scatterometer—NSCAT/1996), and global tropical precipitation (Tropical Rainfall Measuring Mission—TRMM/1997), among others. These provide the scientific and technological foundation on which EOS builds.

Complementing EOS will be a series of small, rapid-development Earth System Science Pathfinder (ESSP) missions to study emerging science questions and make innovative measurements in parallel with the 15-year mission of EOS. The first ESSP mission should be ready for launch in 2000. In addition, the New Millennium Program (NMP) provides for the infusion of innovative new technologies into the MTPE program with an initial focus on the second and third series' of EOS measurements, and will emphasize fast-track development and low-cost demonstration missions. These technologies, which will lead to the development of smaller and lighter-weight instruments, will reduce annual program expenditures in the post-FY2000 time frame. ESSP will feature low life-cycle costs, peer-reviewed science, and missions based on best science value.

The FY98 budget request includes three new initiatives which will further contribute to a robust science program and to technology infusion. These initiatives include an uncrewed aerial vehicle (UAV) science research program, an instrument incubator, and a study effort to explore global change measurements which might best be made from geostationary orbit.

MTPE is committed to continue to look for ways to reduce near-term funding requirements. The Chemistry-1, Laser Altimetry, and AM-2 missions are all under

study to determine whether cost savings can be achieved through the use of new approaches to these missions, such as the utilization of smaller spacecraft.

Data from MTPE missions, both current and future, are captured, processed into useful data products, and broadly distributed by the EOS Data and Information System (EOSDIS). EOSDIS will ensure that data from these diverse missions will remain available in active archives for use by current and future scientists. Since these data are useful beyond the Earth system science research community, EOSDIS will be accessible to environmental decisionmakers, resource managers, commercial firms, social scientists and the general academic community, educators, state and local government—anyone who wants the information. Following the recommendation of the National Research Council, MTPE is exploring the creation of a federation of Earth science information partners in academia, industry, and government to broaden the participation in the creation and distribution of EOSDIS information products.

Related Research. NASA includes all research in support of global change within the focused research program.

Mapping of Budget Request to Appropriations Legislation. In the Departments of Veterans Affairs and Housing and Urban Development, and Independent Agencies Appropriations Bill, National Aeronautics and Space Administration USGCRP activities are funded under the NASA section of Title III–Independent Agencies, within the Science, Aeronautics, and Technology account. Within this account, Appropriations Committee reports specify funding for the Mission to Planet Earth program, which is the NASA contribution to the USGCRP.

National Science Foundation

Areas of Global Change Research. NSF global change research programs support research and related activities that advance fundamental understanding of dynamic physical, biological, and socio-economic systems, and the interactions among those systems. In addition to research on Earth system processes and the consequences of changes in those systems, NSF programs facilitate data-acquisition and data-management activities necessary for basic research on global change, promote the enhancement of modeling designed to improve representations of Earth system interactions, and develop advanced analytic methods to facilitate fundamental research. NSF also supports fundamental research on the general processes used by governments and other organizations to identify and evaluate different types of policies for mitigation, adaptation, and other responses to changing global environmental conditions.

NSF	Program Title	FY96	FY97	FY98 Request
	Antarctic Ecosystems	1.0	1.0	1.0
	Arctic System Science	14.2	14.5	15.2
	Climate Modeling, Analysis, and Prediction	11.7	11.5	11.8
	Climate Variability and Predictability	11.5	11.0	11.0
	Coastal Long-Term Ecological Research	2.8	2.9	2.4
	Earth System History	9.4	10.4	11.2
	Ecological Diversity	4.8	4.8	5.0
	Ecological Rates of Change	3.0	3.0	3.2
	Geodata	1.4	1.4	1.8
	Global Ocean Ecosystems Dynamics	7.4	8.8	9.8
	Global Tropospheric Chemistry Program	12.4	12.5	13.0
	Greenhouse Gas Dynamics	0.2	0.2	0.2
	Human Dimensions of Global Change	12.2	12.2	12.1
	Joint Global Ocean Flux Study	19.4	18.7	17.5
	Methods and Models for Integrated Assessment	3.4	3.4	3.4
	Polar Ozone Depletion/UV Radiation Effects	3.5	3.5	4.1
	Regional Research Institutes	3.2	3.2	3.2
	Ridge Interdisciplinary Global Experiments	3.7	3.3	3.3
	Sea Level Changes	5.8	5.8	5.8
	Solar Influences	6.0	6.1	6.0
	Water & Energy: Atmospheric-Vegetative-Earth Interactions	8.7	8.6	8.8
	World Ocean Circulation Experiment	17.8	16.7	16.8
	Total	**163.3**	**163.5**	
	President's Request	183.4	170.0	**166.4**

FY98 Program Highlights. During FY98, NSF will continue to support research and related activities across all of its global change programs. A significant share of the agency's efforts will focus on continuation of major international collaborative field programs. Of these programs, the World Ocean Circulation Experiment (WOCE) and the Joint Global Ocean Flux Study (JGOFS) are phasing down field observations and moving toward intensive analysis and synthesis. Modest growth is expected for research related to Global Ocean Ecosystem Dynamics (GLOBEC) and Earth System History (ESH), among other, programs. GLOBEC expansions will

support studies from the Atlantic to the Pacific Ocean, with special focus on sensitivity of target species to global changes and analysis of ecosystem productivity and interactions. Growth related to ESH will allow for international collaboration between ESH scientists and the International Marine Past Global Changes Study (IMAGES) on high accumulation ocean sediment from the Indo-Pacific region. ESH-sponsored scientists also will collaborate with the International Continental Drilling Program for recovery and analysis of long, high-resolution sediment cores and with CLIVAR scientists for recovery and analysis of paleo-environmental records on seasonal to century time scales. In FY98, continued support for CLIVAR activities will sponsor research aimed at the improvement of seasonal-, interannual-, and decadal-scale climate understanding and prediction.

NSF will continue to support the development, testing, and application of climate system models and improved methods to enhance model representations of related Earth processes. In support of this work, NSF plans to enhance the development and application of the community-use Climate System Model (CSM) at the National Center for Atmospheric Research (NCAR). Consistent with this plan, NSF will continue to make available advanced computational facilities for USGCRP-sponsored Earth system modeling. NSF also will maintain support for research on fundamental understandings of human contributions and responses to global change as well as research on ecological dynamics and consequences of global environmental change.

Related Research. In addition to focused research, NSF conducts contributing research on many topics, including laboratory and field studies of the atmosphere and the factors that affect it; data management for scientific research and modeling activities; generation, transportation, and fate of chemicals in natural systems; long-term monitoring and detailed studies of ecosystems; geophysical, hydrological, geological, and geochemical processes operating on the Earth's surface; composition, structure, and history of ocean floors; and global environmental history.

Mapping of Budget Request to Appropriations Legislation. In the Departments of Veterans Affairs and Housing and Urban Development, and Independent Agencies Appropriations Bill, National Science Foundation USGCRP activities are funded under the NSF section of Title III–Independent Agencies, within the NSF Research and Related Activities account.

Smithsonian Institution

Areas of Global Change Research. Within the Smithsonian Institution, research conducted at the Smithsonian Astrophysical Observatory, the National Air and Space Museum, the Smithsonian Environmental Research Center, and the National Museum of Natural History concentrates on monitoring indicators of natural and anthropogenic environmental change on daily to decadal time scales, and on longer term indicators present in the historical artifacts and records of the museums as well as in the geologic record at field sites. The primary thrust of the Smithsonian's work is to improve knowledge of the natural processes involved and to continue to provide a long-term repository for present and future studies.

SI	Program Title	FY96	FY97	FY98 Request
NMNH/STRI	Long-Term Environmental Change	1.6	1.6	1.6
SAO/NASM/SERC	Monitoring Natural Environmental Change	1.2	1.2	1.2
NZP/NMNH/SERC	Biological Responses	4.2	4.2	4.2
	Total	**7.0**	**7.0**	
	President's Request	7.3	7.0	**7.0**

NASM National Air and Space Museum
NMNH National Museum of Natural History
NZP National Zoological Park
SAO Smithsonian Astrophysical Observatory
SERC Smithsonian Environmental Research Center
STRI Smithsonian Tropical Research Institute

FY98 Program Highlights. Studies of atmospheric composition, the absorption and transmission of radiation, and atmospheric chemistry are continuing to receive emphasis at SAO. Remote-sensing measurements of trace species in the stratosphere that play an important role in ozone chemistry will be done, as well as accurate laboratory measurements of the photoabsorption characteristics of trace atmospheric species. In addition, solar activity is being monitored and modeled to better understand the causes of variability in the Earth's ultimate energy source and to improve our capabilities in making solar predictions.

Research at NASM will emphasize the use of remote-sensing data to improve theories of drought, sand mobility, soil stability, and vegetation dynamics in the Earth's drylands, with particular emphasis on the use of Shuttle Imaging Radar to understand the effects of past climate change in the Sahara.

Monitoring of the influx of UV-B radiation will be performed at SERC, where spectral radiometers are used for a continuous record now more than 25 years long.

The Biological Responses program is divided into two broad areas: Tropical biological diversity, and ecosystem response to fragmentation. Studies of tropical biological diversity are performed at the Smithsonian Tropical Research Institute (STRI) and the National Museum of Natural History. The Tropical Biological Diversity (TROBID) program concentrates on inventories of biodiversity and species distribution in tropical forests, monitoring biodiversity through repeated standardized sampling of flora and fauna, and identifying the physical and biological processes of growth and decline of species.

A major thrust for all units in FY98 will be to inform the public of the resources available at the Smithsonian via electronic means, as well as to provide outreach in

all areas of the Institution's collections. Valuable documentation will be made available to both the general public and the community of researchers to aid in long-term environmental studies.

Related Research. Studies of environmental change over long time periods are aided by the Institution's collections. Utilized by staff and researchers from other institutions, these materials provide raw data for evaluating changes in the physical and biological environment that occurred before human influences.

Mapping of Budget Request to Appropriations Legislation. In the Interior and Related Agencies Appropriations Bill, Smithsonian Institution USGCRP activities are funded in the SI section of Title II–Related Agencies, within the Salaries and Expenses account. Appropriations Committee reports specify funding for a Sciences line item component of this account, which includes USGCRP programs.

Tennessee Valley Authority

Areas of Global Change Research. Research by the Tennessee Valley Authority focuses on the regional- and local-scale aspects of climatic and hydrologic systems, biogeochemical dynamics, climate change impacts assessment, and greenhouse gas sources and sinks.

TVA	Program Title	FY96	FY97	FY98 Request
	Global Change Research	1.0	1.0	1.0
	Total	**1.0**	**1.0**	
	President's Request	1.0	1.0	**1.0**

Related Research. TVA also sponsors research emphasizing environmental and economic concerns, including programs for managing water resource systems and power operations, water quality, biological health of reservoirs and rivers, and wetlands.

Mapping of Budget Request to Appropriations Legislation. In the Energy and Water Development Appropriations Bill, TVA Environmental Research Center (ERC) USGCRP activities are funded under the TVA section of Title IV–Independent Agencies.

APPENDIX C

THE U.S. GLOBAL CHANGE RESEARCH PROGRAM

The USGCRP was established in 1989, and was included as a Presidential Initiative in the FY90 budget as a high-priority research effort, designed to:

- Address key uncertainties about changes in the Earth system, both natural and human-induced
- Monitor, understand, and predict global change
- Provide a sound scientific basis for national and international decisionmaking on global change issues.[1]

Congress codified the USGCRP in the Global Change Research Act of 1990, in order to provide for:

- "...development and coordination of a comprehensive and integrated United States research program which will assist the Nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change."
- "...increasing the overall effectiveness and productivity of Federal global change research efforts."[2]

The Global Change Research Act defines global change as "changes in the global environment (including alterations in climate, land productivity, oceans or other water resources, atmospheric chemistry, and ecological systems) that may alter the capacity of the Earth to sustain life."

This mandate for the USGCRP makes it clear that the program is to have a broad scope and consider the full set of issues dealing with actual and potential global environmental change. This approach recognizes the profound economic, social, and ecological implications of global changes and the need to maintain U.S. leadership in this area.

Since its inception, the USGCRP has been directed toward strengthening research on key scientific issues, and has fostered much improved insight into the processes and interactions of the Earth system. The

[1]Committee on Earth Sciences, U.S. Global Change Research Program. *Our Changing Planet: The FY 1990 Research Plan*, July 1989.
[2]Global Change Research Act of 1990, 15 USC 2921.

results of research supported by the USGCRP play an important role in international scientific assessments, including assessments of climate change and stratospheric ozone depletion. The USGCRP research results provide the scientific information base that underpins consideration of possible response strategies, but the USGCRP does not recommend policies on global change issues, nor does it include support for research and development of energy technologies, development of mitigation strategies, or for the Climate Change Action Plan.

Presidents Bush and Clinton, and Congress, have supported the USGCRP as a high priority in the national scientific research agenda.

Program Direction and Agency Research Contributions

The Subcommittee on Global Change Research (SGCR) of the Committee on Environment and Natural Resources (CENR), a component of the National Science and Technology Council (NSTC), provides overall direction and executive oversight of the USGCRP. Within this framework, agencies manage and coordinate Federally supported scientific research on global change. In addition to USGCRP review of the overall set of agency research programs, each agency is responsible for the review of individual projects within its programs. These reviews are almost exclusively based on an external peer-review process, which is deemed an important means of ensuring continued program quality.

The Global Change Research Act specifies a minimum of 14 Federal agencies as well as planning and oversight offices of the Executive Office of the President to be represented in the oversight of global change research. The SGCR includes representatives of the Departments of Agriculture, Commerce (the National Oceanic and Atmospheric Administration and National Institute of Standards and Technology), Defense, Energy, Health and Human Services (the National Institute of Environmental Health Sciences), Interior, and State as well as the Environmental Protection Agency, the National Aeronautics and Space Administration, the National Science Foundation, the Smithsonian Institution, the Office of Science and Technology Policy, the Office of Management and Budget, and the intelligence community.

Global environmental issues are very complex and require a wide range of expertise. Overcoming obstacles to cooperation among agencies is well worth the effort to coordinate their contributions because of the wide range of challenges to be addressed, the interests and capabilities of each agency, and the need to make the most effective use of

available budgetary resources to implement a strong research program. A few of the agencies participating in the USGCRP support research on a broad range of issues, while others have a more specialized focus. Programmatic contributions are closely matched to agency missions and areas of expertise.

Thus, for example, NASA leads efforts relating to satellite observations of the Earth as well as research to interpret and understand these observations; NOAA leads efforts relating to its interests in improving predictions of atmospheric and oceanic behavior; DOE focuses on research to predict the behavior of the global climate system on decade to century time scales in response to changes in atmospheric composition, and to evaluate the contribution of energy-based emissions to climate change; NSF focuses on broadly based fundamental research to improve understanding of the Earth system; USDA focuses on the roles of and consequences for agriculture, food production, and forests of global-scale environmental change; NIH focuses on potential health-related impacts; DOI focuses on climate system history and impacts on water resources and public lands; EPA focuses on ecosystem and societal impacts of global change; DOD focuses on prediction of seasonal climate anomalies affecting its national security operations; and the Smithsonian Institution focuses on improving knowledge of the natural processes involved in global change.

To help ensure effective program integration, the SGCR established the Coordination Office of the USGCRP in July 1993. This office, which is staffed by the participating agencies and departments, is responsible for drafting the annual edition of *Our Changing Planet* and periodic research plans, as well as facilitating the year-to-year planning and day-to-day coordination and communication needs of the program.

The planning, coordination, and execution of USGCRP research activities are carried out in close association with and in support of the science priorities of the international research community—particularly those put forth by the Intergovernmental Panel on Climate Change, the World Climate Research Programme, the International Human Dimensions of Global Environmental Change Programme, and the International Geosphere-Biosphere Programme. These efforts underpin U.S. participation in and contributions to the international assessments related to aspects of global change.

The USGCRP maintains an active interaction with the National Academy of Sciences through its Board on Sustainable Development, its Committee on Global Change Research, and several other boards, committees, and panels of the National Research Council that interface with many of the international scientific research programs.

The overall USGCRP is evaluated periodically for scientific merit and continued relevance to the policy process, both domestic and international, by the National Academy of Sciences.

APPENDIX D

EXPLANATORY NOTES FOR FIGURES

Figure 1 (page 10): Consideration of both natural and human-induced influences on climate is leading to an understanding of the causes of changes in global average temperature since the mid-19th century. Carefully quality-controlled records of surface temperatures over land and ocean regions indicate that the global average temperature has increased about 0.5°C (about 1°F) since the mid-19th century and about 0.7°C (about 1.3°F) since the cool decade that opened the 20th century.

The sharp year-to-year variations in the observed record result both from the limited number of observation stations and from natural fluctuations. Natural fluctuations seem to be caused largely by air-sea interactions (e.g., El Niño events) and by cooling following major volcanic eruptions. Other random fluctuations may also be occurring.

Results from simplified climate models, which have been calibrated to comprehensive general circulation models used to study the climate, have been used to analyze which factors have been influencing global average temperatures. These results (shown in the smoother curves), which are calculated for climate sensitivities of 1.5, 2.5, and 4.5°C temperature increase at equilibrium for a doubling of the carbon dioxide concentration, suggest that several influences have been important. The increases in the concentrations of carbon dioxide and other greenhouse gases have created a strong warming influence. This warming influence has been countered by a regional-to-global cooling influence due to the reflection of a portion of solar radiation back into space by sulfate and other aerosols that have resulted mainly from coal combustion. In addition, changes in the intensity of solar radiation (as indicated by sunspot cycling) have created inter-decadal variations in temperature.

The somewhat chaotic nature of climate fluctuations prevents perfect agreement between model results and observations. Present understanding seems to be capturing most of the major changes. The remaining significant deviations between model results and observations suggest the possible need to consider the roles of additional natural influences, such as volcanic eruptions and snow and other atmospheric interactions with the land surface, which have mainly intra-decadal effects, as well as human influences, such as changes in land cover and tropospheric ozone, which may have multi-decadal effects. However, these influences, which are not yet included in climate models, do not appear to be the dominant factors in long-term climate change.

Figure 2 (page 28): The central panel shows observations for winter (January-February-March mean) geopotential height anomaly for 1989. The geopotential height is a measure of the build-up of colder and warmer air masses in different regions of the atmosphere. The top and bottom panels show the model-simulated geopotential height anomalies (determined using a model that takes as input observed sea-surface temperatures) for the older and newer versions, respectively, of the atmospheric model of the Center for Ocean-Land-Atmosphere Studies (COLA). The contour interval is 150 m. The solid shading denotes a positive anomaly (indicative of warmer air) of 75 m; the cross-hatched shading denotes a negative anomaly

(indicative of colder air) of 75 m. The solid contour denotes a positive anomaly of 225 m; the dashed contour denotes a negative anomaly of 225 m.

These results indicate that, if the sea-surface temperatures can be predicted accurately using ocean models, the present versions of the atmospheric models have the ability to accurately predict seasonal mean climate anomalies over North America and the adjoining areas, thereby allowing predictions of dry and wet and of cold and warm conditions, at least under some climatic conditions.

Figure 3 (page 34): Reconstructions of the history of temperature and of the atmospheric CO_2 concentration going back 150,000 years have been made from the air bubbles trapped in the ice of Antarctica. The baseline temperature (the "0" point) is for average conditions over the past few millenia for the ice cores and for the 19th century for the recent record. Note that the paleoclimatic temperature variations are for Antarctica, so will show larger swings than that for the global average temperatures shown for the period since 1850.

Considerable research has been conducted to understand the causes of the temperature changes. These records can be continued to the present with instrumental observations. For the period prior to human activities, there is general agreement that the natural cycles of solar radiation due to changes in the shape and orientation of the Earth's orbit are likely the major driving force for large-scale swings in temperature.

However, these variations are not enough to explain the glacial cycling unless the radiative effects of changes in the concentrations of CO_2 and CH_4 are amplifying the influence of variations in solar radiation on the climate. The high correlation in the CO_2 and temperature curves suggests that this is indeed happening, so that warmth is associated with high CO_2 concentrations and cool conditions with low CO_2 concentrations, and that a number of feedbacks must be operating in determining the climatic response.

On the right side of the figure, the CO_2 concentration is extended to its present level, then to the level projected for the year 2100 using a central case scenario that assumes no special control measures are adopted (IPCC scenario IS92a). The inset shows the detailed record of the increase in the CO_2 concentration over the past 40 years as recorded at the Mauna Loa Observatory in Hawaii by C.D. Keeling and by NOAA. This pioneering record first demonstrated that an increase in CO_2 concentration was underway. Based on projected emissions scenarios, climate models predict a sharp rise in the atmospheric CO_2 concentration out to 2100, resulting in a few-degree rise in the global average temperature.

Figure 4 (page 38): Increased UV radiation can cause several types of damaging effects, depending on the energy level and intensity of the radiation and the susceptibility of the receptor of the radiation. The figure shows the percentage rate of increase (in percent per decade) in the exposure to UV radiation for the period 1979 to 1992 for three types of receptors.

This study used daily satellite estimates of cloud cover and information on local terrain height and reflectivity, and changes in ozone and aerosol concentrations to calculate the changes and seasonal variations in surface intensity of UV-radiation as a function of latitude. This constructed record of UV-radiation at the surface was then combined with the action spectra (i.e., the susceptibility to damage) for the skin, for genes, and for plants to estimate the weighted exposures and changes that resulted from 1979 to 1992. Trend lines were then fit so that rates of change could be calculated. Statistically significant increases in exposure are seen in middle and high latitudes, primarily in the spring and summer months when people and plants would be most exposed to sunlight.

Figure 5 (page 42): The maps show the summer range and relative abundance of the bobolink relative to their maximum density in this domain, as estimated from an

empirical-statistical model. The correspondence in predicted patterns with the abundances determined from the Breeding Bird Survey suggests that the empirical model for present conditions (top panel) captures many of the features of the observed abundance of this species over North America. The bottom panel shows the predicted range and abundance of the bobolink assuming the climate change response of a model with a doubled CO_2 concentration (see J. Price, *Potential impacts of global climate change on the summer distribution of some North American grasslands birds*. Ph.D. dissertation, Wayne State University, Detroit, Mich., 1995, 540 pp.).

Figure 6 (page 48): The wind field shown in the NSCAT figure for 21 September 1996 is typical of conditions near the solar equinox. The trade winds, which are quite strong and show up as intense blue, blow steadily from the cooler subtropical ocean areas toward the Intertropical Convergence Zone (ITCZ) that is located just north of the equator. Instead of blowing north to south, the trade winds are deflected westward by the Earth's rotation (which creates the Coriolis force). The air rises over the warm waters of the ITCZ then sinks in the subtropical regions (called the "horse latitudes"), forming the Hadley Cell circulation. Both the convergence area at the ITCZ and the divergence area in the horse latitudes have relatively low wind speeds (and so are indicated by the paler color).

Two typhoons are shown in the western Pacific. Typhoon Violet is just south of Japan; after these data were taken, Typhoon Violet struck the east coast of Japan causing damage and deaths. Typhoon Tom is located further east and is evolving into an extratropical (mid-latitude) storm.

The image is based on preliminary processing of the first set of NSCAT observations, using prelaunch model functions and calibration. Improvement is expected after the standard calibration and beam balancing procedures. The NSCAT data are objectively interpolated into 12-hourly and 1° longitude by 1° latitude grids (about 100 km) using the methodology described by W. Tang and W.T. Liu (Jet Propulsion Laboratory publication 96-19, 1996) using no other data for initialization.

This preliminary analysis demonstrates that the high spatial resolution of NSCAT and its observing capability under both clear and cloudy conditions will improve the monitoring of severe storms such as typhoons, whose location and intensity are usually not well-defined by conventional methods, and will therefore improve weather forecasts and public-warning capabilities. The NSCAT results also show that NSCAT's global coverage will provide a much more detailed and reliable description of atmospheric circulation over the ocean, which will improve predictions of features such as El Niño warmings and other oceanic conditions that play an important role in causing seasonal average climates to change (e.g., because of shifts in the jet stream).

Figure 7 (page 57): Worldwide sea-level rise is caused as water is added to the oceans when glaciers and ice sheets melt and because the ocean waters increase in volume as they warm (as do most substances due to their positive thermal expansion coefficient). The flooding of islands colonized several centuries ago is evidence that the local sea level has been rising in the Chesapeake Bay.

Over the past 100 years, sea level has risen ~0.3 m (~12 in) in the U.S. mid-Atlantic region. About half of this change has been due to worldwide sea-level rise and about half has been due to a slow sinking of the land due to local factors, including a very long-term response to the removal of glacial ice and a shorter term land-subsidence response due to significant pumping of groundwater. Climate change is projected to cause the rate of global sea-level rise to increase, implying an overall rise from both human influences and the continuing preindustrial rate of rise of ~0.65 m (~26 in) by 2100 in the mid-Atlantic region. Populated place and associated elevation data for this figure were taken from the Geographic Names Information System (GNIS). The GNIS is the official Federal repository of domestic geographic feature

names information. USGS's 1:24,000-scale topographic maps are one of several sources of data for the GNIS, which is currently in Phase II of its compilation. The elevations in the GNIS are typically read or interpolated for a single point at or near the center of the populated place. To construct this map, the GNIS was queried for populated places with elevation entries of 1 m or less.

Figure 8 (page 60): The Crary Ice Rise (83°S, 174°W) is situated in the southeastern corner of the Ross Ice Shelf, Antarctica. Surrounded by about 400-m-thick ice floating on the Ross Sea, the Crary Ice Rise is an ice-capped island that causes the ice to rise nearly 50 m above the adjacent ice shelf. The rise rests in the downstream ice flow from two West Antarctic ice streams. As such, some investigators conjecture that the ice rise presents an obstruction to ice flow, effectively damming the upstream ice and contributing to the stability of the inland ice sheet.

Recent studies suggest that the Crary Ice Rise is changing, which alters the effect that the ice rise has on local ice flow. Based on ice thickness and ice surface velocity data, the shelf immediately downstream of the ice rise is estimated to be thinning by about 1 m/yr. Southwest of the ice stream (downward on the figures), the ice shelf is believed to be thickening by a similar amount. These calculations have led authors to speculate that the orientation of the ice rise may be shifting. Photographs taken by DOD's Corona satellite in 1963 (and recently declassified as part of the MEDEA project) and then, 32 years later, by the commercially operated SPOT satellite support this idea. Seemingly fresh, sinusoidal cracks are present in 1963, along the northeastern "hook" of the ice rise. By 1995, the cracks have evolved into segmented blocks that are being rotated by the shearing flow past the ice rise.

Large portions (100-km scale) of this sector of Antarctica are susceptible to dramatic changes in ice flow. Ice streams, large rivers of ice that drain the West Antarctic Ice Sheet into the Ross Ice Shelf, are known to turn "on and off" on time periods of many hundreds of years. This in turn leads to local changes in the grounding line, which is the location where grounded ice starts to float free of the descending ocean floor. It is believed that rapid changes in ice sheet behavior are in fact due to changes in the internal dynamics of the ice sheet. Changes in glacier physical properties, such as subglacial water flow patterns, are presumed to be the important feedback mechanisms controlling rapid changes in the ice sheet, rather than external climate forces.

With an extended delay, the structure of the Crary Ice Rise responds to changes in the inland ice sheet by growing or retreating as the upstream ice flux shifts. The present pattern of thinning along the northeastern margin of the ice shelf and thickening along the southwestern margin may have been repeated in the past. Evidence for this comes from ice thickness patterns far downstream of the ice rise. Because of this, the ice shelf acts as a "tape-recorder," preserving remnants of ice thickness patterns of an earlier time. Paired ice thickness hollows and domes similar to the pattern seen today are located about 200 km downstream of the ice rise. Using present day ice velocities, these observations suggest a similar process occurred around the ice rise some 400 years ago. The Corona and SPOT data suggest researchers may now have an opportunity to study a repeat of that same, and perhaps episodic, process.

APPENDIX E

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Our Changing Planet FY98 Edition

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Agencies, through their Subcommittee on Global Change Research representatives (listed in front of book), provided FY98 agency program highlights.

Abstract

Our Changing Planet: The FY 1998 Global Change Research Program is a report to Congress supplementing the President's FY98 budget, pursuant to the Global Change Research Act of 1990. The report describes the U.S. Global Change Research Program (USGCRP); reviews progress in global change research over the past decade; presents highlights of recent and current research on key global change environmental science issues; outlines integrative activities and perspectives supported by the USGCRP; discusses new global change research challenges in the coming decade; and provides a detailed view of the FY98 USGCRP budget, including FY98 program components and program highlights by agency. Achieving the goals and objectives of this program will require continued strong support for the scientific research needed in order to improve understanding of how human activities are affecting the global environment, as well as how natural and human-induced change is affecting society.

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On the Back Cover

The long-term climate of a region is the primary determinant of the region's vegetation. The two maps show how the global warming predicted by two climate models would be expected, over time, to change the density of the vegetation of the United States. In the Mapped Atmosphere-Plant-Soil System (MAPSS) vegetation distribution model, the vegetation density is represented as the potential leaf area that could be supported at any upland location in a region, given constraints of water and energy. The leaf area serves as an index of the overall vegetation carrying capacity, or productivity, of an area.

To generate these maps, the MAPSS model is run for current average climate conditions and for the potential future average climate assuming the persistence of a doubled atmospheric CO_2 concentration, as simulated by different general circulation models (GCMs). Green areas indicate enhanced vegetation growth, generally from a more favorable water balance; yellow to red areas indicate where vegetation density could be reduced, generally from increased drought stress. Forested regions subjected to increased drought stress could experience drought-induced dieback, increased pest infestations, and increased probabilities of fire. Zones of high or low agricultural productivity would also be expected to shift as the climate shifts. The Southwest could become more favorable for grass, but there could be a fuel build-up that would lead to more intense fires.

The GCM simulations are from the NOAA Geophysical Fluid Dynamics Laboratory (GFDL) and the United Kingdom Meteorological Office (UKMO). For a doubled CO_2 concentration, the GFDL model produces an average increase in temperature of 4.3°C (about 7.7°F) and an increase in precipitation of 21% over the conterminous United States. The UKMO model predicts a 6.7°C (about 12°F) temperature increase and a 12% precipitation increase.

Note that the climate will actually change over time toward conditions such as those indicated and that the time-dependent pattern of vegetation changes would not be exactly the same as those indicated in these model simulations of doubled CO_2 conditions. Time-dependent model simulations are being started in order to provide more realistic estimates of potential changes.

Figure courtesy of Ronald P. Neilson, USDA/Forest Service, Corvallis, Oregon.

The U.S. Global Change Research Program