17

Pacific Northwest Laboratory Annual Report for 1988 to the DOE Office of Energy Research

**Part 3: Atmospheric Sciences
April 1989**

**Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830**

**Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute**

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor Battelle Memorial Institute, nor any of their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or Battelle Memorial Institute. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

PACIFIC NORTHWEST LABORATORY
operated by
BATTELLE MEMORIAL INSTITUTE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC06-76RLO 1830

Printed in the United States of America
Available from
National Technical Information Service
United States Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161

NTIS Price Codes
Microfiche A01

Printed Copy

Pages	Price Codes
001-025	A02
026-050	A03
051-075	A04
076-100	A05
101-125	A06
126-150	A07
151-175	A08
176-200	A09
201-225	A10
226-250	A11
251-275	A12
276-300	A13

**Pacific Northwest Laboratory
Annual Report for 1988 to the
DOE Office of Energy Research**

Part 3: Atmospheric Sciences

Staff members of Pacific Northwest
Laboratory

April 1989

Prepared for
the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Richland, Washington 99352

PREFACE

This 1988 Annual Report from Pacific Northwest Laboratory (PNL) to the U.S. Department of Energy (DOE) describes research in environment, safety, and health conducted during fiscal year 1988. The report again consists of five parts, each in a separate volume.

The five parts of the report are oriented to particular segments of the PNL program. Parts 1 to 4 report on research performed for the DOE Office of Health and Environmental Research in the Office of Energy Research. Part 5 reports progress on all research performed for the Assistant Secretary for Environment, Safety and Health. In some instances, the volumes report on research funded by other DOE components or by other governmental entities under interagency agreements. Each part consists of project reports authored by scientists from several PNL research departments, reflecting the multidisciplinary nature of the research effort.

The parts of the 1988 Annual Report are:

- Part 1:** Biomedical Sciences
Program Manager: J. F. Park   D. L. Felton, Report Coordinator and Editor
- Part 2:** Environmental Sciences
Program Manager: R. E. Wildung   S. G. Weiss, Report Coordinator and Editor
G. P. O'Connor, Editor
- Part 3:** Atmospheric Sciences
Program Manager: C. E. Elderkin   C. E. Elderkin, Report Coordinator
E. L. Owczarski, Editor
- Part 4:** Physical Sciences
Program Manager: L. H. Toburen   L. H. Toburen, Report Coordinator
K. A. Parnell, Editor
- Part 5:** Environment, Safety, Health,
and Quality Assurance
Program Managers: L. G. Faust   L. G. Faust and W. T. Pennell, Report
W. T. Pennell   Coordinators
J. M. Selby   S. K. Ennor, Editor

Activities of the scientists whose work is described in this annual report are broader in scope than the articles indicate. PNL staff have responded to numerous requests from DOE during the year for planning, for service on various task groups, and for special assistance.

Credit for this annual report goes to the many scientists who performed the research and wrote the individual project reports, to the program managers who directed the research and coordinated the technical progress reports, to the editors who edited the individual project reports and assembled the five parts, and to Ray Baalman, editor in chief, who directed the total effort.

Members of the Scientific Advisory Committee, established in 1985, are:

Dr. Franklin I. Badgley	University of Washington
Dr. Leo K. Bustad	Washington State University
Dr. Franklin Hutchinson	Yale University

Dr. Albert W. Johnson
Dr. J. Newell Stannard

San Diego State University
University of Rochester, University of California, San Diego

W. J. Bair, Manager
T. S. Tenforde
Environment, Health and Safety
Research Program

Previous reports in this series:

Annual Report for

1951	HW-25021, HW-25709
1952	HW-27814, HW-28636
1953	HW-30437, HW-30464
1954	HW-30306, HW-33128, HW-35905, HW-35917
1955	HW-39558, HW-41315, HW-41500
1956	HW-47500
1957	HW-53500
1958	HW-59500
1959	HW-63824, HW-65500
1960	HW-69500, HW-70050
1961	HW-72500, HW-73337
1962	HW-76000, HW-77609
1963	HW-80500, HW-81746
1964	BNWL-122
1965	BNWL-280, BNWL-235, Vol. 1-4; BNWL-361
1966	BNWL-480, Vol. 1; BNWL-481, Vol. 2, Pt. 1-4
1967	BNWL-714, Vol. 1; BNWL-715, Vol. 2, Pt. 1-4
1968	BNWL-1050, Vol. 1, Pt. 1-2; BNWL-1051, Vol. 2, Pt. 1-3
1969	BNWL-1306, Vol. 1, Pt. 1-2; BNWL-1307, Vol. 2, Pt. 1-3
1970	BNWL-1550, Vol. 1, Pt. 1-2; BNWL-1551, Vol. 2, Pt. 1-2
1971	BNWL-1650, Vol. 1, Pt. 1-2; BNWL-1651, Vol. 2, Pt. 1-2
1972	BNWL-1750, Vol. 1, Pt. 1-2; BNWL-1751, Vol. 2, Pt. 1-2
1973	BNWL-1850, Pt. 1-4
1974	BNWL-1950, Pt. 1-4
1975	BNWL-2000, Pt. 1-4
1976	BNWL-2100, Pt. 1-5
1977	PNL-2500, Pt. 1-5
1978	PNL-2850, Pt. 1-5
1979	PNL-3300, Pt. 1-5
1980	PNL-3700, Pt. 1-5
1981	PNL-4100, Pt. 1-5
1982	PNL-4600, Pt. 1-5
1983	PNL-5000, Pt. 1-5
1984	PNL-5500, Pt. 1-5
1985	PNL-5750, Pt. 1-5
1986	PNL-6100, Pt. 1-5
1987	PNL-6500, Pt. 1-5

FOREWORD

The Atmospheric Sciences Program at the Pacific Northwest Laboratory (PNL) centered its initial emphasis on short-range diffusion and worldwide fallout studies for the Atomic Energy Commission (AEC). Early tracer developments were used in dispersion experiments to produce an extensive data base defining instantaneous and continuous plumes diffusing over a limited, relatively flat portion of the Hanford Site. Plume characteristics for a uniform surface in steady-state conditions were evaluated as a function of meteorological parameters. In fallout studies, very sensitive radiological detection methods permitted detailed characterization of seasonal and year-to-year variations in air concentrations of radionuclides over western North America.

As the program evolved, early research also dealt with wet and dry scavenging of nuclear contaminants. Much of the field experimentation on scavenging processes involved simulation of nuclear particulates with tracers. Releases of tracers at the surface investigated dry removal and below-cloud wet removal processes and, later in our initial research aircraft operations, tracers were released into clouds to study in-cloud scavenging processes. As energy development was undertaken more broadly, our research extended beyond nuclear concerns to include the transport, transformation, and wet removal of fossil energy contaminants on a local to multistate basis, preceding by several years the recognition of acid rain as a national problem.

Currently, the broad goals of atmospheric research at PNL are to describe and predict the nature and fate of atmospheric contaminants and to develop an understanding of the atmospheric processes contributing to their distribution on local, regional, and continental scales in the air, in clouds, and on the surface. For several years, studies of transport and diffusion have been extended to mesoscale areas of complex terrain. Atmospheric cleansing research has expanded to a regional-scale, multilaboratory investigation of precipitation scavenging processes involving the transformation and wet deposition of chemicals composing "acid rain." In addition, the redistribution and long-range transport of transformed contaminants passing through clouds is recognized as a necessary extension of our research to even larger scales in the future. Eventually, large-scale experiments on cloud processing and redistribution of contaminants will be integrated into the national program on global change, investigating how energy pollutants affect aerosols and clouds and the transfer of radiant energy through them. As the significance of this effect becomes clear, its global impact on climate will be studied, more generally, in International Geosphere-Biosphere Program (IGBP) efforts through experimental and modeling research, undertaken with other U.S., Canadian, and European scientists. It is also recognized that our future research must deal in an integrated manner with transfer processes for energy, moisture, and nutrients involved in the maintenance of biological systems at the earth's surface, together with the contaminants introduced by humans that may impact these systems. Indeed, the IGBP will also include as a high priority the study of interactions between the atmosphere and the earth's biological and geological systems.

The description of ongoing atmospheric research at PNL is organized in terms of the following study areas:

- **Atmospheric Studies In Complex Terrain**
- **Large-Scale Atmospheric Transport and Processing of Emissions**
- **Measurement and Analysis Techniques.**

This report describes the progress in FY 1988 in each of these areas. A divider page summarizes the goals of each area and lists project titles that support research activities.

CONTENTS

PREFACE	iii
FOREWORD	v
ATMOSPHERIC STUDIES IN COMPLEX TERRAIN	
Valley Geometry: Driving Force for Along-Valley Wind Systems, <i>C. D. Whiteman and T. B. McKee</i>	3
Ventilation of Pollutants Trapped in Valleys: A Simple Parameterization for Regional-Scale Dispersion Models, <i>K. J. Allwine and C. D. Whiteman</i>	5
Effects of Terrain-Induced Shear on Tracer Transport, <i>J. C. Doran</i>	8
Large-Eddy Simulations of Concentration Fluctuations, <i>D. C. Bader and T. W. Horst</i>	9
Slope Flow Model for Nesting with Mesoscale Code, <i>J. C. Doran</i>	15
Nocturnal Boundary Layer Development Above a Large Plateau, <i>D. C. Bader</i>	15
PNL Contributions to the 1988 ASCOT Field Experiment, <i>J. M. Hubbe, C. D. Whiteman, and J. C. Doran</i>	19
LARGE-SCALE ATMOSPHERIC TRANSPORT AND PROCESSING OF EMISSIONS	
The PRECP-VI (3CPO) Field Experiment, <i>A. C. D. Leslie, M. Terry Dana, W. E. Davis, J. M. Thorp, and S. D. Tomich</i>	25
Initial Precipitation Chemistry Results from the PRECP-VI June 8 Rain Event, <i>M. Terry Dana, S. D. Tomich, G. W. Dennis, and D. W. Glover</i>	27
The Use of Precipitation Chemical Concentration Distributions in Acidic Deposition Model Evaluation, <i>M. Terry Dana and J. M. Hales</i>	32
Progress Report: Global Chemistry Model (GChM), <i>C. M. Berkowitz, D. J. Luecken, and D. C. Bader</i>	36
MEASUREMENT AND ANALYSIS TECHNIQUES	
The MAP3S Precipitation Chemistry Network in FY 1988, <i>W. R. Barchet</i>	43
Computer-Controlled Automated Rain Sampler (CCARS), <i>S. D. Tomich, M. Terry Dana, D. W. Glover, E. V. Allen, and J. M. Hales</i>	46
Development of the G-1 Research Aircraft, <i>K. M. Busness</i>	48
Airborne and Surface Measurement of Hydrogen Peroxide During the Cloud Chemistry and Cloud Physics Organization (3CPO) Experiment, <i>R. N. Lee and S. Bachman</i>	52
Development and Application of Radiometric Instrumentation for Atmospheric Sensing, <i>B. A. LeBaron, J. J. Michalsky, L. C. Harrison, and N. S. Laulainen</i>	55
Variability and Speciation of Atmospheric Mercury, <i>N. S. Bloom</i>	58

PUBLICATIONS	59
PRESENTATIONS	63
AUTHOR INDEX	65
DISTRIBUTION	Distr-1

Atmospheric Studies in Complex Terrain

ATMOSPHERIC STUDIES IN COMPLEX TERRAIN

The Atmospheric Studies in Complex Terrain (ASCOT) program investigates atmospheric boundary-layer circulations and contaminant transport and dispersion in areas where surface features strongly influence or control these processes. Three projects at PNL investigate related aspects of the ASCOT research and are closely coordinated with ASCOT projects at other DOE laboratories.

The primary transfers of energy and momentum that drive and retard all atmospheric circulations take place at the earth's surface and in the adjacent atmospheric boundary layer. In areas of complex terrain these transfers can first be reflected in local and mesoscale circulations before being passed on to the general atmosphere. Relatively isolated circulations can develop within the constraints of significant terrain features during strong diurnal energy loss from the near-surface air. These are later reversed and coupled once again to the general atmospheric gradient flow as diurnal gains in energy reconfigure airflow over slopes and within valleys. Contaminants released within these boundary-layer circulations can be trapped in valleys and basins, then "fumigated" to the valley surfaces, and eventually vented from valleys as energy exchanges evolve. Even in rather idealized complex terrain, these flows and the associated contaminant transport and dispersion are not easily described or predicted. Consequently, ASCOT research is aimed at understanding the role of energy exchange, terrain configuration, and scale interactions for coupled flows (e.g., slope, valley, and gradient) in developing and destroying boundary-layer circulations and in dispersing contained contaminants. Experiments are conducted at mountainous sites where prominent terrain features are thoroughly characterized and the strong diurnal variations in energy fluxes are well documented. Resultant temperature, wind, and turbulence fields in the thermally generated mesoscale circulations are measured with in situ and remote sensing instrumentation. The general flow features over the region to which the terrain-induced circulations and contaminant plumes are periodically linked are characterized with soundings and tracers.

Generalization of ASCOT results is reaching the point where plans are now being made to more closely focus ASCOT experimental, theoretical, and modeling efforts on input to emergency response needs for DOE. Products of the research will continue to be basic research results of general interest and value to the boundary-layer sciences and relevant to a variety of energy-related problem areas. But models and analytical expressions of the complex processes involved will be especially aimed at providing a foundation that applied research can readily translate into improved tools and methodologies for emergency response assessments. A high priority, then, in ASCOT research is to gain understanding that will permit forecasting of boundary-layer conditions hours in advance, given the transient air flow and turbulence structures that occur and change abruptly under the influence of complex terrain and energy transfer at the surface. Another priority is to obtain sufficient generality in the ASCOT results so that they can be transposed to areas of other terrain and energy exchange characteristics and confidently transferred into applications.

The three projects that compose the ASCOT research program at PNL are:

- **Atmospheric Boundary-Layer Studies**
- **Atmospheric Diffusion in Complex Terrain**
- **Coupling/Decoupling of Synoptic and Valley Circulations.**

Atmospheric Studies in Complex Terrain

Valley Geometry: Driving Force for Along-Valley Wind Systems: C. D. Whiteman and T. B. McKee

Along-valley wind systems develop from horizontal pressure gradients that result from the diurnal temperature range in the valley atmosphere being greater than in the adjacent plains atmosphere at the same height. The larger temperature range in the valley results in warmer temperatures in the valley during daytime and colder temperatures in the valley during nighttime than in the adjacent plain. These horizontal temperature contrasts lead to horizontal pressure gradients that result in the development of up-valley winds during daytime and down-valley winds during nighttime.

The greater temperature range in the valley atmosphere comes primarily from a geometrical factor, in which energy fluxes into or out of the valley atmosphere are distributed through a smaller volume than over the plains, thereby amplifying the temperature change in the valley volume relative to the plains, in accordance with the first law of thermodynamics. This concept was first proposed by Wagner (1938), but has been extended by Steinacker (1984) to account for more realistic watershed topography, and by McKee and O'Neal (1989) to account for intra-valley forcing of along-valley winds. The effects of valley geometry on the development of along-valley wind systems can be investigated by calculating **topographic amplification factors (TAF)** for particular valleys, defined as follows:

$$\text{TAF} = \frac{\left[\frac{A_{xy}}{V} \right]_{\text{VALLEY}}}{\left[\frac{A_{xy}}{V} \right]_{\text{PLAIN}}} = \frac{\left[\frac{W}{A_{yz}} \right]_{\text{VALLEY}}}{\left[\frac{W}{A_{yz}} \right]_{\text{PLAIN}}} \quad (1)$$

where A_{xy} is the horizontal area through which energy is gained or lost from the valley and plains atmospheres ($A_{xy \text{ plain}} = A_{xy \text{ valley}}$), V is the volume of the atmosphere below this horizontal area, W is the valley width at ridgetop ($W_{\text{plain}} = W_{\text{valley}}$), and A_{yz} is the valley cross-sectional

area. The TAF is a measure of the topographically amplified diurnal temperature range in the valley compared to the adjacent plain.

TAF calculations will be made for the valley geometries illustrated in Figure 1a, in which we have chosen valleys that are twice as wide as they are deep. Following Equation (1), TAFs for the idealized valleys are 1.27, 2, and 4.66 for the U-shaped, V-shaped and convex sidewall valleys, respectively. Clearly, the valley with convex sidewalls, having less volume for the same area at its top, if the energy change is confined within the volume, will have a substantially larger diurnal temperature range that may lead to well-developed along-valley wind systems. Many actual valleys have a pronounced convex shape in their upper sections.

Figure 1b shows cross sections for valleys with similar sidewall shapes, but with a horizontal valley floor of width l . As the valley floor width approaches infinity the TAF approaches one and the valley becomes indistinguishable from a plain.

FIGURE 1. Idealized Valley Cross Sections. (a) Valley 1 is U-shaped with radius r , Valley 2 is V-shaped, Valley 3 has convex sidewalls with radius r . (b) Valley cross sections, as in (a), but with a horizontal valley floor of width l . From Müller and Whiteman (1988).

In view of the great practical value of a purely geometric or topographic method of estimating the strengths of wind circulations in valleys for applications in complex-terrain air pollution dispersion, calculations of TAFs have been made for a number of valleys. Initial results from a study by McKee and O'Neal (1988) showed that measurements of the strengths of along-valley wind systems in three Colorado valleys agree with TAF calculations. Valleys in which the TAF increases in the down-valley direction are poorly drained; valleys in which the TAF decreases with down-valley distance are well drained. Calculations of TAF can also be made as a function of height to identify the watershed areas that are most important in producing daytime warming or nighttime cooling of the valley atmosphere. Figure 2 presents such TAF calculations for three valleys--the upper 23-km-long section of Colorado's Brush Creek valley, the entire watershed of Colorado's 7- by 15-km oval-shaped Sinbad Basin, and the upper 11.5-km-long section of Switzerland's Dischma Valley. This set of valleys is thought to be representative of a broad range of different topographic configurations. The Brush Creek valley drains a broad mesa area. Calculations there show high TAF values in the

upper parts of the valley, suggesting the important influence of the upper mesa areas in producing cold air at night and warm air during the day. The Sinbad Valley, on the other hand, is a small closed basin (i.e., U-shaped) for which TAF values are small and the absence of exposed surfaces in the upper elevations of the basin will result in reduced cooling and heating compared to the Brush Valley (Whiteman et al. 1989). Finally, the Dischma Valley is thought to be a more representative valley having typical convex sidewalls with moderately high TAF values. The dependence of Dischma Valley inversion breakup on the TAF has been previously investigated by Müller and Whiteman (1988). Future work with other valleys is expected to focus on intravalley TAF variations, variation of TAF values with altitude, and validation of the TAF-wind system relationship.

Further development of the TAF concept seems a promising approach for investigating valley wind systems. Several further developments of this approach will be necessary. Confinement of cooled air within the valley volume is a requirement of the present thermodynamic calculations. In actual valleys where the ridgetops drop with

FIGURE 2. Normalized Drainage Area Versus Normalized Height for the Brush Creek and Sinbad Valleys of Colorado, and for Switzerland's Dischma Valley. Normalization parameters include the valleys' depths (h) and the valleys' total drainage areas [$A_{xy}(h)$].

down-valley distance, the confinement of cooled air is not assured; similarly, calculations during daytime are complicated by warm air export from the valley after the temperature inversion is broken. Methods of accounting for this exchange must be developed. Clearly, present calculations of intravalley contrasts are applicable only when there is no motion in the valley. Once valley flow begins, contrasts in TAF values along the valley length will be smoothed out by advection. Thus, the effects of dynamic processes are not accounted for in the static thermodynamic approach presently being utilized. Finally, the TAF concept should be applied to dynamic models of complex terrain flows. When a dynamic model simulation is run on model topography, the TAF of the model terrain should be calculated for comparison with the TAF of the actual topography.

References

- McKee, T. B., and R. D. O'Neal. 1989. "The Role of Valley Geometry and Energy Budget in the Formation of Nocturnal Valley Winds." Accepted by *J. Appl. Meteor.*
- Müller, H., and C. D. Whiteman. 1988. "Breakup of a Nocturnal Temperature Inversion in the Dischma Valley During DISKUS." *J. Climate Appl. Meteor.* 27:188-194.
- Steinacker, R. 1984. "Area-Height Distribution of a Valley and Its Relation to the Valley Wind." *Contrib. Atmos. Phys.* 57:64-71.
- Wagner, A. 1938. "Theorie und Beobachtung der Periodischen Gebirgswinde [Theory and Observation of Periodic Mountain Winds]." *Gerlands Beitr. Geophys.* (Leipzig) 52:408-449.
- Whiteman, C. D., J. M. Hubbe, J. C. Doran, and T. B. McKee. 1989. "Atmospheric Mass and Heat Budgets in a Closed Canyonland Basin." To be presented at the International Conference on Mountain Meteorology and ALPEX, June 5-9, 1989, Garmisch-Partenkirchen, FRG.

Ventilation of Pollutants Trapped in Valleys: A Simple Parameterization for Regional-Scale Dispersion Models: K. J. Allwine and C. D. Whiteman

Pollutants emitted within a deep valley during nighttime can be trapped within the stably stratified valley atmosphere and carried down the valley in locally developed drainage wind systems. After sunrise, as the valley atmosphere becomes heated and destabilized, the nighttime pollutant plume is released into the regional-scale flows above the valley. Existing regional-scale transport and diffusion models unable to resolve the local circulations simply approximate pollutant transport during both day and night as a continuous release of pollutants from the valley source into the overlying regional-scale flows. Because regional flows generally blow in a different direction from the local flows in valleys and because pollutant release into the regional flows is assumed continuous in the regional models, regional models often show poor performance in these circumstances.

A method was recently developed (Allwine and Whiteman 1988) for parameterizing nighttime valley-scale pollutant transport and post-sunrise breakup of the valley plume in regional-scale transport and diffusion models. Following this method, pollutant plumes released within a valley during nighttime are carried down the valley in nighttime drainage flows. They are then released into the above-valley regional-scale flows as a line source during the post-sunrise temperature inversion destruction period using an inversion breakup model developed by Whiteman and McKee (1982). The parameterization has been demonstrated in a puff-modeling framework using the Mesoscale Location Specific Air Resources (MELSA) model, as described by Allwine and Whiteman (1985), and is expected to improve regional-scale model performance in complex terrain areas. The effects of the parameterization are illustrated in Figures 1 and 2.

FIGURE 1. The Pollution Release Rate to the Regional Flow from a Continuous Source Located in the Eagle (October 15-16, 1977) and Yampa (February 22-23, 1978) Valleys for a 24-h Period. The release rate from the valley, Q_v , is normalized by the pollutant source strength, Q_s .

In Figure 1, the dashed line labeled "Continuous Source" illustrates the assumption commonly made in regional-scale models that cannot resolve valley-scale circulations. All pollution is assumed to be released continuously (day and night), to the regional-scale flows, so that $Q_v/Q_s = 1$, where Q_v is the release rate from the valley into the overlying regional-scale flow and Q_s is the release rate from the pollution source. In contrast, the valley-scale release rate parameterization is illustrated in Figure 1 for Colorado's Yampa Valley in winter and for Colorado's Eagle Valley in summer. With the use of the valley-scale parameterization, the release rate varies through the course of the day. Pollution released within the valley during the decoupled nighttime period is not seen as a source term in the regional-scale model (i.e., $Q_v/Q_s = 0$) until the post-sunrise coupling period begins. At this time, the pollutant source is assumed to release

directly into the regional-scale flows and the pollution trapped overnight within the valley is dispersed over the length of the coupling period, so that $Q_v/Q_s > 1$ during the coupling period. Note that conservation of pollutant mass requires that the area under the continuous source curve be equal to the areas under the individual valley curves. For the individual valley curves, the mass deficit during the decoupled period is offset by the mass excess during the coupling period.

Figure 2 illustrates the effects of the parameterization on ground-level pollutant concentrations calculated with the MELSAR regional-scale puff model, as run for a hypothetical valley system embedded in a flat 500- by 500-km region. The physical and meteorological characteristics of the Eagle Valley case demonstrated in Figure 1 were used to define the hypothetical valley system.

FIGURE 2. Results from MELSAR for a Continuous Point Source (1 g s^{-1}) Located in a Hypothetical Valley System (thick line). The valley system is assumed to have the characteristics of Colorado's Eagle Valley. The simulation begins at 1500 on October 17, 1977, and ends at 1300 the next day. Winds are constant from the west at 3 m s^{-1} . Domain shown in each part is 120 km square (each tick mark is 20 km). (a) through (h): Time evolution of ground-level concentrations in which labels on isopleths are exponents of 10. (i): Continuous plume from MELSAR without parameterization invoked.

The simulation started at 1500 MST on October 15, 1977, and ended at 1300 MST the next day, with the model operating with 1-h time steps. The valley system was oriented in a north-south direction, as shown by the solid thick line in the various parts of Figure 2; down-valley was to the south. A continuous source releasing at 1 g s^{-1} was located at the north end of the valley. The regional winds were constant at 3 m s^{-1} from the west, and the stability of the atmosphere above the valley was assumed to be neutral. Sunset occurred at 1700 MST and sunrise at 0700 MST, for a decoupling period of 11 h. At an average down-valley wind speed of 2 m s^{-1} , the pollution would fill approximately 80 km of valley. However, for this simulation the valley transport was limited to approximately

60 km, representing a block to the down-valley flow. The valley axis was represented by a total of eight line segments; all segments were assumed to have the same physical and meteorological characteristics.

The plume after 2 h is shown in Figure 2a. The valley atmosphere is not yet decoupled from the regional flow, and the pollution is being carried in the regional flows. Just after sunset (~ 1700 MST) the valley atmosphere decouples, and the pollution is not released to the regional winds but is contained in the valley until sunrise. In Figures 2b, c, and d, the initially released plume is carried off to the east through the night. Just after sunrise (~ 0700 MST), the valley atmosphere begins to couple with the regional

winds and the pollution trapped in the valley during the night begins to be released to the regional winds (Figure 2e). The valley inversion is destroyed near 1100 MST, and the last of the pollution trapped in the valley is released (Figure 2f). Figures 2g and h show the valley pollution being carried off to the east with the continuous source releasing to the regional winds. For comparison, Figure 2i shows the plume that would result without the valley decoupling/ coupling parameterization invoked. The plume would look like Figure 2i from approximately 0500 MST to the end of the simulation (Figures 2d through h). Before this time, the plume would look exactly as shown in Figure 2a, and in Figures 2b and c the continuous plume would be connected back to the source.

References

Allwine, K. J., and C. D. Whiteman. 1988. "Ventilation of Pollutants Trapped in Valleys: A Simple Parameterization for Regional-Scale Dispersion Models." *Atmos. Environ.* 22(9):1839-1845.

Allwine, K. J., and C. D. Whiteman. 1985. *MELSAR: A Mesoscale Air Quality Model for Complex Terrain. Vol. 1, Overview, Technical Description and User's Guide; and Vol. 2, Appendices.* PNL-5460, Pacific Northwest Laboratory, Richland, Washington.

Whiteman, C. D., and T. B. McKee. 1982. "Breakup of Temperature Inversions in Deep Mountain Valleys: Part II. Thermodynamic Model." *J. Appl. Meteorol.* 21(3):290-302.

Effects of Terrain-Induced Shear on Tracer Transport: J. C. Doran

A situation in which the wind field over relatively simple terrain was strongly affected by the presence of an extensive ridge approximately 25 km upwind has been analyzed through the use of a mesoscale model. During a tracer release on the Hanford Site, a network of surface wind observations had revealed a complex but well-defined flow pattern near the ground. However, tracer sampling showed that material released near the surface several hours after sunrise failed to follow the indicated flow patterns; instead, at

elevations of 200 m or more the tracer was detected as much as 120° from the direction deduced from the ground observations. In a second case with generally similar surface winds, the tracer trajectory was accurately predicted by the surface wind observations.

The atmospheric conditions during the first release were dominated by the presence of a thermal low over the Columbia River Basin. The positioning of this feature produced a surface northwest geostrophic wind of approximately 10 m/s. Radiosonde soundings were combined with a local pilot release and data from a 122-m tower to construct profiles of the winds and temperatures shortly before sunrise. Locally, a strong northwest wind (15 m/s) decreased with height to a weak southerly wind above 1000 m AGL. On the synoptic scale, there was a weak westerly flow above 1000 m with a gradual speed increase to about 30 m/s near the tropopause. A pronounced nocturnal inversion existed in the layer beneath 100 m with isothermal conditions up to approximately 1500 m, explaining the strong thermal nature of the surface low. These synoptic conditions were used as initial conditions for the model simulations.

An extensive ridge system, with vertical relief of over 1000 m, lies west of the release and sampling areas, which were over relatively flat terrain. This ridge system has major gaps to the north and west through which the Columbia and Yakima rivers flow. Numerical simulations show that this topography, combined with the strong stability existing before sunrise, results in a near-surface wind field that is southwesterly near the tracer release point, despite the northwesterly geostrophic wind. This result agrees well with observations from the local wind monitoring network. The winds veer to the west and then northwest, so that as the tracer diffuses upward, its direction of travel also changes. A series of airborne SF₆ tracer measurements confirmed this feature. In the second case study, the observed surface wind field appeared similar to that in the first case. However, the large-scale pressure gradient indicated a much weaker thermal low and a shallower layer of northwest geostrophic winds. Results from numerical simulations for this case differed markedly from the first one, and showed much less directional shear in the

vertical. Tracer data obtained during this period supported the model results, with the SF_6 plume moving in the same general direction as the surface winds.

This study illustrates the difficulties in predicting pollutant transport over or near complex terrain, even with an extensive network of surface observation sites. However, the study also demonstrates how mesoscale models can be used successfully for identifying situations where surface information alone is inadequate, and suggests methods in which additional necessary data might be obtained.

Large-Eddy Simulations of Concentration Fluctuations: D. C. Bader and T. W. Horst

Increasing interest in the instantaneous concentrations within diffusing plumes of atmospheric contaminants has both direct and indirect applications. Many direct applications are based on a need to know the instantaneous concentrations of a contaminant, such as a toxic or flammable gas. Indirect applications are based on a need to know the concentration variance to estimate the uncertainty of the predicted mean. Many simple models have been proposed to predict various statistics of the instantaneous concentration distribution (Hanna 1984; Weil 1985), but the development and testing of these models has in many cases been handicapped by the lack of observations of concentration fluctuations.

This article describes an initial effort to develop a model for numerical simulation of atmospheric diffusion that has spatial and temporal resolution adequate for the estimation of concentration fluctuation statistics. Our intention is to develop a research model whose output has the realism necessary for development and testing of simpler models and parameterizations of concentration fluctuation statistics, which can in turn be used to solve applied problems. This model is built on a large-eddy simulation (LES) model of the turbulent flow field and a time-dependent solution of a passive tracer conservation equation, with a turbulence closure that parallels the LES closure of the Navier-Stokes equations.

The model is used to simulate the neutral boundary-layer wind tunnel experiments of Fackrell and Robins (1982), and the results are evaluated against their measurements. We believe that once the model can faithfully reproduce observed data, it can then be used as an experimental tool to produce realistic simulations of new and currently unobserved cases.

The Model

An LES version of the nonhydrostatic boundary-layer model described by Tripoli and Cotton (1982) and Bader et al. (1987) was used for this study. This model uses a compressible, quasi-Boussinesq primitive equation set. Computational efficiency is gained through a time-split finite difference scheme in which the terms in the momentum and continuity equations that propagate the meteorologically insignificant sound waves are integrated separately over a shorter timestep than the meteorologically active advection and diffusion terms. The sub-grid scale (SGS) closure is a modified version of that used by Deardorff (1980) in which the local eddy viscosity is based upon the predicted SGS turbulent kinetic energy (TKE). This formulation uses a prognostic equation in which the local SGS TKE tendency is balanced by the production, dissipation, and transport of SGS TKE.

The model domain consisted of 42 points in the streamwise direction, 21 in the spanwise direction, and 28 points vertically with a constant grid spacing of 50 m. The top 13 layers of the model composed a Rayleigh friction zone that was topped by a gravity wave radiation boundary condition while the lateral boundary conditions were periodic. Because the standard velocity-scalar grid stagger was used, the lowest computational layer was half of a grid interval above the lower boundary. The local surface momentum flux was calculated from the velocity at the lowest level using mixing-length similarity scaling with a constant value of z_0 . An arbitrary number of additional Eulerian conservation equations can be added easily within the model framework. Five of these additional equations were added to describe the dispersion of a conservative passive scalar field.

Flow Simulation

Because several LES studies of neutral channel flow have emphasized the importance of correctly initializing the large eddies in the model (Mason and Callen 1986), the simulated boundary layer was allowed to grow and develop its own mean velocity profile. No initial flow field was specified beyond the mean translational velocity of the domain. For the first 30 min of simulated time, a white noise perturbation field was added to the surface momentum flux to excite the non-linear tendencies that give rise to the large eddies. After this time the perturbation field was removed and the boundary layer was allowed to grow until it encompassed 10 to 11 model layers; typically this consumed another 150 min. By this point, the boundary layer had achieved a near steady state, permitting the start of the diffusion experiments.

Figure 1 compares Fackrell and Robins wind tunnel flow data to the flow fields generated with the LES model. As is apparent in the model-generated flow fields, the surface-layer parameterization does not match smoothly with the model-generated turbulence above the surface. Above the surface layer, however, the model flow fields agree well with those observed in the wind tunnel. Additionally, through most of the boundary layer, the resolved-scale turbulence, i.e., the turbulent motion dynamically simulated by the model, is much larger than the SGS turbulence. This indicates the degree to which the simulated turbulence is insensitive to the model SGS parameterization.

Diffusion from a point source cannot be simulated correctly with an Eulerian model until the plume is large enough to be resolved by the model grid. To overcome this problem in our preliminary experiments, we modeled a continuous point source with a sequence of puff releases whose trajectories were followed until the puffs had diffused sufficiently to be resolved by the model. At that point, typically at a distance of 16.8 boundary-layer depths (H) downwind of the source, the puff was added to the passive scalar concentration field. Concentration statistics were computed over a 20-min period for the region

from 18 H to 34 H downwind of the source. Figure 2a shows the instantaneous plume distribution on a horizontal plane at the source height, while Figure 2b shows the plume on a crosswind vertical plane. As is apparent, the model-generated turbulent flow field distorts the instantaneous plume and generates a high degree of fine structure in the concentration field.

Figure 3 shows σ_y and σ_z as a function of downwind distance. The σ_y curve has a greater slope than that for σ_z , because lateral crosswind diffusion is controlled by plume meander while vertical diffusion is principally gradient diffusion. This is consistent with the calculated velocity variances that show σ_v to be dominated by resolved-scale fluctuations, while σ_w is composed mostly of SGS fluctuations. This is further illustrated by Figure 4, which shows the plume intermittency (the fraction of the time that the concentration at a point was essentially non-zero) on a crosswind vertical slab. The region inside the 10% intermittency isopleth occupies an area over 1.5 H wide, while the instantaneous plume, Figure 2, was only 0.8 H wide.

Figure 5 shows the ratio of the rms concentration variance field to the mean concentration at each point. As expected, this value increases near the plume edges where variability is the greatest. Figure 6 displays the ratio of the peak rms concentration variance to the peak mean as a function of σ_y . The model results ranged between 0.6 and 0.7, near the asymptotic value approached by Fackrell and Robins' measurements. The model does not include the SGS (less than 50 m) fluctuations that appear in point measurements. This aspect of the results needs further investigation, but the reduction in variance is consistent with the amount of unresolved turbulent energy in the model flow field. The rapid decrease after $\sigma_y/H = 0.3$ is produced as the simulated plume fills the model domain.

These results agree well with the data, given the limitations of the simulation and the preliminary nature of the project. The underprediction of concentration variance results from the neglect

FIGURE 1. Comparison of a) Fackrell and Robins Wind Tunnel Flow Data with b) Flow Fields Generated by LES Model.

FIGURE 2. a) Horizontal and b) Vertical Cross Sections of LES-Generated Instantaneous Plume.

FIGURE 3. Sigma-y and Sigma-z as a Function of Downwind Distance X (sigma and X normalized with boundary layer depth H).

of SGS fluctuations implying that both domain size and resolution must be increased to simulate near-source diffusion. The only impediment to this next phase is the availability of computer time on the existing class of machines capable of running this type of simulation. Point-source simulations will still require a better SGS parameterization for diffusion very close to the source.

References

- Bader, D. C., T. B. McKee, and G. J. Tripoli. 1987. "Mesoscale Boundary Layer Evolution Over Complex Terrain. Part I: Numerical Simulation of the Diurnal Cycle." *J. Atmos. Sci.* 44:2823-2838.
- Deardorff, J. W. 1980. "Stratocumulus-Capped Mixed Layers Derived from a Three-Dimensional Model." *Bound.-Layer Meteor.* 18:495-527.

FIGURE 4. Crosswind Distribution of Concentration Intermittency.

FIGURE 5. Crosswind Distribution of Ratio of rms Concentration Variance Field to Mean Concentrations.

FIGURE 6. Ratio of Peak rms Concentration Variance to Peak Mean Concentration as a Function of Sigma-y. (Sigma-y normalized with boundary layer depth H.)

Fackrell, J. E., and A. G. Robins. 1982. "Concentration Fluctuations and Fluxes in Plumes from Point Sources in a Turbulent Boundary Layer." *J. Fluid Mech.* 117:1-26.

Hanna, S. R. 1984. "Concentration Fluctuations in a Smoke Plume." *Atmos. Environ.* 18:1091-1106.

Mason, P. J., and N. S. Callen. 1986. "On the Magnitude of the Subgrid-Scale Eddy Coefficient in Large-Eddy Simulations of Turbulent Channel Flow." *J. Fluid Mech.* 162:439-462.

Tripoli, G. J., and W. R. Cotton. 1982. "The Colorado State University Three-Dimensional Cloud/Mesoscale Model - 1981. Part 1: General Theoretical Framework and Sensitivity Experiments." *J. Rech. Atmos.* 16:185-219.

Weil, J. C. 1985. "Updating Applied Diffusion Models." *J. Climate Appl. Meteor.* 24:1111-1130.

Slope Flow Model for Nesting with a Mesoscale Code: J. C. Doran

A two-dimensional slope flow model is being developed for use in a nested mode with a three-dimensional numerical code; together, the two models will be used to study the interactions of slope and valley flows in some detail. The three-dimensional code will provide the ambient, larger scale environment in which the two-dimensional code will operate; the two-dimensional code will, in turn, provide improved resolution near the surface and a lower boundary condition for the larger scale model.

The model assumes that the slope angle is constant, and the equations to be solved are written in a coordinate system that is parallel (s component) and normal (n component) to the sloping surface. Equations are solved for the down-slope wind component u , the cross-slope component v , the turbulent kinetic energy e , and the potential temperature difference θ' . Here, θ' is the difference between the potential temperature in a layer affected by the cooling of the sidewall surface and the ambient potential temperature found in the middle of the valley. The momentum equations are given by

$$\frac{\partial u}{\partial t} = -u \frac{\partial u}{\partial s} - w \frac{\partial u}{\partial n} - g \frac{\theta'}{\theta_0} \sin \beta + \frac{\partial}{\partial n} \left(K_m \frac{\partial u}{\partial n} \right) + \frac{g}{\theta_0} \cos \beta \frac{\partial}{\partial s} \left(\int_n^{h_r} \theta' dn \right)$$

and

$$\frac{\partial v}{\partial t} = \frac{\partial}{\partial n} \left(K_m \frac{\partial v}{\partial n} \right),$$

where w is the wind component normal to the slope, β is the slope angle, K_m is a turbulent exchange coefficient for momentum, θ_0 is the ambient potential temperature, $\theta' = \theta'(n)$ is the deviation from the ambient potential temperature arising from the cooling of the surface at the sidewalls, and h_r is a height where θ' goes to zero.

The thermodynamic equation is

$$\frac{\partial \theta}{\partial t} = -u \frac{\partial \theta}{\partial s} - w \frac{\partial \theta}{\partial n} + \frac{\partial}{\partial n} \left(K_h \frac{\partial \theta}{\partial n} \right)$$

and the equation for the turbulent kinetic energy e is

$$\frac{\partial e}{\partial t} = -u \frac{\partial e}{\partial s} - w \frac{\partial e}{\partial n} + K_m \left\{ \left(\frac{\partial u}{\partial n} \right)^2 + \left(\frac{\partial v}{\partial n} \right)^2 \right\} + \frac{\partial}{\partial n} \left(K_e \frac{\partial e}{\partial n} \right) - \frac{g}{\theta} K_h \frac{\partial \theta}{\partial n} \cos \beta [F] - 2 \frac{3}{2} \frac{C_e \theta^{\frac{3}{2}}}{l}.$$

The model equations are similar in many respects to those described by Nappo and Rao (1987), but the formulations for the turbulent exchange coefficients K and mixing length l are more closely related to those of Mellor and Yamada (1982).

Preliminary tests of the model were carried out using a data set collected in a valley in southeastern Washington in a related program for the Army Research Office. Results were encouraging and the use of the model helped answer a number of questions raised by the data. Efforts to modify some aspects of the model and to combine this model with a three-dimensional code will begin this year.

References

- Mellor, G. L., and T. Yamada. 1982. "Development of a Turbulence Closure Model for Geophysical Fluid Problems." *Rev. Geophys. Space Phys.* 20:851-875.
- Nappo, C. J., and K. S. Rao. 1987. "A Model Study of Pure Katabatic Flows." *Tellus* 39A:61-71.

Nocturnal Boundary Layer Development Above a Large Plateau: D. C. Bader

In 1982 and 1984, the ASCOT program embarked on a series of field experiments in Brush Creek, Colorado, to study the diurnal evolution and structure of valley wind systems. It was found that the nocturnal valley wind system below the ridgeline was influenced by the winds blowing above the valley. An initial investigation by Bader et al. (1987) revealed that in many cases the winds above the valley are large-scale, topographically influenced circulations that interact with the synoptic-scale flow. These

circulations develop over the Roan Plateau, a broad gently sloping plateau that forms the ridges above the smaller valleys in Colorado's oil shale region. The high barriers to the east of the region produce large-scale mountain-plain winds above the plateau. At night, these winds blow from east to west and oppose the prevailing flow. The shear between these two layers enhances the mixing of the cooler surface air vertically and extends the nocturnal boundary layer (NBL) several hundred meters above the plateau.

A primitive equation, mesoscale numerical model was used to examine the interaction between the topographically driven circulations and the synoptic flow. A series of model simulations using idealized topography was executed in which the strength of the external winds was varied between runs. The model used was a two-dimensional version of the model described by Tripoli and Cotton (1982) as modified by Bader et al. (1987). Figure 1 shows the domain used in the simulations. The topography is an idealized cross section through the Roan Plateau. A flat plain on the western edge of the domain

yields to a 42.75-km-long, gently sloping plateau with a 1% grade. A 500-m-high blocking ridge is connected to the plateau by a more steeply sloping ramp with an 8% grade. The horizontal model top is 6 km above the low plain and the total domain width is 300 km. Horizontal grid spacing is a constant 375 m in the interior model domain, and vertical grid spacing is a constant 50 m in the lowest 10 levels (before application of the terrain following coordinate system, which reduces spacing above elevated topography). The grid then telescopes logarithmically with height to include an additional 22 levels below the model top.

Results

Four simulations were run with wind speeds of 0, 3, 5 and 7 m/s. The model was initialized with a deep, well-mixed layer extending from the surface to 1.5 km above the low plain. In the cases with an initial wind, the winds were introduced slowly over a 15-min spinup period that was followed by a 45-min adjustment period. Following initialization, or at the start of the

FIGURE 1. Model Domain (not to scale).

simulation in the no wind case, a specified time-dependent surface sensible heat flux was prescribed at the lower surface and the simulations were continued for an additional 6 h. Figures 2 through 5 show the resulting wind and potential temperature fields for the four cases after 6 h. The vertical dimension has been exaggerated 20 times with respect to the horizontal in these figures. The wind vectors have been rotated so that winds that blow parallel to the slope are represented by vectors that are parallel; this rotation overemphasizes the vertical velocity component to a large degree. Figure 2 shows the results for the case with no external wind field. A 7 K potential temperature inversion extends through 200 m over most of the plateau. Drainage winds with speeds over 2.0 m/s within the layer are compensated by a very weak return flow apparent in the remnants of the mixed layer above the inversion. A very deep cold air pool formed over the elevated eastern ridge.

Figure 3 shows the results for the 3 m/s external wind case. In this simulation, the deep cold air pool above the ridge does not appear because

of the scouring effect of the overlying wind. The surface-based inversion above the plateau that was seen in the previous simulation develops in this case as well. However, the shear between the external wind and the drainage flow mixes some of the cold inversion layer upward to form a shallow, weakly stable transition layer. This effect is even more pronounced in the 5 and 7 m/s cases (Figures 4 and 5). The transition layer is over 200 m deep in the 7-m/s simulation and extends the NBL nearly 500 m above the ground.

Conclusions

As is evident from these results, the NBL structure above the Roan Plateau is significantly influenced by small changes in external wind speed. Higher external winds produce a deeper NBL above the plateau, but in all cases, a 200-m-deep surface-based inversion layer is present. The effect of the transition layer is to buffer the high speed synoptic-scale winds from the circulations within the inversion layer, and similarly in the valleys cut into the plateau. This may partly

FIGURE 2. Wind and Potential Temperature Fields After 6 h for No Wind Case (contour interval is 1 K).

FIGURE 3. Wind and Potential Temperature Fields After 6 h for 3 m/s Case.

FIGURE 4. Wind and Potential Temperature Fields After 6 h for 5 m/s Case.

FIGURE 5. Wind and Potential Temperature Fields After 6 h for 7 m/s Case.

explain the remarkable consistency in the valley wind structure, despite differences in the synoptic-scale circulations. The current study is being extended to look at other factors that influence the NBL structure above the Roan Plateau, such as wind direction and initial mixed layer depth.

References

- Bader, D. C., T. B. McKee, and G. J. Tripoli. 1987. "Mesoscale Boundary Layer Evolution Over Complex Terrain. Part I: Numerical Simulation of the Diurnal Cycle." *J. Atmos. Sci.* 44:2823-2838.
- Tripoli, G. J., and W. R. Cotton. 1982. "The Colorado State University Three-Dimensional Cloud/Mesoscale Model-1981. Part 1: General Theoretical Framework and Sensitivity Experiments." *J. Rech. Atmos.* 16:185-219.

PNL Contributions to the 1988 ASCOT Field Experiment: J. M. Hubbe, C. D. Whiteman, and J. C. Doran

PNL conducted experiments in two Colorado valleys during July 1988 as part of DOE's ASCOT program. The first experiment was in the Sinbad Valley, a small basin in the Canyonlands region. Soundings of temperature, humidity, and wind were taken using both tethered and free balloon-borne packages. Surface energy budget variables were measured. The second experiment was in Hunter Creek in cooperation with the other ASCOT laboratories who were taking measurements in nearby valleys. Tethered balloon soundings and surface energy measurements were taken.

Sinbad Valley

The Sinbad Valley is a unique experimental laboratory. The 600-m-deep basin was formed geologically by the collapse of a salt dome in such a way that the 7- by 15-km, oval-shaped basin has a sharply defined ridge line and drainage area. The basin is drained by the Salt Creek canyon, a narrow slickrock canyon with near-vertical sidewalls.

Tethered balloon measurements were taken in the center of the Sinbad Basin during the evening, nighttime, and morning transition periods of four days to observe wind and temperature structure evolution. A second tethered balloon system, operated by a Colorado State University (CSU) team, was used to take measurements in the outflow canyon on two evenings to observe the strength of the drainage from the basin.

The nocturnal evolution of the temperature structure in the basin typically resulted in a 10 to 11°C temperature inversion through the depth of the 600-m-deep valley by sunrise. The volume of the cooled air in the basin at sunrise was ~28 km³. Nocturnal wind speeds near the basin floor indicated a shallow drainage flow toward the basin outlet at speeds of up to 5 m/s in the early evening. Flow out of the Salt Creek canyon attained maximum speeds of 5 or 6 m/s at about 100 m AGL, but average down-valley wind speed components through the canyon depth were about 3 m/s.

The temperature inversion broke up following sunrise as a convective boundary layer grew upward from the heated surface of the basin.

A simplified energy budget station recorded net radiation and a soil temperature profile. By estimating soil heat capacity and assuming that latent heat flux in the arid basin is negligible, the time variation of surface sensible heat flux at the basin floor can be estimated.

Hunter Creek

Hunter Creek is at the other end of a spectrum of valley shapes. Instead of being full at the bottom with steep upper walls, it is narrow in the bottom with shallow upper slopes approaching the ridge line. Instead of being trapped, valley air drains

freely into the Piceance Creek basin at its mouth. The 23-km-long valley is between 4.25 and 8.5 km wide and has a depth of about 125 m over most of that length.

Tethered balloon soundings were taken from the valley floor at a site about halfway up the valley during the period beginning at 1800 MST and ending at 1000 MST the following day. The nocturnal valley wind system established itself by about 2000 MST with a wind speed maximum at between 20 and 50 m AGL. Drainage parallel to the valley continued to build above the ridge top to depths of between 150 m and 200 m AGL during the next few hours, by which time a 10 to 12°C temperature inversion had formed. Additional drainage wind speed maxima were found above the ridge tops to heights of 200 m AGL. During the course of the night the strong temperature inversion grew to typically 200 m and occasionally 300 m in depth.

With respect to surface energy budget measurements, the Hunter Creek valley showed higher levels of soil moisture than in the Sinbad Valley; therefore, the assumption that latent heat flux is negligible may not be valid.

The temperature inversion layer in the valley was found to be destroyed after sunrise by subsidence throughout the inversion layer rather than by convective boundary layer growth from below.

Discussion

Data from the Sinbad Valley and the Hunter Creek valley are being processed as part of the overall ASCOT 1988 data base. Processed data will be sent to investigators at other laboratories that participated in the summer experiments. Analyses of the ASCOT data sets will focus on the onset and cessation of the daytime wind systems as well as the evolution of the nighttime wind systems. Special comparisons will be made of wind system evolution in adjacent valleys during conditions when the synoptic conditions above the valleys were similar, so that the effect of the differing terrain in the valleys can be isolated as a driving force for the wind systems.

At PNL, research will focus on atmospheric mass and energy budgets for the Sinbad Valley and

studies of inversion breakup in the Hunter Valley. Atmospheric energy budgets in the Sinbad Valley will be much simplified because of the relatively negligible contribution of advective effects in the closed basin. In the Hunter Creek

valley, inversion breakup occurs in a fundamentally different manner from other valleys in the region. Investigations will focus on the roles of topography and forest cover on inversion breakup mechanisms.

Large-Scale
Atmospheric
Transport and
Processing of
Emissions

LARGE-SCALE ATMOSPHERIC TRANSPORT AND PROCESSING OF EMISSIONS

Current research on large-scale atmospheric transport and processing of emissions through storms is a natural outgrowth of the long-term emphasis in atmospheric sciences research at PNL on atmospheric cleansing processes. This research has expanded from its initial focus on localized precipitation scavenging of nuclear materials to the removal of widespread fossil and other energy effluents as responsibilities have evolved for DOE. When national attention focused on acid rain, PNL, together with other DOE laboratories, joined in planning and conducting the interagency efforts within the National Acid Precipitation Assessment Program (NAPAP). DOE's program within NAPAP, Processing of Emissions by Clouds and Precipitation (PRECP), examines the source-receptor relationships of the regional-scale acid rain impacts issue.

PRECP's scientific domain addresses the physical and chemical processes within the cloud and precipitation systems; cloud dynamics defining inflow and outflow characteristics, microphysics and in-cloud scavenging properties, aqueous phase chemistry, regional wet deposition patterns, and storm chemistry climatology receive direct attention. A major effort in PRECP has been to conduct large-scale experiments involving surface-based measurements and aircraft probing frontal and convective storm systems. These activities are a combined effort of Argonne and Brookhaven National Laboratories (ANL and BNL) and PNL. The magnitude of the field experiments has also prompted cooperative efforts with other agency scientists who are concentrating on other aspects of the storm systems. Modeling research, which organizes field research results into a descriptive and predictive framework, has emphasized cloud and precipitation chemistry and microphysics. These modeling efforts have also benefited from strong interfaces with subcontracted university researchers and other scientists on related research topics such as photochemistry, synoptic- and regional-scale circulations, and cloud dynamics. This close cooperation is permitting us to integrate a comprehensive modeling description of the combined processes leading to acid deposition. In future PRECP research, model experiments will simulate storm processing of pollutants interactively with analysis of field experiments to improve understanding and contribute input modules to assessment codes that agencies will ultimately use for policy and regulatory considerations.

The importance of large-scale transport is becoming increasingly evident as PRECP results demonstrate that significant levels of SO₂ are often vented through clouds and redistributed throughout deep layers of the atmosphere and carried to great distances before further processing occurs. Nitrogen oxides (except for nitric acid) are also transported and processed on a larger scale than the regional focus originally undertaken. Their reactions and removal, especially in the presence of organic contaminants, must receive attention for both clear and cloudy conditions in the future. The processing of energy contaminants by clouds, their chemical and photochemical reactions within and beyond their residence in clouds, the production of aerosols by cloud processing, and the interaction between anthropogenic and biogenic atmospheric chemicals are important elements of future research. It is evident that this research must be conducted on an international scale because of the extent to which energy production and use influence atmospheric chemistry and its role in the global environment. Thus, new experiments independent of the concluding NAPAP research will investigate these processes as well as the redistribution of contaminants on larger scales in the future. Extended models will become increasingly important in numerical experimentation and in hypothesizing focused field experiments to study anticipated behavior. Less frequent but larger-scale confirming field campaigns will be planned in evaluating continental to global-scale distributions and budgets of energy pollutants.

The studies included within this section were conducted within the following projects:

- PRECP
- Exploratory Research.

Large-Scale Atmospheric Transport and Processing of Emissions

The PRECP-VI (3CPO) Field Experiment: A.C.D. Leslie, M. Terry Dana, W. E. Davis, J. M. Thorp, and S. D. Tomich

The DOE PRECP program coordinated a comprehensive, multiagency field study of summertime convective storms that was held in central Illinois in June 1988. The sixth field program in the PRECP series, PRECP-VI, was the nucleus around which this study was assembled. The study was arranged through an ad hoc group of government and private organizations known as the Cloud Chemistry and Cloud Physics Organization (3CPO). The central objective of 3CPO was to provide as complete a description of the dynamical, microphysical, and chemical processes occurring within convective storms as was technically possible. To that end, a month-long 3CPO/PRECP-VI field experiment was conducted at Champaign, Illinois, using surface measurement facilities and research aircraft contributed by PRECP-VI and other collaborating programs.

The PRECP program instigated and coordinated the creation of 3CPO as an attempt to draw a broad base of technical capability to a central location on a data-sharing effort, in support of PRECP's goals of precipitation-scavenging research and model evaluation. A full description of the early planning that went into 3CPO was given in last year's annual report (Leslie and Dana 1988). The agencies participating in 3CPO--in addition to the three core-effort DOE national laboratories (Argonne, Brookhaven, and Pacific Northwest)--included the National Science Foundation (NSF), the National Center for Atmospheric Research (NCAR), the National Oceanic and Atmospheric Administration (NOAA), the Federal Aviation Administration (FAA), the Electric Power Research Institute (EPRI), the Illinois State Water Survey (ISWS), Maryland University, Yale University, and the University of Washington.

Field measurements were centered primarily on a 62.5- x 62.5-mile (100- x 100-km) square near Champaign. These measurements included detailed surface-network measurements of

meteorological parameters, rain chemistry, and pollution features; aircraft measurements of cloud physics and pollution fields; and numerous types of radar measurements of storm features and flow patterns. Research aircraft and surface facilities included: a P-3 (NOAA) for mid-tropospheric and boundary level measurements, a Sabreliner (NCAR) for upper-tropospheric measurements, and a Cessna-210 (NOAA) for chaff release; a CHILL Doppler radar with Real-time Aircraft Tracking System [(RATS) ISWS]; a CLASS automated balloon system (operated by ISWS); an X-band polarized Doppler radar (NOAA/EPRI); phased array profilers (NOAA); two surface-pollution-measurement laboratories (BNL and ANL); and a 38-site network of computer-controlled automatic rain samplers [(CCARS) PNL]. A summary of activities during the experiment is given in Table 1.

The 3CPO experiment was completed in June, despite many setbacks. The experiment took place fundamentally as planned but was limited by damage to a key aircraft, fiscal constraints, and, most significantly, lack of rainfall.

Two weeks before the onset of the 3CPO experiment, Battelle's Gulfstream G-1 research aircraft was badly damaged in a hangar during maintenance carried out by an outside contractor. As a result, the G-1 was unable to participate as had been planned. (The G-1 subsequently has been repaired and has flown very successfully in a 2-month model-verification study in the eastern United States, sponsored by the U.S. Environmental Protection Agency.) As a substitution, additional flight hours were programmed for the NOAA P-3 and mission flight plans adjusted. An additional light aircraft (a NOAA Cessna-210) was obtained to carry out the chaff releases that had been planned to be made from the G-1.

Several groups who planned to join the 3CPO effort were unable to do so. The Precipitation Augmentation for Crops Experiment (PACE) was not funded by NSF and was unable to participate with their planned T-28 and Beach Baron aircraft; likewise, the University of North Dakota did not

TABLE 1. Summary of Activities During PRECP-VI/3CPO

Date	P-3	SABRE	CES / X-BAND	NETWORK	BONVILLE	MONTCLO	CLAS	PROFLR	CHILL	Mission
06/02	*	*		*	*		*		*	To characterize air mass between the "back door" cold front north-east of Champaign and cold front to the southwest. Sabreliner made 2 flights.
06/07	*	*			*	*	*			Sabreliner clear air profiles from 39,000 ft in evening (06/06 local date). Clear air butterfly box patterns within a "RADM" grid centered on Champaign. To determine species variability and to inter-compare measurements on P-3 and Sabreliner aircraft.
06/08	*	*	*	*	*	*	*	*	*	MCC moved east, stalling to west of network in the afternoon. Southerly inflow air sampled. Doppler measurements attempted. Chaff released for X-band radar tracking. This mission had the best weather for 3CPO.
06/11		*					*			Test flight for Sabreliner to check out NO instrument.
06/13	*	*	*				*			Clear air missions: measurements of species variation within a RADM grid downwind (NE) of St Louis urban plume, test of P-3 dual Doppler, test of NO _x -NO _y on Sabreliner, test of Chaff release.
06/15	*	*	*	*		*	*		*	Attempted convection mission; however, only weak cells developed. Chaff release successful.
06/17	*	*	*				*			2-aircraft inflow/outflow experiment in area remote from network, 190 nm NWW of Champaign, in Iowa. Chaff release test conducted with X-band radar in local area.
06/19				*						No aircraft mission.
06/20	*	*			*	*	*		*	Thunderstorm mission; however, nothing developed. No chaff release attempted. *Sabreliner aircraft left 3CPO, returning to NCAR, Colorado.
06/21								*		No aircraft mission.
06/22	*								*	Possible convective formation; however, clear air prevailed. Boundary layer characterized in RADM grid SW of Champaign. Free tropospheric air then sampled. Chaff release cancelled.
06/23								*		No missions.
06/24	*		*		*	*	*	*		Low probability of convective formation, but experiment conducted to measure inflow air, and subsequent outflow. However, no convective activity. Boundary-layer and mid-tropospheric measurements made centered over Champaign. Chaff release made in clear air. This was the last aircraft mission.

TABLE 1. (contd)

Key:

P-3	NOAA WP-3D research aircraft
SABRE	NCAR Sabreliner research jet aircraft
CES/X-RD	NOAA Cassia chaff aircraft in association with the surface X-band radar site
NETWK	38-site CCARS network active
BONVLE	Bondville surface site active with any one of the BNL and ANL mobile surface stations and PNL/University of Auckland Rain Spectrometer
MONTCLO	PNL site at Monticello active. Aerosol, HNO ₃ , SO ₂ , NH ₃ , filter samples and organic aerosol sampler
CLASS	CLASS soundings taken at Champaign airport
PROFLR	Surface-based wind profiler active at Flatland radar site
CHILL	CHILL Doppler radar active at Champaign

participate with their Citation II as they were not funded by EPRI. The HOT radar to be operated by ISWS was also not funded by NSF.

A key weather component in 3CPO was to be the occurrence of rain, and as the reader may recollect, Mother Nature provided too little of that in the Midwest during the summer of 1988. Rather than the normal 4-plus in. of June rainfall, only 0.32 in. were recorded at the 3CPO base at Champaign.

This was the lowest recorded value ever, breaking the old mark of 0.44 in. set in the Dust Bowl year of 1936. The average daily temperatures were 6°F to 10°F higher than normal. Nevertheless, two storm systems associated with precipitation in the 3CPO surface network were successfully studied on June 2 and June 8. Non-precipitating systems were also studied. Some upper-level data collected by the Sabreliner indicated that a high fraction of nonscavenged species could be vented to the upper troposphere. The excellent opportunities frequently presented for clear air missions were taken advantage of, and significant data on species variation in the boundary layer were collected. The lack of suitable weather, however, made the X-band radar/chaff release experiment disappointing.

Within the PRECP component of 3CPO, the setup of ground-based field operations commenced by May 15 and strip-down was finished by July 3 (see the article by M. Terry Dana et al.). Aircraft operations were planned to start on June 1 and finish by June 28. As it turned out, aircraft missions were flown on 11 separate days after June 2 and were terminated on June 24.

In summary, nature dealt 3CPO a cruel hand--the driest June in a 150-year period. The perversely abnormal dry conditions that were encountered were a good reminder of the need to be able to accept and recognize the risks inherent in committing to a major study. To date the weather is not under the control of mankind. Some data were collected during this study, despite the lack of rainfall. The cooperation and synergism generated between the groups participating in 3CPO was truly magnificent.

Reference

Leslie, A.C.D., and M. Terry Dana. 1988. "Plans for the 3CPO/PRECP-VI Field Experiment." In *Pacific Northwest Laboratory Annual Report for 1987 to the DOE Office of Energy Research, Part 3 - Atmospheric Sciences*, pp. 33-36. PNL-6500 Pt. 3, Pacific Northwest Laboratory, Richland, Washington.

Initial Precipitation Chemistry Results from the PRECP-VI June 8 Rain Event: M. Terry Dana, S. D. Tomich, G. W. Dennis, and D. W. Glover

The rain event of June 8, 1988, during 3CPO/PRECP-VI (see the preceding article by Leslie et al.) was one of four events sampled by the PRECP ground sampling network and provided the majority of the measurable precipitation to the network area during the operational period (June 1 - July 2). The sampling device employed on the network was the Computer Controlled Automated Rain Sampler (CCARS--see the descriptive contribution by Tomich et al., this

report). The June 8 event was the first significant sampling experience we had with this device, and a few problems were encountered. Two serious problems were shading of rain sensors on many collectors (the sensors were mounted on the anticipated upwind side of the CCARS, but the predominant wind direction on June 8 was opposite this), and failure of some lid-opening mechanisms. As a result, only 20 of the 42 CCARS deployed collected usable samples, although rainfall occurred over the entire network. Table 1 lists the sites, total rainfall sampled, precipitation timing, and preliminary quality

level assessments. The primary compromise to quality was failure to sample all rainfall because of irregular rain sensor activation.

Figure 1 is a map of the 3CPO/PRECP-VI ground sampling network, showing site numbers for all sites and quality descriptors for sites with samples. Also shown are the locations of Champaign-Urbana (C-U) and the 3CPO headquarters at Willard Airport (W). The inference from the existing data is that about 10 mm of rain fell over the entire region; this corresponds to about 3 or 4 CCARS sequential stages (about 2.5 mm/stage) for the units that operated properly.

TABLE 1. Event Timing, Total Rainfall, and Quality Assessment for Active Sampling Sites, June 08 Event

Site No.	QC Code (a)	Precipitation, mm	Start Time, CDT	End Time, CDT
13	B	7.22	1509	1809
15	C	3.08	1600	1815
21	A	10.60	1446	1841
22	C	6.91	1439	1709
26	C	3.30	1548	1927
32	A	10.33	1448	2015
33	A	9.47	1512	2030
34	A	10.64	1520	2013
36	B	7.20	1530	1948
41	B	7.32	1501	1915
43	A	8.89	1512	1953
44	X	2.60	1541	1657
54	A	10.24	1528	2042
64	A	8.73	1545	2010
133	B	6.23	1521	1909
134	X	3.14	1536	1701
142	A	9.65	1508	1918
143	B	7.49	1525	1956
144	X	2.77	1550	1657
344	A	8.52	1533	2019

- (a) A = Best quality: all precipitation sampled, timing good.
 B = Insignificant loss of precipitation at start or end, or missing stage.
 C = Apparent low collection efficiency or significant loss of precipitation.
 X = Very low capture, contamination (chemistry invalidated).

Figure 2 shows event-composite chemistry data for the high-quality sites, with micro-molar concentrations of sulfate, nitrate, ammonium, and hydrogen ion from pH. The event chemistry was quite uniform over the western section of the network, but there is evidence of more concentrated and acidic rainfall to the south. Detailed evaluations of the meteorological situation (e.g., locations of imbedded thunderstorms) and air chemistry may help to explain the spatial variations.

Illustrative of the spatial and temporal uniformity of the rainfall is Figure 3, which shows cumulative rainfall at three sites in the center of the network. Figures 4 and 5 detail rainfall and sequential precipitation chemistry at two sites. Although the rainfall rate (stage averaged) did not vary a great deal (certainly less than for energetic convective storms), the chemistry follows a familiar temporal pattern: highest concentration at the event beginning, a decrease in the middle, and an increase near the end. Some of the chemical variability may be related to the fine structure of the rainfall rate, which is determined by the CCARS for each 0.25 mm of rain.

FIGURE 1. 3CPO Ground Sampling Network.

FIGURE 2. Event-Composite Chemistry Data.

FIGURE 3. Cumulative Rainfall at Sites 133, 034, and 142.

FIGURE 4. Rainfall and Sequential Precipitation Chemistry at Site 013.

FIGURE 5. Rainfall and Sequential Precipitation Chemistry at Site 142.

The Use of Precipitation Chemical Concentration Distributions in Acidic Deposition Model Evaluation: M. Terry Dana and J. M. Hales

Regional acidic deposition models, such as the Regional Acidic Deposition Model (RADM), can generate both short-term and long-term average concentration and deposition fields for the chemistry of precipitation. These models should be able to simulate concentration distributions (including reasonably accurate estimates for moments higher than the first, or mean) at sampling points, and reflect seasonal and spatial variations that result from physical and chemical processes included in the models. The availability of over 10 years of regional event precipitation chemistry data in the MAP3S data base makes it possible to produce robust distributions of observations for the modeling community's use in evaluation and further development.

The data base of the 9-site MAP3S precipitation chemistry network contains up to 11 years of

measurements of daily or event precipitation amounts, chemical concentrations of the major ionic species, and field conditions. Details of the network operation, quality assurance and quality control, and analyses of observations may be found in journal articles (MAP3S 1982; Dana and Easter 1987), in annual summary reports [the latest of these is by Dana (1988)], and in another contribution to this report (see the article by W. R. Barchet).

Distribution parameters were calculated for the four major ionic species [sulfate, nitrate, hydrogen (from pH), and ammonium] for cumulative seasons and for cumulative years. Parameters describing the data included those involving the first four moments (means, standard deviations, and skewness and kurtosis parameters), and minima, maxima, and centiles. The standard distribution form providing the best fit in most cases (suggested by the near-identity of the geometric mean and the median) was the lognormal; thus, most analyses are limited to moments of the logarithm of concentration distributions.

Inspection of the tables and applications of graphical techniques reveal certain spatial and seasonal patterns for the various species. The most useful graphs were bar charts showing seasonal values of geometric mean, normalized geometric mean (the seasonal geometric mean divided by the annual geometric mean), and geometric standard deviation. This approach was used to identify groupings of sites having similar characteristics, and to reveal seasonal variations for the species. Precipitation amount was also considered a "species" in order to identify any chemical variations that might follow from precipitation amount variations. Typical sites from these groupings were chosen for display of probability density plots of the data and fitted lognormal distributions, for the summer and winter seasons, and for the annual or all seasons data base.

Table 1 lists the distribution statistics for summer, winter, and all seasons for sulfate (corrected for the presence of sea-salt sulfate). Shown are the total and edited numbers (after removal of missing data) of samples, minima and maxima, arithmetic and geometric means and standard deviations, medians, and skewness and kurtosis parameters. The latter two are derived from the third and fourth moments, respectively; positive skewness implies a longer tail to the right (toward higher concentrations), and positive kurtosis indicates a more peaked distribution than the appropriate standard form. Standard seasons were used, and the data bases included the total numbers of available complete seasons (or years) for each site.

Figures 1 and 2 illustrate the method of examination of the distributions for spatial and seasonal variations in the geometric means, in this case for sulfate. Figure 1 shows the spatial variation by season, and Figure 2 shows how the geometric mean varies with the seasons, the ordinate being the ratio of the seasonal geometric mean to the annual geometric mean. Sulfate has the largest seasonal and spatial variations among the four species studied; in particular, sulfate is greatly reduced in the winter at all sites. Figures similar to Figure 1, but showing geometric standard deviation, reveal variations in the breadth,

or scatter of the distributions; no important systematic variations were seen in these.

Examination of these types of plots for all four species of interest led to a rudimentary classification of site types for the purpose of illustrating typical distributions. Three groups are apparent: "inland northeast" sites (Whiteface, Ithaca, Penn State, and Virginia); "midwest" sites (Illinois, Oxford, and Oak Ridge); and "coastal" sites (Brookhaven and Lewes). Certain characteristics are shared by members of these groups that differ from other groups. The northeast sites show the greatest difference between summer and winter for sulfate, but the least seasonal variation for nitrate. The coastal sites have the greatest overall scatter, the lowest sulfate, and the most seasonal variation for nitrate. The midwest sites show higher wintertime sulfate and the least seasonal variation, except for ammonium. In arriving at these classifications, other spatial groupings were considered, such as east to west, and north to south; the chosen arrangement, reflected in the order of placement on the abscissae of Figures 1 and 2, appears the best on the basis of the distribution parameters considered.

The lognormal distribution form is a good fit to most of the site and season data distributions, particularly for sulfate and nitrate. The hydrogen ion and ammonium distributions are more complex; the former being influenced electrochemically by the other ions in the sample solutions, and the latter subject to more local sources and greater variation from event to event. If necessary, more complicated forms could be applied to make better fits for these species. Rough classifications of sites within the eastern United States region, in terms of species and seasonal variations, are possible and useful for simplification of the model validation process. Model runs for comparison could be limited to a few season and site-class cases.

The techniques used in this study (which will be detailed in a forthcoming article) are applicable to data from other high-time resolution sampling networks such as UAPSP, CAPMON, and the model-validation networks.

TABLE 1. Concentration Distribution Statistics for Sea-Salt Corrected Sulfate (μM)

Site	N	NEDT	MIN	MAX	AME	ASD	GME	GSD	MED	SKEW	KURT	LSKEW	LKURT
SUMMER (June, July, August)													
WH	284	243	1.9	240	38	32	29	2.19	29	2.46	8.97	-0.203	0.161
IT	209	200	7.3	315	57	43	46	1.93	45	2.43	8.61	0.082	0.072
PS	252	215	2.2	340	65	39	54	1.97	57	2.14	11.20	-1.269	3.404
VA	206	158	6.8	224	51	37	41	1.98	40	1.87	4.44	-0.083	-0.057
IL	209	143	3.6	280	49	36	40	1.89	37	2.79	12.40	-0.096	0.979
BR	169	128	1.2	144	42	32	30	2.50	35	1.03	0.47	-0.699	0.345
LE	175	140	1.9	157	43	32	32	2.39	38	1.23	1.63	-0.782	0.389
OX	190	151	11.9	179	53	30	46	1.70	47	1.62	3.48	0.100	-0.292
OR	113	108	8.1	250	51	41	40	1.99	42	2.16	5.53	0.266	-0.202
WINTER (December, January, February)													
WH	195	158	1.3	109	15	14	11	2.22	11	3.26	15.80	-0.122	0.318
IT	170	144	1.8	155	17	15	13	2.00	14	5.40	44.60	-0.021	0.369
PS	239	199	1.9	147	22	20	16	2.25	16	2.58	10.00	-0.141	-0.037
VA	131	101	2.7	84	20	15	15	2.08	16	1.88	4.40	-0.217	-0.073
IL	147	82	2.4	97	26	17	22	1.90	22	1.99	5.49	-0.712	1.766
BR	137	111	1.3	112	19	19	13	2.38	12	2.51	7.70	0.072	-0.239
LE	146	116	0.7	55	17	13	12	2.47	12	1.01	0.24	-0.649	0.341
OX	156	104	1.7	119	22	15	18	2.10	20	2.75	13.70	-0.920	1.484
OR	76	75	4.1	60	24	13	21	1.77	22	0.88	0.30	-0.389	-0.119
ALL SEASONS (All months)													
WH	993	852	1.3	240	28	26	20	2.37	22	2.75	12.50	-0.267	0.041
IT	764	699	0.7	315	39	35	28	2.34	29	2.82	12.10	-0.291	0.398
PS	921	793	1.9	340	44	37	31	2.39	35	2.40	11.50	-0.440	-0.009
VA	651	500	2.7	245	37	33	27	2.24	27	2.49	8.67	-0.084	-0.038
IL	785	506	2.4	290	40	31	32	1.91	31	3.23	17.00	0.032	0.949
BR	598	484	0.4	187	32	30	21	2.63	22	1.80	3.63	-0.352	0.170
LE	552	455	0.7	157	28	24	19	2.54	20	1.83	4.70	-0.433	0.025
OX	713	537	1.7	179	36	24	29	1.96	29	1.91	5.79	-0.576	1.512
OR	382	373	4.1	250	36	28	29	1.93	29	2.94	13.20	0.110	0.255

Key:

N = Total number of samples
 NEDT = Sample number after edit
 MIN = Minimum
 MAX = Maximum
 AME = Arithmetic mean
 ASD = Arithmetic standard deviation
 GME = Geometric mean
 GSD = Geometric standard deviation
 MED = Median
 SKEW = Skewness parameter
 KURT = Kurtosis parameter
 LSKEW = Skewness parameter (natural logarithm distribution)
 LKURT = Kurtosis parameter (natural logarithm distribution)

Site Abbreviations:

WH = Whiteface
 IT = Ithaca
 PS = Penn State
 VA = Virginia
 IL = Illinois
 BR = Brookhaven
 LE = Lewes, Delaware
 OX = Oxford, Ohio
 OR = Oak Ridge, Tennessee

FIGURE 1. Geometric Mean Sea-Salt Corrected Sulfate (SSCS) Concentrations for All Available Seasons for the MAP3S Network.

FIGURE 2. Geometric Mean, Normalized to All Seasons, Sea-Salt Corrected Sulfate (SSCS) for All Available Seasons for the MAP3S Network.

References

Dana, M. Terry. 1988. *MAP3S Network Data and Quality Control Summary for 1985*. PNL-6461, Pacific Northwest Laboratory, Richland, Washington.

Dana, M. Terry, and R. C. Easter. 1987. "Statistical Summary and Analyses of Event Precipitation Chemistry from the MAP3S Network, 1976-1983." *Atmos. Environ.* 21:113-128.

MAP3S. 1982. "The MAP3S/RAINE Precipitation Chemistry Network: Statistical Overview for the Period 1976-1980." *Atmos. Environ.* 16:1603-1631.

Progress Report: Global Chemistry Model (GChM): C. M. Berkowitz, D. J. Luecken, and D. C. Bader

The objective of this exploratory research program is the development and preliminary demonstration of an Eulerian model capable of simulating chemical processes in the troposphere on scales ranging from meso (16 to 160 km, <2 days) to macro (>483 km, >3 days) (Atkinson 1981). The model is being developed for use with a similar Eulerian model that solves the dynamic/thermodynamic conservation equations for these spatial and temporal scales. This interactive capability is anticipated to facilitate investigations of feedback processes between a PNL representation of clouds and aerosols and the energy and momentum budgets simulated by a dynamic code.

History of the GChM Code

The starting point for formulating the chemical-species balance governing equations of GChM is (Bird, Stewart, and Lightfoot 1960)

$$\frac{\partial c_{Am}}{\partial t} = -\nabla \cdot (c_{Am} \mathbf{V}_{Am}) + R_{Am} \quad (1)$$

which describes the time rate of change of the concentration, c , of species A in medium m (i.e.,

rain or cloud) moving with velocity $\mathbf{V}$, and having source and sink terms R . The selection of a global circulation model to define the meteorological fields would essentially define the coordinate system. Ease of access, good vertical resolution (20 layers), and quality of documentation led to the selection of the NCAR Community Climate Model (CCM1) as a source of meteorological data (Williamson et al. 1987). The scientific staff at Los Alamos National Laboratory is using CCM1 for studies of nuclear winter and is providing PNL with the necessary data.

This global circulation model uses a modified spherical system for the horizontal coordinates^(a) and normalized pressure, $\sigma_k = p_k/p_{sfc}$, in the vertical, where p_k is the pressure at layer k and p_{sfc} is the pressure at the bottom of the column. σ , or some variation, is a common vertical coordinate in global-scale modeling because $\sigma = 0$ at the top of the atmosphere (where $p = 0$) and $\sigma = 1$ at the surface, where $p = p_{sfc}$. The problem of having a vertical coordinate intersect mountains is thus avoided because the $\sigma = 1$ level by definition follows the model's orography. Casting Equation (1) into the scalar form required for numerical evaluation in this coordinate system is tedious but straightforward, with the only complication being the non-orthogonality of the σ surfaces relative to the horizontal surfaces (see Haltiner and Williams 1980).

Peters and Jouvanis (1979) of the University of Kentucky investigated the global transport of methane and carbon monoxide in the troposphere within a three-dimensional model using climatological data. The chemical mechanism described in this study was selected for initial use in GChM for several reasons. First, it is a relatively simple scheme having methane decompose (in the presence of OH) to formaldehyde and ultimately to CO; time spent coding up this scheme was therefore minimal. Second, there is little evidence that clouds play any significant role in this cycle; this fact allowed model

(a) Colatitude (north pole = +90°, south pole = -90°) and east longitude.

development to proceed without having to worry about an intrinsically complicated aspect of global chemistry modeling. Third, many of the intermediate species of the reactions are very reactive and adjust to perturbations in the concentration of methane, formaldehyde, and carbon monoxide rapidly; therefore, they do not need to be treated as a computed species defined by Equation (1). They can be treated as steady-state variables and their mixing ratio evaluated whenever necessary, resulting in a significant reduction in computer resources needed. And fourth, although the mechanism is simple, methane is a significant trace gas for radiation studies and could play a role in future studies linking atmospheric chemistry with radiation balance calculations.

With the governing equations coded, a 10-h test data set provided to us by Los Alamos National Laboratory was used for a series of test runs. Sample meteorological data from such runs are shown in Figures 1 and 2. Figures 3 and 4

illustrate the spatial scale of the chemical processes simulated in this meteorological environment. The model domain shown in Figure 3 may be moved or expanded. A 30-day meteorological data set will be used upon completion of tests using the smaller data set already provided.

Short-Term Application of the GChM Code

An immediate application of GChM is to evaluate the role of fair-weather cumulus clouds in the long-range transport and chemistry of methane. In one simulation, methane will be traced from sources over the eastern United States to the region over the western Atlantic. In a second simulation, the effects of vertical transport by fair-weather cumuli will be included through the addition of a sub-grid scale parameterization. The role of these clouds on the transport and subsequent gas phase chemistry of methane will be examined by comparing results from these two cases.

FIGURE 1. Sample Temperature Fields (Kelvin) Scaled to the GChM Study Areas.

FIGURE 2. Sample Surface Wind Fields Scaled to the GChM Study Areas.

FIGURE 3. Global View of Model Domain.

FIGURE 4. Test Model Domain.

References

- Atkinson, B. W. 1981. *Meso-scale Atmospheric Circulations*. Academic Press, London.
- Bird, R. B., W. E. Stewart, and E. N. Lightfoot. 1960. *Transport Phenomena*. Wiley and Sons, New York.
- Haltiner, G. J., and R. T. Williams. 1980. *Numerical Prediction and Dynamic Meteorology*. Wiley and Sons, New York.
- Peters, L. K., and A. A. Jouvani. 1979. "Numerical Simulation of the Transport and Chemistry of CH_4 and CO in the Troposphere." *Atmospheric Environment* 13:1443-1462.
- Williamson, D. L., J. T. Kiehl, V. Ramanathan, R. E. Dickinson, and J. J. Hack. 1987. *Description of NCAR Community Climate Model (CCM1)*. Climate and Global Dynamics Division, National Center for Atmospheric Research, Boulder, Colorado.

Measurement and Analysis Techniques

MEASUREMENT AND ANALYSIS TECHNIQUES

The development and deployment of new measurement and analysis systems for both surface-based and airborne operations are continually being addressed by PNL primarily in the Multi-State Air Pollution and Power Production Study/Precipitation Chemistry Network (MAP3S/PCN) and the Research Aircraft Operations projects. PNL's internally funded exploratory research also contributes to these advancements. Measurements in air, clouds, and precipitation began more than a decade ago on a multi-state basis to identify and characterize energy-related pollutants, chemical species resulting from their transformation, and other relevant atmospheric constituents through the MAP3S network and our instrumented DC-3 aircraft. As new understanding of important processes and reactions has progressed, measurement and analytical capabilities have been advanced to ensure that regional air and surface chemistry distributions and their changes can be characterized sufficiently to anticipate new and growing threats to the environment. Our close association through the MAP3S/PCN network with scientists at universities and other national laboratories and our detailed analysis of precipitation samples from their measurement sites have created a valuable data base serving a host of related investigations on atmospheric chemistry and environmental cycling at their sites and across the network.

Aircraft measurements are focusing on the production and distribution of oxidants throughout the atmosphere and their crucial role in cloud processing. Where insufficient oxidants are present, the high altitude venting from clouds and subsequent long-range transport of contaminants have been identified and must be thoroughly characterized in the future. A Gulfstream-1 turboprop aircraft, recently acquired by Battelle for the more demanding requirements of future aircraft operations, is being equipped to probe the outflow as well as inflow regions of clouds and to measure more diverse and complex chemical processes over expanded spatial scales of interest. Ultimately, aircraft measurements, remote and in situ, of cloud physics and radiative transfer processes must also characterize the response of energy budgets to pollution-induced changes in aerosol and cloud properties.

Recent advances in measurement and analysis techniques will serve future plans for developing a climatology of atmospheric chemistry with BNL. Regular soundings with aircraft and surface-based sensors under various meteorological conditions will initiate a data base to define the evolution of the contaminants entering, accumulating, transforming, and eventually depositing within or exiting a volume of air over the northeastern United States. These measurements, together with the model of air and cloud chemistry developed from experiments of pollution processing, will be used in constructing a methodology for evaluating the budgets of energy pollutants produced within the United States, their residence times, and the fraction and form exported beyond our borders. The advanced measurement and modeling (expanded to hemispheric and global scales) methodology will also be used to examine the long-range transport and chemistry of pollutants from other continents to the United States. Included in this exercise will be chemical emissions from the ocean into the air approaching the west coast of the United States. Airborne soundings and surface data will again define the components of an atmospheric chemistry climatology for "background" air arriving at the U.S. West Coast for comparison with model evaluations.

Changes in the MAP3S network for the next decade of its operation are being considered for such expanded global objectives. Recently developed techniques for trace metal evaluations to permit source region signatures for long-range transport to and from the United States are included. We will also examine speciation methods for trace organometallics such as mercury species, produced in cycling energy-related contaminants between the ocean and atmosphere, as global-scale environmental impacts begin to appear. The need to identify growing levels of energy contaminants in air as well as rain will introduce the investigation of remote detection methods for trace gases and their column-integrated burdens through the troposphere. Similarly, new radiative transfer instrumentation, providing optical depth measurement for aerosol burdens in the troposphere and their size distributions, will be investigated for use at MAP3S stations. As global change issues begin to be addressed, data on radiative transfer through aerosol and cloud layers will be especially important in determining if climate can be altered on a hemispheric and global basis by changes resulting from pollution chemistry.

The studies described in the following articles were supported by:

- **MAP3S/PCN**
- **PRECP**
- **Research Aircraft Operations**
- **Exploratory Research.**

Measurement and Analysis Techniques

The MAP3S Precipitation Chemistry Network In FY 1988: W. R. Barchet

The MAP3S Precipitation Chemistry Network (MAP3S/PCN) completed its twelfth year of operation (at four of its nine sites) in 1988. This network [see details in Barchet (1988a)] operates in seven states east of the Mississippi River. Network management, site supply, chemical analysis, and data reporting are handled by PNL for the U.S. DOE. Site operation and research are funded separately at each site by the DOE.

Network Operation

Site supply and network management are ongoing operations at PNL. Inventories of site supplies, including sample buckets and bottles, lids, and other field and shipping supplies, are maintained at PNL, and needed supplies are provided to the sites on a regular basis.

A meeting of MAP3S/PCN principal investigators and site operators was held in Gaithersburg, Maryland, during January 1988 to discuss operations and research activities at the various sites. The main site operation topic was the need for sample collection seven days per week and a more regular time at which the sample is to be collected. It was agreed that full-week coverage was desirable. However, full-week coverage would impose serious financial strains on some sites. Similarly, a standard collection time was considered desirable for some applications but not for others. Standard collection time simplifies the interpretation of the sampling period. However, a standard collection time may have no relationship to the chronology of meteorological processes that affect the chemistry of the sample. Sites were encouraged to check their collector and rain gauge record for lid openings every morning between 8:00 and 11:00 a.m. local time. However, sites were given the option to sample "meteorological" events rather than daily if their research program required such sampling.

Each site collects precipitation samples on a daily (or event) basis. A small portion of the sample is used for field measurement of pH. Another small portion of the sample (20 mL) is treated with tetrachloromercurate to prevent the oxidation of dissolved SO_2 . The remaining sample is transferred to plastic bottles for refrigerated storage until the samples are sent to PNL for analysis. Table 1 shows the number of samples received from each site during 1986 and 1987.

Site audits are a part of network management. Our objective is to visit every site each year. However, only the Oak Ridge site was audited in FY 1988.

Chemical Analyses

The Precipitation Chemistry Laboratory (PCL) at PNL receives samples on a monthly basis from each site. Chemical analyses and other measurements are made on each sample for pH, conductivity, and ionic concentrations of sulfate, nitrate, chloride, phosphate, ammonium, sodium, calcium, potassium, and magnesium. The methods used for these analyses have been listed in a previous report (Barchet 1988a).

The MAP3S/PCN participates in an external Quality Assurance program administered by the U.S. Geological Survey (USGS) (Dana 1988a). Blind audit samples are sent to the sites, given fictitious sample identifications, and returned to PNL for analysis. These audit samples are identified at the time our quarterly data reports are prepared. The audit sample results are sent to the USGS, and the USGS provides us with the USGS-accepted values for each audit sample. Table 2 summarizes the blind audit results for 1986 and 1987.

These results are consistent with the goals for analytical precision, accuracy, and bias set by the PCL for sulfate and sodium. However, these results also suggest that the goals for chloride and potassium need to be revised to indicate the

TABLE 1. Annual Precipitation-Weighted Ionic Concentrations ($\mu\text{mol/L}$) and Precipitation (cm) at MAP3S/PCN Sites for 1986 and 1987

Name (State)	ID	NTOT	NEDT	PPT	SO_4^{2-} (a)	NO_3^-	NH_4^+	H^+	pH (b)
1986									
Whiteface (NY)	WH	134	110	129	22	20	15	44	4.36
Ithaca (NY)	IT	97	83	112	27	29	19		(c)
Penn State (PA)	PS	90	69	107	33	33	16	76	4.12
Charlottesville (VA)	VA	84	49	86	30	35	21	64	4.19
Bendville (IL)	IL	100	69	90	28	23	14	50	4.30
Brookhaven (NY)	BR	69	58	109	20	23	10	40	4.40
Lewes (DE)	LE	72	56	93	23	23	15	46	4.34
Oxford (OH)	OX	98	64	103	27	22	19		(c)
Oak Ridge (TN)	OR	60	59	109	25	19	13	48	4.32
1987									
Whiteface (NY)	WH	111	83	108	18	21	16	37	4.43
Ithaca (NY)	IT	101	86	97	26	32	19	54	4.27
Penn State (PA)	PS	78	52	95	34	35	24	70	4.15
Charlottesville (VA)	VA	71	51	153	18	20	13	37	4.43
Bendville (IL)	IL	117	74	94	29	25	24	45	4.35
Brookhaven (NY)	BR	68	58	107	20	24	12	45	4.35
Lewes (DE)	LE	71	56	99	22	24	16	45	4.35
Oxford (OH)	OX	114	47	76	31	27	21	56	4.25
Oak Ridge (TN)	OR	63	61	98	26	20	14	49	4.31

(a) Sea-salt corrected sulfate concentration.

(b) $\text{pH} = -\log_{10}[\text{H}^+]$.

(c) Less than 50% of the annual precipitation was associated with valid laboratory pH measurements.

NTOT = total number of samples collected.

NEDT = number of valid samples after data editing.

TABLE 2. External Blind Audit Results for the MAP3S/PCN Precipitation Chemistry Laboratory for 1986 and 1987

Species	Accuracy, %	Bias, %	Weighted PCL Goal, (a) %	ODL, $\mu\text{mol/L}$
SO_4	9.2	-1.5	10	0.2
Na	23	14	16	0.4
Mg	21	10	-19	0.2
K	85	-150	47	0.5
Cl	140	-140	64	2.0
Ca	20	2.9	12	0.2

(a) Average of PCL goal ($\pm$ for bias), a function of analyte concentration and quantitative detection limit (ODL), weighted by number of each sample analyzed.

proper tolerances for these ions. A change in analytical method for Na and K from plasma emission spectroscopy to ion chromatography for the purpose of improving the precision, accuracy, bias and minimum detection limits for these species will be explored in FY 1989.

Data Reporting

Data reporting is an important function of network management. Event data through the end of 1987 reside in the Acid Deposition System data base at PNL and are available for distribution outside of the MAP3S/PCN. Quarterly data reports are regularly distributed to the site operators and principal investigators about 6 months after the end of the quarter. Quarterly data reports through July 1988 have been issued to date. Annual summary reports covering the years through 1985 have been published (e.g., Dana 1988a); a summary report for 1986 and 1987 is in preparation. Analytical results are also provided to each site on personal computer disks. These disks are available to others on request.

Data analysis programs were developed during the year to extract information from the hourly precipitation data base that coincided in time with the precipitation chemistry sample period. This information includes the times of precipitation start and end for the sample, the time of and maximum precipitation intensity during the sample period, and the average precipitation rate during the time precipitation was being collected. These precipitation-related data are being integrated with the precipitation chemistry data to allow easier analysis of the relationships between precipitation chemistry, rainfall amount, and time of rainfall occurrence.

Summary of Results

Data editing and summarization are carried out at PNL in preparation for calculating annual (or seasonal or monthly) precipitation-weighted mean ionic concentrations. Data-editing statistics and annual precipitation-weighted mean ionic concentrations for the nine sites in 1986 and 1987 are given in Table 1. The results for these years do not appear to be unusually different from previous years.

A reanalysis of the temporal trends at the MAP3S/PCN sites [see Dana and Easter (1987) for earlier results] shows that concentrations of almost all ions have been gradually decreasing over the period of record at almost all sites. An example of this decrease is shown in Figure 1 in which the annual precipitation-weighted mean sulfate ion concentrations for 1986 and 1987 are compared to the long-term average for each site. However, only a few of these decreases (for any ion or site) appear to be statistically significant. Sulfate concentrations have decreased significantly only at the Ithaca, New York, and Charlottesville, Virginia, sites.

Peer Review

The MAP3S/PCN project participated in a peer review of all NAPAP Task Group 4 projects held in Austin, Texas, during April 1988. Presentations were made by W. R. Barchet (1988b) and M. Terry Dana (1988b) on the overall network research program and PNL data analysis activities, respectively. Other MAP3S/PCN investigators funded separately for more extensive research programs also gave presentations.

The review panel noted the autonomous research activities at the MAP3S/PCN sites resulted in an apparently uncoordinated research effort even though many of these sites were doing highly productive individual research. Greater emphasis on network-wide data analysis and interpretation was recommended. Also, the panel noted that the sampling protocol, species analyzed, and equipment used at the MAP3S sites have remained static since about 1980. The panel called for significant upgrading of the equipment and breadth of sampling at MAP3S sites so that this network could better address future environmental research issues.

References

Barchet, W. R. 1988a. "The MAP3S Precipitation Chemistry Network in 1987". In *Pacific Northwest Laboratory Annual Report for 1987 to the DOE Office of Energy Research, Part 3, Atmospheric Sciences*, pp. 71-75. PNL-6500 Pt. 3, Pacific Northwest Laboratory, Richland, Washington.

FIGURE 1. Annual Precipitation-Weight Mean Sulfate Ion Concentrations for MAP3S/PCN Sites in 1986 and 1987 Compared to All Previous Years.

Barchet, W. R. 1988b. "MAP3S Precipitation Chemistry Network." In *Research Summaries for Task Group IV Atmospheric Deposition and Air Quality Monitoring*, National Acid Precipitation Assessment Program, Washington, D.C.

Dana, M. T. 1988a. *The MAP3S Network Data and Quality Control Summary for 1985*. PNL-6461, Pacific Northwest Laboratory, Richland, Washington.

Dana, M. T. 1988b. "MAP3S Chemistry and Data Analysis." In *Research Summaries for Task Group IV Atmospheric Deposition and Air Quality Monitoring*, National Acid Precipitation Assessment Program, Washington, D.C.

Dana, M. T., and R. C. Easter. 1987. "Statistical Summary and Analyses of Event Precipitation Chemistry from the MAP3S Network, 1976-1983." *Atmos. Environ.* 21(1):113-128.

Computer-Controlled Automated Rain Sampler (CCARS): S. D. Tomich, M. Terry Dana, D. W. Glover, E. V. Allen, and J. M. Hales

Under the PRECP program, a Computer Controlled Automated Rain Sampler (CCARS) was developed for ground-based sequential rain sampling during precipitation events. The CCARS, shown in Figure 1, consists of a rugged aluminum housing containing a covered collection funnel, inert polyethylene valves and distribution tubes, sample bottles, and a battery-powered, microprocessor-based computer controller. The computer controller was typically programmed to operate the CCARS in a manner such that the precipitation event could be characterized in volume sequential samples, which were analyzed for chemical composition. Because the controller also stores data during the entire event, the data can be processed to yield the time of day for each sample, rainfall rates, volume of each

FIGURE 1. Computer-Controlled Automated Rain Sampler.

sample, and other parameters of the CCARS performance. The CCARS can be deployed in a large sampling grid because each contains its own battery supply, collection parameters, and pre-cleaned sample bottles.

The CCARS functions are entirely under control of a microprocessor using appropriate interface electronics and software. During field deployment the CCARS operates in two distinct modes: a sleep or low-power mode, and an awake or fully functional mode. In the sleep mode the entire electronic circuit board has power removed with the exception of a few necessary circuits. Power is supplied to the CCARS using a sealed battery tube for holding 10 "D"-size alkaline batteries producing an unregulated 15 V. The CCARS can operate in the sleep mode for about 2000 h, or 83 days, and still have sufficient power to perform a 3-h storm-sampling sequence. The awake-mode, continuous-operational time is approximately 40 h, or about 13 storms that may average 3 h each.

The CCARS can be awakened by either a preset alarm using the real time clock, water on a rain

detector grid, or manually by an operator. Once activated, the computer checks the rain detector and clock alarm to determine why it was awakened. If the clock alarm or rain detector did not wake the unit, then it will default into serial port mode. The computer communicates via RS232 at 1200 baud through a standard, 25-pin "D" connector to many common terminals. In serial port mode the CCARS can be operated manually, programmed for rain collection, or data can be retrieved. If awakened by the rain detection circuitry, and if the parameters have been set for rain collection, the computer will execute the instructions required to collect sample bottles of precipitation during the event.

The present version of CCARS is normally sealed using a small spring-loaded cover over the collection funnel. This lid is released by the computer at the beginning of a precipitation event, exposing the collection funnel to the rainfall which is channelled into a rain gauge valve. The rain gauge valve is designed to hold the collected rain until a predetermined volume is detected by optical sensors. Once the correct volume is sensed, the rain gauge valve is activated, stopping incoming rain and releasing the collected volume into the distribution valve. The distribution valve contains a channel that diverts the water into one of nine sample bottles as determined by its rotational position. Based on the desired collection parameters, the CCARS sequences the precipitation event into sample bottles and completes its operation when either the rain ceases or all collection parameters are met.

After collecting the desired samples, the CCARS returns to low-power mode and awaits servicing. If the event is short and another precipitation cycle starts, the CCARS is programmed to collect multiple events (beginning with the next clean sample bottle) until the nine bottles have been used. When servicing the unit, an operator will remove and cap the sample bottles, the data memory will be read, and the collection parameters will be reset. The CCARS then undergoes a complete rinsing; the collection parameters are checked, and clean sample bottles are installed. The removable funnel cover is then put back into place, and the CCARS is placed in sleep mode awaiting the next precipitation event.

Further development of the CCARS is under way and additional enhancements will be added as they are refined. A new cover open/close assembly is being developed that will allow the CCARS to cover the collection funnel when the precipitation event ends. Over the next year several CCARS will be deployed at monitoring stations associated with the MAP3S sites and at other locations around the Hanford Site.

Development of the G-1 Research Aircraft: K. M. Busness

In September 1987, Battelle purchased a Gulfstream 1 (G-1) aircraft as a replacement for the aging DC-3 aircraft used by PNL since late 1974 to perform atmospheric research (Busness and Hales 1988). While the development of the G-1 research platform will evolve over the next several years, the initial development was begun in FY88 with the design, construction and installation of several systems basic to most research activities to be undertaken with the aircraft.

Aircraft Specifications

The G-1 aircraft, shown in Figure 1, is an intermediate-size, twin-turboprop aircraft built by the Grumman Corporation, Bethpage, New York. The G-1, which can be operated with a pressurized cabin, is powered by two Rolls-Royce Dart engines, 1910 shaft horsepower each, which provide cruising speeds approaching 300 knots. The aircraft has proved to be sturdy, safe and reliable, having performance characteristics which rival those of current production types and serving as a forerunner and bearing many similarities to the successor Gulfstream II-IV jet aircraft series. About 190 of the 200 G-1 aircraft built are still in service.

Dimensions of the aircraft are: length - 63 ft 9 in., wingspan - 78 ft 4 in., and height - 23 ft 4 in. The main cabin, as configured, is approximately 21 ft long, 7 ft 4 in. wide, and 6 ft 1 in. high, with additional forward and aft equipment and storage areas. Performance characteristics for the G-1 are shown in Table 1.

FIGURE 1. The G-1 Aircraft.

TABLE 1. Aircraft Performance Features

Max gross weight	36,000 lb
Max fuel	10,460 lb
Cabin payload	2,800 lb
Max flight G-load	2.5 G (at gross weight)
Max certified altitude	30,000 ft
Standard operating altitude	25,000 ft
Single engine service ceiling	14,000 ft
Typical mission range	1,000 nm
Cruising speed (25,000 ft)	300 knots
Typical research speeds	150 to 250 knots
Endurance, max fuel	6 h
Rate of climb (sea level)	1,900 ft/min
FAA takeoff distance	4,850 ft
FAA landing distance	2,770 ft

Battelle's G-1 has undergone several modifications to make it useful as an atmospheric research platform for air chemistry studies. Intentions to use the G-1 in support of the 3CPO/PRECP VI studies in Illinois in June 1988 were sidetracked as a result of a maintenance-related ground accident before that study, but the aircraft has since participated successfully in an EPA field study aimed at characterizing northeastern U.S. air pollutant concentrations for use in regional model validation activities.

Research Instrument Power

Much of the instrumentation used in typical airborne sampling is standard surface-operated equipment (or such equipment with modifications), which requires 115 VAC, 60 Hz power. Since the only available power on the G-1 is 28 VDC provided by the aircraft engine generators, it was necessary to develop a power conversion, control and distribution system for research equipment installed in the cabin. The nucleus of this system exists in a single rack, shown in Figure 2, which is mounted in the forward right area of the cabin. Included in this rack are four inverters that are powered from the aircraft DC bus and provide 4000 volt-amperes of 60 Hz AC power. Provisions have been made for two additional inverters that can provide 2000 volt-amperes of 400 Hz AC power required by some instruments not yet implemented. A control panel provides operator control of power selection, protective circuit breakers for every device powered from the system, and visual

indication of DC and AC power conditions. This power control rack also houses meteorological instrument modules.

Power distribution throughout the cabin is provided through aluminum raceways mounted at the cabin walls. Identical twist-lock-type MS connectors at six cabin stations provide DC, 60 Hz and 400 Hz power to power outlet modules, which are mounted on each equipment rack so that power connections can be easily disconnected when racks are removed or relocated.

An essential part of the research power system is a safety circuit, which automatically disconnects research power in the event of an aircraft emergency. The research power system was purposely connected directly to the main aircraft DC bus instead of selectively to one of the aircraft engine generators to avoid any ambiguity or indecisiveness in the event of a lost generator. Enabling circuits are powered through the aircraft generator bus control relays in a manner that ensures automatic disconnect of research power if either of the aircraft generators fail, so that all remaining generator power is available for aircraft systems only. Additionally, a switch located in the cockpit center console can be used to deselect all research power if deemed necessary by the flight crew.

Air Jet Vacuum Ejectors

To provide sample air movement for filter collection and gas species monitors, vacuum ejector devices were installed on each aircraft engine. The ejector, essentially a venturi device, receives motive high-pressure air from the aircraft turbine engine compressor. As the air passes through the ejector at increased velocity, suction is created on a vacuum line routed through the leading edge of the wing into the cabin, where it is available to provide pumping for instrumentation. Electric valves, which are operated from the power control panel in the cabin, control the flow of air from the engine compressor to the ejectors so that the systems can be deenergized when not in use. This is also necessary during engine startup and takeoff when compressor air is needed for tailpipe cooling and full engine power. The simplicity of the ejector affords many advantages. While it does consume an almost

FIGURE 2. Research Equipment Power Control Rack.

negligible amount of power from the engine, its light weight and ability to provide pumping without consuming electrical power, without creating cabin noise, and without generating cabin heat make it an ideal air mover.

Sampling Ports

Air sampling inlets bring ambient air into the cabin for filter sampling and gas instruments. Two 1-in.-diameter probes, lined with Teflon® to minimize contamination and sample modification, connect directly to the filter-sampling systems. A single smaller probe directs ambient air to a sampling manifold in the central cabin that serves all the gas instruments.

The removable probes are mounted in an aluminum panel mounted in a window located on the

right side of the aircraft. This window serves as a cabin emergency escape hatch in the normal aircraft configuration. Thus, the sampling probe hatch can be readily removed and replaced by the standard emergency hatch or by other research configurations. Similarly, a second window-escape hatch just aft of the sampling ports has been replaced by another hatch that provides additional ports used for exhausting air from certain instruments and pumps. All external aircraft ports are fitted with valves or bulkhead fittings that can be closed off when the aircraft is operated in a pressurized mode during high-altitude ferry flights. Currently, sampling flights are conducted with a non- or minimally pressurized cabin.

A hatch on the forward upper fuselage also serves as a research device mounting area. A radiation sensor has been installed, and additional probes for collecting cloud water and aerosols contained in cloud droplets are being

---

®Trademark of the I. E. duPont de Nemours & Co., Wilmington, Delaware.

readied for installation in preparation for future cloud chemistry studies. The upper hatch can also be quickly replaced to accommodate other research requirements or to return the aircraft to its original configuration.

Instrumentation

The aircraft is currently configured for a required two-member crew on the flight deck and four scientific personnel in the cabin area. Figure 3 shows the cabin layout for crew and instrument installations. Several lightweight, sturdy racks were constructed for mounting research equipment in the cabin. The rack frames are constructed of commercially available aluminum castings and tubular extrusions with gussets and roll pins installed at corner joints for additional strength. Laterally reinforced sheet aluminum side and top panels were riveted to the frame to provide enclosure and to strengthen the racks. As shown, two double-wide racks are installed laterally across the cabin rather than, as typically done, along the cabin wall. This configuration allows advantageous access to both the front and rear panels of the rack-mounted instruments during flight operations.

A computer-controlled data acquisition system resides in the right-hand aft area of the cabin. The data system receives and records signals from all the on-board instruments and from the aircraft Loran navigation system. Wiring has been installed in the cabin cable raceways and beneath the floor, providing concealed data line connections to the data system from all instrument stations. As in the case of power connections, data connections are also made through twist-lock connectors installed in the side-wall raceways. Each rack is equipped with a data panel providing for data input connections from instruments and an output cable connecting to the raceway and subsequently to the data system. Wiring is also provided in the raceways to permit routing signals between racks throughout the cabin.

Future Systems Development

Near-term future development of G-1 systems will include the design and installation of liquid cloudwater collectors and a cloud droplet to aerosol converter for cloud-chemistry studies. Additionally, aerosol and cloud droplet spectrometer probes will be installed to enable cloud-physics

FIGURE 3. Cabin Layout for Crew and Instrument Installations.

measurements, such as particle counting and droplet size characterization.

Reference

Busness, K. M., and J. M. Hales. 1988. "PNL Research Aircraft Activities." In *Pacific Northwest Laboratory Annual Report for 1987 to the DOE Office of Energy Research, Part 3, Atmospheric Sciences*, pp. 75-76. PNL-6500 Pt. 3, Pacific Northwest Laboratory, Richland, Washington.

Airborne and Surface Measurement of Hydrogen Peroxide During the Cloud Chemistry and Cloud Physics Organization (3CPO) Experiment: R. N. Lee and S. Bachman^(a)

During the early summer of 1988, PNL joined with several other organizations to conduct the 3CPO study in east central Illinois (Tichler, Norden, and Sharp 1988). This study brought together extensive meteorological and atmospheric chemistry facilities to study convective storms in a region downwind of major source areas. Although the region experienced a prolonged period of drought during the time of operation, gaseous and aqueous-phase peroxide data were accumulated for non-precipitating and weak storm events. These data consist of continuous airborne measurement of gaseous peroxides within and above the mixed layer as well as measurement of total peroxide in a limited number of cloud water and surface precipitation samples. Some measurement capabilities installed for the 3CPO program remained in place during the post-study period in hopes of capturing samples from a major storm event. This report presents examples of peroxide data acquired during the 3CPO program and concentrations measured in sequential precipitation samples gathered later in the summer.

Airborne gaseous peroxide measurements were made on board the NOAA WP3-D aircraft using a

---

(a) Analytical Chemistry Unit, Illinois State Water Survey, Champaign, Illinois.

fluorescence-based instrument (Lazrus et al. 1986). This analyzer provided continuous measurement of total peroxide and hydrogen peroxides. Aqueous samples (cloud water and precipitation) were treated with a derivatizing reagent at the time of collection and stored under refrigeration to preserve them for analysis. Analyses were conducted within 10 h of collection using a dedicated fluorometric system set up in a laboratory at the ISWS.

Continuous Gaseous Peroxide Measurement

Representative peroxide data from the aircraft mission of June 24 are shown in Figure 1. This plot, which displays total peroxide and hydrogen peroxide concentrations for the 1830-2015 Z time period, includes two zero checks and a two-point calibration. Sampling operations during this period were performed in clear air within the mixed layer (1200 m MSL) and in occasional light rain at 3000 m MSL (above the mixed layer). As reported by other investigators, hydrogen peroxide was the dominant peroxide specie accounting for approximately 80% of the observed atmospheric burden. However, unlike previous measurements, the concentration within the mixed layer was significantly greater than that observed at higher elevations. Concentrations of up to nearly 5 ppbv were measured at 1300 m while total peroxide levels of less than 2.0 ppbv were observed at 3000 m MSL. Measurements made within the mixed layer included several plume encounters with a corresponding 2 to 3 ppbv drop in total peroxide concentration. A preliminary interpretation of peroxide data suggests that the light rain noted during sampling operations at 3000 m may have been responsible for the observed peroxide distribution with respect to elevation.

Cloud Water

Late in the mission of June 24, the sampling aircraft moved to a system of non-participating clouds to sample interstitial air and collect cloud water samples. Several penetrations of the clouds were required to collect sufficient cloud water for analysis. Two samples of ~10 ml each

FIGURE 1. Airborne Peroxide Concentration Plot, June 24, 1988.

were obtained during two consecutive 20-min time periods. Half milliliter aliquots of these samples were removed and transferred to a bottle containing the fixing reagent after removing the sample bottle from the collection device. Cloud water samples were then stored at ice bath temperatures until analysis. Peroxide analyses were conducted within 5 h at the ISWS laboratory. Bulk cloud water samples were returned to PNL for anion and cation analyses. Concentration data obtained for these two samples are reported in Table 1. They are unusual with respect to typical cloud water samples in having pHs in excess of 6. Their low acidity is consistent with elevated calcium and magnesium concentrations, which apparently resulted from the transport of terrestrial aerosol to higher elevations with consequent incorporation into cloud droplets.

Peroxide Concentrations in Sequential Precipitation Samples

While no significant precipitation events were recorded during the 3CPO program, post-3CPO operations included sequential precipitation collection on a network operated by ISWS. Several

TABLE 1. Concentration Data for Cloud Water Samples Collected during 3CPO Flight Number 09, June 24, 1988

Collection Time: cloud water sample #1, ~2009-2030 Z
cloud water sample #2, ~2030-2051 Z

#1	#2
pH = 6.43	pH = 6.61
[H ₂ O ₂] = 3690 ppb	[H ₂ O ₂] = 3520 ppb
[Cl] = 149 μmol/L	[Cl] = 32 μmol/L
[NO ₃] = 442 "	[NO ₃] = 107 "
[SO ₄] = 114 "	[SO ₄] = 60 "
[NH ₄] = 119 "	[NH ₄] = 64 "
[Ca] = 1016 "	[Ca] = 170 "
[Mg] = 71.6 "	[Mg] = 19.6 "
[Na] = 124 "	[Na] = 49 "
[K] = 220 "	[K] = 267 "

storms were consequently sampled during mid-July to obtain total peroxide concentrations during these events. Collected samples were fixed at the end of the storm, stored under refrigeration, and analyzed at the ISWS laboratory within one day of collection. Representative concentration data from the second storm sampled on July 20, 1988, are recorded in Figure 2.

FIGURE 2. Measured Concentrations of Peroxide (total) in Sequential Precipitation Samples Collected During Storm #2, July 20, 1988.

The observed peak early in the collection period followed by a decrease and subsequent increase in peroxide levels is a pattern common to other events sampled during July.

Measurements made during 3CPO have extended the airborne peroxide data base. The first extensive airborne peroxide measurements were reported by Heikes et al. (1987) from a study conducted over the eastern United States during the fall of 1984. That measurement series indicated that hydrogen peroxide concentrations typically increased from the surface to mid-altitudes (1.5 to 2.5 km) and either decreased slightly or held constant in moving to higher elevations. The vertical concentration profile reported here for 3CPO flight #7 stands in contrast to that observation. An interpretation of peroxide data from this and other 3CPO flights is in progress. Vertical profiles and concentration patterns in the vicinity of clouds are expected to provide insights to the chemistry of peroxide and its measurement in the atmosphere.

Although the only significant precipitation events occurred after 3CPO, when no upper air chemistry data were available, sequential precipitation data acquired during the period from July 14-20 represent a unique data set. Interpretation of these data, in light of the full precipitation chemistry data set and prevailing meteorology, is also in progress.

References

- Heikes, B. G., G. L. Kok, J. G. Walega, and A. L. Lazrus. 1987. "H₂O₂, O₃, and SO₂ Measurements in the Lower Troposphere Over the Eastern United States During Fall." *J. Geophys. Res.* 92:915-931.
- Lazrus, A. L., G. L. Kok, J. A. Lind, S. N. Gitlin, B. G. Heikes, and R. E. Shetter. 1986. "Automated Fluorometric Method for Hydrogen Peroxide in Air." *Anal. Chem.* 58:594-597.

Tichler, J., K. Norden, and D. Sharp. 1988. *Cloud Chemistry and Cloud Physics Organization, Data Index*. BNL-42203, Brookhaven National Laboratory, Upton, New York.

Development and Application of Radiometric Instrumentation for Atmospheric Sensing: B. A. LeBaron, J. J. Michalsky,^(a) L. C. Harrison,^(a) and N. S. Laulainen

Sun radiometry is a relatively simple and inexpensive method of sensing the atmosphere. Yet the spectrally resolved transmission measurements can yield a wealth of information about the aerosols, clouds, and trace gases present, important elements that influence the earth's radiation budget. Unique radiometric instrumentation and techniques have been developed that have proven to be useful in PNL's research programs. The information derived is crucial to understanding both how the atmosphere affects energy technologies and how emissions from various energy technologies affect the atmosphere. This article briefly describes field instrumentation, analysis highlights, and current developments.

The Geophysics Section at PNL has been working for more than a decade, more recently in collaboration with the Atmospheric Sciences Research Center of the State University of New York at Albany (ASRC/SUNY-A), on measurements of solar transmission through the atmosphere, and the derivation therefrom of important atmospheric data including trace gas abundances and aerosol loading (and potentially size distributions). Measurement techniques developed in this work are useful in monitoring and understanding the effects of climate change.

Instrumentation for Automated Column Extinction Measurements

The emphasis of work at PNL has been the development of instruments that can operate

---

(a) Atmospheric Sciences Research Center, State University of New York, Albany, New York.

remotely with only infrequent visits for maintenance. These design considerations are necessary to permit a large number of sites to be managed effectively; otherwise the labor and transport costs become prohibitive as the number of sites in the network increases. Such instruments must have embedded computers that control the system and record the data. The digital recording of data is necessary in any large network to ensure efficient collection and rapid transport to a polling computer.

PNL has developed and built several tracking radiometers (mobile automatic scanning photometers or MASPs) for measuring solar transmission (Kleckner et al. 1981) and has acquired a data base that dates from 1978. The development of this automated instrument represented a vast improvement over the traditional handheld radiometers that had to be manually pointed at the sun during the measurement period.

Recently, PNL has developed a new instrument, called a Rotating Shadowband Photometer (RSP), that is much less expensive and complex (Michalsky, Berndt, and Schuster 1986) than the MASP. The RSP is a microprocessor-controlled device that automatically measures the direct and diffuse components of the solar radiation over a preselected wavelength range. The instrument's geometry is such that once deployed no seasonal adjustments are required and maintenance is greatly reduced because the instrument is self-calibrating. (This automatic calibration is performed each clear day by Langley plot regression.)

The RSP includes a data acquisition system that can acquire information (such as wind speed and direction, temperature, etc.) from as many as 16 auxiliary sensing devices, and thus can serve as the central data acquisition system for a site. The signals from these input channels can be manipulated in real time, using a simple high-level language. This allows users to run a wide variety of data collection tasks such as conversion to engineering units. The 36-kilobyte data-storage buffer can be dumped either in a binary or ASCII format. A 1200-baud modem, along with Xmodem protocol, has been incorporated,

allowing phone-line communication, particularly useful for large network applications.

The RSP directly yields the solar climatological data, i.e., temporally resolved direct and diffuse illumination. From the direct component (when it can be observed) the tropospheric and stratospheric aerosol burdens can be inferred (LeBaron, Michalsky, and Harrison 1989; Pearson, Michalsky, and LeBaron 1988). The data also contain a record of the statistics of cloudiness, another climate variable of significant importance. The automatic calibration intrinsic to this method allows excellent long-term stability without the cost of periodic calibrations in the field or returning the instrument to a central laboratory. The measurements of the available illumination (and associated statistics) are very important for the assessment of climate change.

Significant Results

Stratospheric Aerosol Detection - Ten years of continuous multispectral data have been collected from the MASP network, which fortuitously spans the largest volcanic event in recent history, El Chichon. These data made possible the development of a technique for separating the volcanic enhancement from the background aerosol burden. Preliminary results showing the volcanic enhancement in the stratospheric optical depth at wavelengths of 1010, 785, 535, 486, and 428 nm were published in *Geophysical Research Letters* (Pearson, Michalsky, and LeBaron 1988) early in the year. The main features of the results are a slight wavelength dependence and a seasonal oscillation superimposed on the expected exponential decay at all wavelengths. A complete analysis of the stratospheric aerosols produced by this volcano is being prepared for submittal to the *Journal of Geophysical Research*. In this work a comparison with lidar data sets at the same latitude indicate close agreement, as expected for a latitudinally, well-mixed stratosphere. Comparison with data sets at other latitudes allowed a demonstration of stratospheric transport. This is an important finding applicable to atmospheric trace gases, such as ozone, as well as to aerosols. Also included in this paper are a wavelength-dependent turbidity inversion for size distribution and the change in this distribution with time, and a careful analysis of

the errors associated with the data acquisition and estimation procedure.

The low optical depths observed in 1988 and so far this year indicate that the stratosphere is once again relatively clean and unperturbed by volcanic activity. Data from these clean periods strengthens our understanding of background conditions against which perturbations (both past and future) can be assessed.

Ozone Measurement Using the Visible Spectral Region - Ground-based measurements of total column ozone typically rely on absorption in the ultraviolet spectral region. Although ozone absorption here is strong, the precipitous decrease in the radiation flux with decreasing wavelength requires sophisticated instrumentation and observing skills. The Chappuis band in the visible spectral region offers an alternative, provided that the effects of aerosols are well characterized. Several models for inferring ozone have been examined from this region and were found to be strongly affected by volcanic aerosol intrusions. A simple model is suggested that is less restrictive with respect to the assumed aerosol size distribution. The results, presented at the International Radiation Symposium '88, Lille, France (LeBaron and Michalsky 1988), compare favorably to total column ozone measured at two Dobson spectrometer sites at approximately the same latitude (Bismarck, North Dakota, and Caribou, Maine).

Visibility Assessment - The RSP is a simple, low-cost instrument that automatically measures the total, diffuse, and direct solar illuminance. On clear days, the direct component yields a measure of the total column extinction. In a paper published in *Atmospheric Environment*, LeBaron, Michalsky, and Harrison (1989) show that this extinction calculation compares favorably with an independent and more conventional determination of extinction. The column extinction measurements can be corrected for the effect of stratospheric aerosols, thereby yielding the lower atmosphere extinction coefficient. This coefficient should be well correlated with visibility. Experience at PNL indicates that a detection limit of better than 0.01 optical depths is possible, representing about a 1% change in atmospheric transparency. What distinguishes the column optical depth from other visibility

measures is that the total loading is measured. Other visibility measurements cannot assess the column integral since neither visibility nor the extinction coefficient are conserved under advection. This is an important distinction, since a knowledge of the behavior of the total burden is needed to assess whether conditions are, in fact, changing in the long term.

Current Activities

PNL's success with the single-band RSP has led to the design and development of a multispectral version. The multispectral capability will allow the instrument to measure aerosol optical depth as a function of wavelength, permitting the inference of size distribution. Ozone and water vapor could be tracked as well (Michalsky and LeBaron, in press; LeBaron and Michalsky 1988). Cloud cover, which may be an important indication of fundamental climate change, would be available from the data set. It could provide a very accurate measurement of the photosynthetic action spectrum (both direct and diffuse irradiances). This ground-based device could also be valuable as a tool for satellite measurement validation.

In this instrument, a simple spectrometer (a prism is used to disperse incoming light across a linear diode array) is coupled to the basic RSP geometry. The incoming radiation is measured simultaneously as a function of wavelength from approximately 330 to 1100 nm. The resolution will be better than 1 nm at the shorter wavelengths, and decrease to approximately 14 nm at 1100 nm. Special consideration is being given to methods for collecting the copious amounts of data this instrument will generate. If the instrument is to be operated at a remote site, it may be necessary for the operating system to determine the optimum times for data collection in order to minimize onboard storage and data transfer.

Acknowledgment

The shadowband radiometer was developed under exploratory research. Prior radiative transfer research was supported by the Office of Basic Energy Sciences Geosciences Program in which other geosciences research continues.

References

- Kleckner, E. W., J. J. Michalsky, L. L. Smith, J. R. Schmelzer, R. H. Severtsen, and J. L. Berndt. 1981. *A Multipurpose Computer-Controlled Scanning Photometer*. PNL-4081, Pacific Northwest Laboratory, Richland, Washington.
- LeBaron, B. A., and J. J. Michalsky. 1988. "Ozone Measurement Using the Chappuis Band in the Visible Spectral Region." In *International Radiation Symposium '88: Current Problems in Atmospheric Radiation*. A. Deepak Publishing (in press).
- LeBaron, B. A., J. J. Michalsky, and L. Harrison. 1989. "Rotating Shadowband Photometer Measurement of Atmospheric Turbidity: A Tool for Estimating Visibility." *Atmospheric Environment* 23(1):255-263.
- Michalsky, J. J., J. L. Berndt, and G. J. Schuster. 1986. "A Microprocessor-Based Rotating Shadowband Radiometer." *Solar Energy* 36:465-470.
- Michalsky, J. J., and B. A. LeBaron. "Optical Extinction Spectroscopy at Moderate Resolution: Insights Into Problems With Weak Absorption Bands." *Journal of Atmospheric and Oceanic Technology* (in press).
- Michalsky, J. J., E. W. Pearson, and B. A. LeBaron. "An Assessment of the Impact of Volcanos on the Northern Hemisphere's Stratospheric Aerosol Layer During the Last Decade." *Journal of Geophysical Research* (in final draft).
- Michalsky, J. J., E. W. Pearson, and B. A. LeBaron. "Ten-Year Pattern of Stratospheric Aerosol Loading Using Ground-Based Radiometry." In *International Radiation Symposium '88: Current Problems in Atmospheric Radiation*. A. Deepak Publishing (in press).
- Pearson, E. W., J. J. Michalsky, and B. A. LeBaron. 1988. "Decay of the El Chichon Perturbation to the Stratospheric Aerosol Layer: Multispectral Ground-Based Radiometric Observations." *Geophys. Res. Lett.* 15:24-27.

Variability and Speciation of Atmospheric Mercury: N. S. Bloom

Mercury is one of the most mobile and toxic of the trace elements in the environment. Much of the mercury in aqueous and atmospheric systems is introduced by human activities such as burning coal. The proportion of mercury in these systems as a result of energy-related activities will most likely rise as world energy consumption increases. Atmospheric mercury, washed to the soil and aqueous systems by rain, may recycle back into the air through volatilization from plants or accumulate in marine biota. Consequently, the potential exists for accelerated increases in global atmospheric and aqueous mercury levels as a result of energy production and use. These increases in mercury may show up in monitored environmental systems (fish, for example) resulting in regulatory limit violations and potentially causing a human health hazard.

This exploratory research project, whose progress is also reported in Part 2 of this annual report (Bloom 1989), has two objectives: to obtain a record of long-term changes and shorter-term variability in the atmospheric mercury burden and to investigate the chemical

speciation and mechanisms of precipitation scavenging for mercury. In work on the first objective, a 20-ft sampling tower and pump house were erected on the Pacific Ocean-facing bluffs of Cheekah Peak in Washington State, at a site currently managed by the University of Washington. Daily samples have been collected at the site since July 1988.

To satisfy the second objective, a novel method for determining the speciation of organomercury compounds in water was developed. This method uses derivatives of organomercury compounds (volatile ethyl-analogs), which are separated by cryogenic gas chromatography and detected by cold vapor atomic fluorescence. Currently the most sensitive and selective method in use, it will be described in two papers to appear in the open literature.

Reference

Bloom, N. S. 1989. "Variability and Speciation of Atmospheric Mercury." In *Pacific Northwest Laboratory Annual Report for 1988 to the Office of Energy Research, Part 2: Environmental Sciences*. PNL-6800 Pt. 2, Pacific Northwest Laboratory, Richland, Washington.

PUBLICATIONS

- Allwine, K. J., and C. D. Whiteman. 1988. "Ventilation of Pollutants Trapped in Valleys: A Simple Parameterization for Regional-Scale Dispersion Models." *Atmos. Environ.* 22(9):1839-1845.
- Bader, D. C. 1987. "Valley Mass and Energy Budgets Computed From Model Simulations." In *Preprints, Fourth Conference on Mountain Meteorology*, pp. 149-150, American Meteorological Society, Boston, Massachusetts.
- Bader, D. C., and T. W. Horst. 1988. "Large-Eddy Simulation of Concentration Fluctuations." In *Preprints, Eighth Symposium on Turbulence and Diffusion*, pp. 5-7, American Meteorological Society, Boston, Massachusetts.
- Bader, D. C., T. B. McKee, and G. J. Tripoli. 1987. "Mesoscale Boundary Layer Evolution Over Complex Terrain. Part 1. Numerical Simulation of the Diurnal Cycle." *J. Atmos. Sci.* 44(19):2823-2838.
- Barchet, W. R. 1988. *An Overview of Previous Evaluations of RADM and ADOM*. Prepared by Battelle, Pacific Northwest Laboratories, Richland, Washington, for Electric Power Research Institute, Palo Alto, California.
- Dana, M. T., and W. G. N. Slinn. 1987. "Acidic Deposition Distribution and Episode Statistics from the MAP3S Network Data Base." *Atmos. Environ.* 22:1469-1474.
- Dana, M. T. 1988. *The MAP3S Network Data and Quality Control Summary for 1985*. PNL-6461, prepared by Battelle, Pacific Northwest Laboratories, Richland, Washington, for U.S. Environmental Protection Agency, Washington, D.C.
- Davis, W. E., A. R. Olsen, B. T. Didier, and D. W. Damschen. 1988. "A Comparison of Multi-Layer Meso-Alpha MLAM Model Results with Surface and Aircraft Observations from CAPTEX." In *Preprints of the NATO-CCMS 16th International Technical Meeting on Air Pollution Modeling and Its Application. VI*, H. van Dop, ed., pp. 321-332. Plenum Publishing Corp., New York, New York.
- Doran, J. C. 1987. "Sensitivity Studies Using Pielke's Model for Øresund Wind Simulations." In *The Øresund Experiment - Proceedings from Workshop II*, pp. 39-42, October 13-14, 1987, Uppsala, Sweden.
- Doran, J. C., M. L. Wesley, W. D. Neff, and R. T. McMillen. 1989. "Measurements of Turbulent Heat and Momentum Fluxes in a Mountain Valley." Submitted to *J. Appl. Meteor.* as part of dedicated ASCOT volume.
- Edmonds, J. A. 1989. "Caveats in Global Energy Modeling--Editorial Response." *Climatic Change* 13.
- Gryning, S.-E., S. Joffre, and J. C. Doran. 1987. "The Øresund Experiment--Wind and Temperature Structure Over a Land-Water-Land Area." *Bound.-Layer Meteor.* 41:309-318.
- Hales, J. M. 1988. "Parameterization of Removal Mechanisms." In *Modeling the Urban Boundary Layer*, pp. 429-463, American Meteorological Society, Boston, Massachusetts.
- Hales, J. M. 1989. "A Generalized Model for Precipitation Scavenging and Precipitation Chemistry." *Atmos. Environ.* (in press).
- Hales, J. M., C. M. Berkowitz, and R. C. Easter. 1988. "Wet Scavenging Processes." In *Preprints of the NATO-CCMS 16th International Technical Meeting on Air Pollution Modeling and Its Application. VI*, H. van Dop, ed., pp. 119-138. Plenum Publishing Corp., New York, New York.
- Horst, T. W., K. J. Allwine, and C. D. Whiteman. 1987. "A Thermal Energy Budget for Nocturnal Drainage Flow in a Simple Valley." In *Preprints, Fourth Conference on Mountain Meteorology*, pp. 15-19, American Meteorological Society, Boston, Massachusetts.
- Horst, T. W., and J. C. Doran. 1988. "The Turbulence Structure of Nocturnal Slope Flow." *J. Atmos. Sci.* 45:605-616.

- Hubbe, J. M., C. D. Whiteman, H. P. Foote, and L. G. McWethy. 1987. "Applications of Digital Image Processing in Ongoing Research in Complex Terrain Meteorology." In *Proceedings of SPIE's 1987 Cambridge Symposium on Digital Image Processing and Visual Communications Technologies in Meteorology*, October 25-30, 1987, Cambridge, Massachusetts.
- Kellogg, M. A., J. A. Edmonds, M. J. Scott, and J. S. Pomykala. 1987. *Key Statistics Related to CO₂ Emissions: Significant Contributing Countries*. PNL-6238, Pacific Northwest Laboratory, Richland, Washington.
- Laulainen, N. S. 1988. *Precipitation Scavenging Module Development Quarterly Progress Report: October - December 1987*. PNL-4647-21, Pacific Northwest Laboratory, Richland, Washington.
- Laulainen, N. S. 1988. *RADM Evaluation: Sensitivity Studies, Data Archiving and Workshop Development Quarterly Report: January - March 1988*. PNL-4647-22, Pacific Northwest Laboratory, Richland, Washington.
- Laulainen, N. S. 1988. *RADM Evaluation: Sensitivity Studies, Data Archiving and Workshop Development Quarterly Report: April-June 1988*. PNL-4647-23, Pacific Northwest Laboratory, Richland, Washington.
- Laulainen, N. S. 1988. *RADM Evaluation: Sensitivity Studies, Data Archiving and Workshop Development Quarterly Report: July-September 1988*. PNL-4647-24, Pacific Northwest Laboratory, Richland, Washington.
- LeBaron, B. A., and J. J. Michalsky. 1988. "Ozone Measurement Using the Chappuis Band in the Visible Spectral Region." In *International Radiation Symposium '88: Current Problems in Atmospheric Radiation*. A. Deepak Publishing (in press).
- LeBaron, B. A., J. J. Michalsky, and L. Harrison. 1989. "Rotating Shadowband Photometer Measurement of Atmospheric Turbidity: A Tool for Estimating Visibility." *Atmospheric Environment* 23(1):255-263.
- Lee, R. N., K. J. Alwine, and M. M. Orgill. 1989. "Real-Time Measurement of Multiple Perfluorocarbon Tracers." Submitted to *J. Atmospheric Oceanic Technology*.
- Lepel, E. A., W. K. Hensley, J. F. Boatman, K. M. Busness, W. E. Davis, D. E. Roberson, and W. G. N. Slinn. 1988. "Airborne Radioactivity Measurements from the Chernobyl Plume." *J. Rad. & Nuclear Chem.* 123(1):7-19.
- Michalsky, J. J., and B. A. LeBaron. "Optical Extinction Spectroscopy at Moderate Resolution: Insights Into Problems With Weak Absorption Bands." *Journal of Atmospheric and Oceanic Technology* (in press).
- Michalsky, J. J., E. W. Pearson, and B. A. LeBaron. "An Assessment of the Impact of Volcanos on the Northern Hemisphere's Stratospheric Aerosol Layer During the Last Decade." *Journal of Geophysical Research* (in final draft).
- Michalsky, J. J., E. W. Pearson, and B. A. LeBaron. "Ten-Year Pattern of Stratospheric Aerosol Loading Using Ground-Based Radiometry." In *International Radiation Symposium '88: Current Problems in Atmospheric Radiation*. A. Deepak Publishing (in press).
- Müller, H., and C. D. Whiteman. 1988. "Buildup of a Nocturnal Temperature Inversion in the Dischma Valley During DISKUS." *J. Climate Appl. Meteor.* 27:188-194.
- Pearson, E. W., J. J. Michalsky, and B. A. LeBaron. 1988. "Decay of the El Chichon Perturbation to the Stratospheric Aerosol Layer: Multispectral Ground-Based Radiometric Observations." *Geophys. Res. Lett.* 15:24-27.
- Reilly, J. M., J. A. Edmonds, R. H. Gardner, and A. L. Brenkert. 1987. "Uncertainty Analysis of the IEA/ORAU CO₂ Emissions Model." *The Energy Journal* 8(3):1-29.
- Slinn, W. G. N. 1988. "Acidic Precipitation" (Book Review). *Bul. Am. Met. Soc.* 69(9):1070-1071.

Slinn, W. G. N. 1988. "A Simple Model for Junge's Relationship Between Concentration Fluctuations and Residence Times for Tropospheric Trace Gases." *Tellus* 40B:229-232.

Slinn, W. G. N. 1988. "Concentration Statistics for Dispersive Media." *Tellus* 40B:214-228.

Slinn, W. G. N. 1989. "Comment on 'Cloud Feedback Processes in a General Circulation Model'." Submitted for publication in *J. Atmos. Sciences*.

Slinn, W. G. N. 1989. "Reply to R. Jaenicke." Accepted for publication in *Tellus B*.

Whiteman, C. D. 1989. "Morning Transition Tracer Experiments in a Deep Narrow Valley." Submitted to *J. Appl. Meteor.* as part of dedicated ASCOT volume.

Whiteman, C. D., K. J. Allwine, J. M. Hubbe, H. P. Foote, M. M. Orgill, and L. J. Fritschen. 1987. "Radiation and Surface Energy Budgets for a Colorado Valley." In *Preprints, Fourth Conference on Mountain Meteorology*, pp. 11-14, American Meteorological Society, Boston, Massachusetts.

Whiteman, C. D., K. J. Allwine, M. M. Orgill, L. J. Fritschen, and J. R. Simpson. 1989. "Deep Valley Radiation and Surface Energy Budget Microclimates. Part I. Radiation." Submitted to *J. Appl. Meteor.* as part of dedicated ASCOT volume.

Whiteman, C. D., K. J. Allwine, M. M. Orgill, L. J. Fritschen, and J. R. Simpson. 1989. "Deep Valley Radiation and Surface Energy Budget Microclimates. Part II. Energy Budget." Submitted to *J. Appl. Meteor.* as part of dedicated ASCOT volume.

Whiteman, C. D., W. E. Clements, R. P. Hosker, S. Barr, C. N. King, W. D. Neff, and W. M. Purch. 1988. *Valley Search Report*. ASCOT-88-1, Los Alamos National Laboratory, Los Alamos, New Mexico.

Wuebbles, D. J., and J. A. Edmonds. 1988. *A Primer on Greenhouse Gases*. TRO40, DOE/NBB0083, National Technical Information Service, Springfield, Virginia.

PRESENTATIONS

Dana, M. T. 1988. "Statistical Techniques for Model Evaluation." Paper presented at the NAPAP Atmospheric Chemistry Task Group II Peer Review, March 13-18, 1988, Knoxville, Tennessee.

Dana, M. T., S. D. Tomich, D. W. Glover, J. M. Hales, E. V. Allen, and D. A. Nelson. 1988. "Computer Controlled Automated Rain Sampler: A New Design for Research and Monitoring Applications." Paper presented at the Rocky Mountain Conference, August 31, 1988, Denver, Colorado.

Darmstadter, J., and J. A. Edmonds. 1988. "Human Development and CO₂ Emissions: The Current Picture and Long-Term Prospects." Paper presented at the Workshop on Controlling and Adapting to Greenhouse Warming, June 14-15, 1988, National Academy of Science, Washington, D.C.

Easter, R. C., and C. G. Lindsey. 1988. "Composite, Meso-Gamma Scale, Diagnostic Modeling." Paper presented at the NAPAP Atmospheric Chemistry Task Group II Peer Review, March 13-18, 1988, Knoxville, Tennessee.

Edmonds, J. A., D. J. Wuebbles, and M. J. Scott. 1987. "Energy and Radiative Precursor Emissions." Paper presented at the 8th International Conference on Alternative Energy Sources, December 14-16, 1987, Coral Gables, Florida.

Hales, J. M. 1988. "Field-Study Design for Module Evaluation: PRECP VI/3CPO." Paper presented at the NAPAP Atmospheric Chemistry Task Group II Peer Review, March 13-18, 1988, Knoxville, Tennessee.

Hales, J. M. 1988. "Overview of the PRECP Program." Paper presented at the NAPAP Atmospheric Chemistry Task Group II Peer Review, March 13-18, 1988, Knoxville, Tennessee.

Hales, J. M., and W. T. Pennell. 1988. "Campsites Simulation Procedure for Designing Airborne Aerometric Monitoring Programs." Paper presented at Tropospheric Profiling: Needs and Technologies, American Meteorological Society, Boston, Massachusetts.

LeBaron, B. A., and J. J. Michalsky. 1988. "Ozone Measurement Using the Chappuis Band in the Visible Spectral Region." Paper presented by B. A. LeBaron at the International Radiation Symposium '88, August 18-24, 1988, Lille, France.

Pennell, W. T., and J. M. Hales. 1988. "Computer Simulation Procedure for Designing Airborne Aerometric Programs." Paper presented at Tropospheric Profiling: Needs and Technologies, American Meteorological Society, Boston, Massachusetts.

Scott, M. J. 1987. "Non-CO₂ Emissions and the Global Greenhouse Effect." Paper presented at the Fifth International Conference on Atmospheric Problems, November 4, 1987, Chicago, Illinois.

Scott, M. J., J. A. Edmonds, M. A. Kellogg, and R. W. Schultz. 1989. "Global Energy and the Greenhouse Issue." Paper accepted for the 14th Congress of the World Energy Conference, September 19, 1989, Montreal, Quebec.

Author Index

AUTHOR INDEX

Allen, E. V.; 46
Allwine, K. J.; 5

Bachman, S.; 52
Bader, D. C.; 9, 15, 36
Barchet, W. R.; 43
Berkowitz, C. M.; 36
Bloom, N. S.; 58
Busness, K. M.; 48

Dana, M. Terry; 25, 27, 32, 46
Davis, W. E.; 25

Dennis, G. W.; 27
Doran, J. C.; 8, 15, 19

Glover, D. W.; 27, 46

Hales, J. M.; 32, 46
Hamson, L. C.; 55
Horst, T. W.; 9
Hubbe, J. M.; 19

Laulainen, N. S.; 55
LeBaron, B. A.; 55

Lee, R. N.; 52
Leslie, A. C. D.; 25
Luecken, D. J.; 36

McKee, T. B.; 3
Michalsky, J. J.; 55

Thorp, J. M.; 25
Tomich, S. D.; 25, 27, 46

Whiteman, C. D.; 3, 5, 19

Distribution

DISTRIBUTION

<u>No. of Copies</u>	<u>No. of Copies</u>	<u>No. of Copies</u>
<u>OFFSITE</u>		
10 DOE/Office of Scientific and Technical Information	J. R. Barker Office of Environmental Audit and Compliance U.S. Department of Energy Washington, DC 20545	J. C. Brown Environmental Studies Group MS-A114 Los Alamos National Laboratory P.O. Box 1663 Los Alamos, NM 87545
R. E. Alexander ORPBR, NL U.S. Nuclear Regulatory Commission Washington, DC 20545	H. M. Barnes ASRL (MD-39) U.S. Environmental Protection Agency Research Triangle Park, NC 27711	P. Buhl FE-232, GTN U.S. Department of Energy Washington, DC 20545
D. Anderson ENVIROTEST 1108 N.E. 200th St. Seattle, WA 98155	N. F. Barr ER-72, GTN U.S. Department of Energy Washington, DC 20545	D. Bunch EH-30, GTN U.S. Department of Energy Washington, DC 20545
J. A. Auxier IT/Radiological Sciences Laboratory 1550 Bear Creek Road Box 549 Oak Ridge, TN 37831	S. Barr Environmental Studies Group MS-F665 Los Alamos National Laboratory P.O. Box 1663 Los Alamos, NM 87544	G. Burley Office of Radiation Programs (ANR-458) U.S. Environmental Protection Agency Washington, DC 20460
F. Badgley 13749 41st Street, N.E. Seattle, WA 98125		
R. E. Baker 8904 Roundleaf Way Gaithersburg, MD 20879-1630	W. R. Bibb Energy Programs and Support Division U.S. Department of Energy P.O. Box B Oak Ridge, TN 37831	W. W. Burr Medical & Health Sciences Division Oak Ridge Associated Universities P.O. Box 117 Oak Ridge, TN 37830
R. W. Barber EH-131, GTN U.S. Department of Energy Washington, DC 20545	J. F. Boatman NOAA/R/E/AR4 325 Broadway Boulder, CO 80303	L. K. Bustad College of Veterinary Medicine Washington State University Pullman, WA 99164-7010
A. D. Barker Battelle Columbus Division 505 King Avenue Columbus, OH 43201	L. C. Brazley, Jr. NE-22, GTN U.S. Department of Energy Washington, DC 20545	

No. of
Copies

R. Catlin
Electric Power Research
Institute
3412 Hillview Avenue
P.O. Box 10412
Palo Alto, CA 94304

J. Chang
Atmospheric Sciences
Research Center
State University of New
York at Albany
100 Fuller Road
Albany, NY 80307

R. J. Charlson
Department of
Atmospheric Sciences,
AK-40
University of Washington
Seattle, WA 98195

J. A. Coleman
NE-24, GTN
U.S. Department of Energy
Washington, DC 20545

Council on Environmental
Quality
722 Jackson Place, NW
Washington, DC 20503

T. V. Crawford
E. I. duPont de Nemours
and Co.
Atomic Energy Division
Savannah River Laboratory
Aiken, SC 29808

J. B. Cuning
NOAA/ERL
325 Broadway
Boulder, CO 80303

No. of
Copies

P. H. Daum
Brookhaven National
Laboratory
Upton, Long Island,
NY 11973

J. Decker
ER-1, FORS
U.S. Department of Energy
Washington, DC 20585

K. Demerjian
Atmospheric Sciences
Research Center
State University of New
York at Albany
100 Fuller Road
Albany, NY 80307

R. L. Dennis
ASRL (MD-80)
U.S. Environmental
Protection Agency
Research Triangle Park,
NC 27711

G. DePlanque, Director
Environmental Measure-
ments Laboratory
U.S. Department of Energy
375 Hudson Street
New York, NY 10014

M. H. Dickerson
Lawrence Livermore
National Laboratory
L-262
P.O. Box 808
Livermore, CA 94550

R. R. Dickerson
Department of Meteorology
University of Maryland
College Park, MD 20742

No. of
Copies

H. Drucker
Argonne National
Laboratory
9700 South Cass Avenue
Argonne, IL 60439

A. P. Duhamel
ER-74, GTN
Department of Energy
Washington, DC 20545

J. L. Durham
ASRL (MD-59)
U.S. Environmental
Protection Agency
Research Triangle Park,
NC 27711

C. W. Edington, Director
Board on Radiation Effects
Research
National Research Council
2101 Constitution Avenue,
NW
Washington, DC 20418

W. H. Ellett
BRER--National Research
Council, MH-370
2101 Constitution Avenue,
NW
Washington, DC 20418

R. J. Engelmann
11701 Karen
Potomac, MD 20854

B. M. Erickson
DOE - Schenectady Naval
Reactors Office
P.O. Box 1069
Schenectady, NY 12301

No. of
Copies

G. J. Foley
EMSL (MD-75)
U.S. Environmental
Protection Agency
Research Triangle Park,
NC 27711

T. F. Gesell
Idaho Operations Office
U.S. Department of Energy
785 DOE Place
Idaho Falls, ID 83402-4149

R. D. Gilmore
Environmental Health
Sciences, Inc.
Nine Lake Bellevue
Building, Suite 104
Bellevue, WA 98005

G. H. Gronhøvd
Grand Forks Energy
Research Center
U.S. Department of Energy
Box 8213, University
Station
Grand Forks, ND 58202

J. W. Healy
51 Grand Canyon Drive
White Rock, NM 87544

B. Hicks
Atmospheric Turbulence
and Diffusion Laboratory
National Oceanic
and Atmospheric
Administration
P.O. Box 2456
Oak Ridge, TN 37830

F. Hutchinson
Department of Molecular
Biophysics and
Biochemistry
Yale University
260 Whitney Ave.
P.O. Box 6666
New Haven, CT 06511

No. of
Copies

H. Ishikawa
Nuclear Safety Research
Association
P.O. Box 1307
Falls Church, VA 22041

A. W. Johnson
Vice President for
Academic Affairs
San Diego State University
San Diego, CA 92128

L. J. Johnson
Idaho National Engineering
Lab
IRC MS 2203
P.O. Box 1625
Idaho Falls, ID 83415

G. Y. Jordy
ER-30, GTN
U.S. Department of Energy
Washington, DC 20545

F. Koomonoff
ER-12, GTN
U.S. Department of Energy
Washington, DC 20545

R. Kornasiewicz
Mail Stop 1130-55, ONRR
U.S. Nuclear Regulatory
Commission
Washington, DC 20555

R. T. Kratzke
EH-131, GTN
U.S. Department of Energy
Washington, DC 20545

D. Lal
Geological Research
Division A-020
Scripps Institute of
Oceanography
La Jolla, CA 92093

No. of
Copies

T. V. Larsen
Department of Civil
Engineering
University of Washington
Seattle, WA 98195

W. Lauder
Office of Health and
Environmental Research
Office of Energy Research
U.S. Department of Energy
Germantown, MD 20545

L. Levin
Electric Power Research
Institute
3412 Hillview Ave.
P.O. Box 10412
Palo Alto, CA 94303

Librarian
Brookhaven National
Laboratory
Research Library,
Reference
Upton, Long Island,
NY 11973

Librarian
Colorado State University
Documents Department—
The Libraries
Ft. Collins, CO 80521

Librarian
Electric Power Research
Institute
3412 Hillview Ave.
P.O. Box 10412
Palo Alto, CA 94303

Librarian
Atmospheric Sciences
Library, AK-50
University of Washington
Seattle, WA 98195

No. of
Copies

Librarian
Health Sciences Library,
SB-55
University of Washington
Seattle, WA 98195

Librarian
Lawrence Livermore
National Laboratory
University of California
Technical Information
Dept., L-3
P.O. Box 808
Livermore, CA 94550

Librarian
Los Alamos National
Laboratory
MS P364
P.O. Box 1663
Los Alamos, NM 87545

Librarian
National Oceanic and
Atmospheric
Administration
Atmospheric Turbulence
and Diffusion Laboratory
P.O. Box 2456
Oak Ridge, TN 37831

Librarian
Tri-Cities University
Center
100 Sprout Road
Richland, WA 99352

Librarian
Washington State
University
Pullman, WA 99164-6510

Library
Serials Department
(#80-170187)
University of Chicago
1100 East 57th Street
Chicago, IL 60637

No. of
Copies

I. R. Linger
ER-63, GTN
U.S. Department of Energy
Washington, DC 20545

D. L. Lundgren
Lovelace - ITRI
P.O. Box 5890
Albuquerque, NM 87185

O. R. Lunt
Laboratory of Nuclear
Medicine and Radiation
Biology
University of California
900 Veteran Avenue
West Los Angeles,
CA 90024

D. P. MacDonald
10830 S.W. Canterbury
Lane, Apt. 66
Tigard, OR 97224

J. N. Maddox
ER-73, GTN
U.S. Department of Energy
Washington, DC 20545

W. J. Madia
Battelle Columbus
Division
505 King Avenue
Columbus, OH 43201

J. R. Maher
ER-65, GTN
U.S. Department of Energy
Washington, DC 20545

J. Mahoney
National Acid Precipitation
Assessment Program
722 Jackson St.
Washington, DC 20006

No. of
Copies

B. Manowitz
Energy and Environment
Division
Brookhaven National
Laboratory
Upton, Long Island,
NY 11973

S. Marks
c/o U.S. Marine Corps Air
Station
ABCC/RERF
FPO
Seattle, WA 98764-5000

D. D. Mayhew
ER-63, GTN
U.S. Department of Energy
Washington, DC 20545

H. M. McCammon
ER-75, GTN
U.S. Department of Energy
Washington, DC 20545

R. O. McClellan, President
Chemical Industry Institute
of Toxicology
P.O. Box 12137
Research Triangle Park,
NC 27709

T. F. McCraw
EH-132, GTN
U.S. Department of Energy
Washington, DC 20545

C. B. Meinhold
Radiological Sciences
Division
Bldg. 703M
Brookhaven National
Laboratory
Upton, Long Island,
NY 11973

No. of
Copies

M. L. Mendelsohn
Biomedical and
Environmental Research
Program
Lawrence Livermore
National Laboratory,
L-452
University of California
P.O. Box 5507
Livermore, CA 94550

P. Michael
Brookhaven National
Laboratory
Upton, NY 11973

C. Miller
P.O. Box 180
Watertown, NY 11976

M. L. Minthorn, Jr.
ER-72, GTN
U.S. Department of Energy
Washington, DC 20545

V. Mohnen
State University of New
York at Albany
100 Fuller Road
Albany, NY 80307

B. Morgan
Environmental Division
DOE - Savannah River
Operations Office
P.O. Box A
Aiken, SC 29801

H. Moses
ER-74, GTN
U.S. Department of Energy
Washington, DC 20545

W. E. Mott
EH-12, GTN
U.S. Department of Energy
Washington, DC 20545

No. of
Copies

P. K. Mueller
Environmental Science
Department
Electric Power Research
Institute
3412 Hillview Ave.
P.O. Box 10412
Palo Alto, CA 94304

R. Nathan
Battelle Project
Management Division
505 King Avenue
Columbus, OH 43201

W. Neff
Wave Propagation Lab,
NOAA
325 Broadway
Boulder, CO 80303

N. S. Nelson
U.S. Environmental
Protection Agency
Washington, DC 20460

L. Newman
Brookhaven National
Laboratory
Upton, Long Island,
NY 11973

W. R. Ney
National Council on
Radiation Protection
and Measurements
Suite 1016
7910 Woodmont Avenue
Bethesda, MD 20814

Nuclear Regulatory
Commission
Advisory Committee on
Reactor Safeguards
Washington, DC 20555

No. of
Copies

M. J. O'Brien
Radiation Safety Office,
GS-05
University of Washington
Seattle, WA 98105

G. Oertel
Deputy Assistant Secretary
for Safety, Health and
Quality Assurance
U.S. Department of Energy
Washington, DC 20545

A. A. Patrinos
ER-74, GTN
U.S. Department of Energy
Washington, DC 20545

R. Pawr
EMSL (MD-44)
U.S. Environmental
Protection Agency
Research Triangle Park,
NC 27711

A. A. Pitrolo
Morgantown Energy
Research Center
U.S. Department of Energy
P.O. Box 880
Morgantown, WV 26505

R. G. Rader
ER-33, GTN
U.S. Department of Energy
Washington, DC 20545

D. P. Rall
NIEHS
P.O. Box 12233
Research Triangle Park,
NC 27709

C. R. Richmond
Oak Ridge National
Laboratory
4500N, MS-62523
P.O. Box 2008
Oak Ridge,
TN 37831-6253

No. of
Copies

J. S. Robertson
ER-73, GTN
U.S. Department of Energy
Washington, DC 20545

S. L. Rose
ER-73, GTN
U.S. Department of Energy
Washington, DC 20545

R. D. Rosen
Environmental Measure-
ments Laboratory
U.S. Department of Energy
376 Hudson Street
New York, NY 10014

J. M. Rusin
404 W. Halladay
Seattle, WA 98119

L. Sagan
Electric Power Research
Institute
3412 Hillview Avenue
P.O. Box 10412
Palo Alto, CA 94304

P. Samson
Atmospheric and Oceanic
Sciences
University of Michigan
Ann Arbor, MI 48109

R. A. Scarano
Mill Licensing Section
U.S. Nuclear Regulatory
Commission
Washington, DC 20545

F. A. Schiermeier
Environmental Sciences
Research Laboratory
(MD-80)
U.S. Environmental
Protection Agency
Research Triangle Park,
NC 27711

No. of
Copies

M. Schulman
ER-70, GTN
U.S. Department of Energy
Washington, DC 20545

R. B. Setlow
Brookhaven National
Laboratory
Upton, NY 11973

R. Shiklar
Battelle - Seattle
4000 NE 41st Street
Seattle, WA 98105

P. Silverman
Lawrence Berkeley
Laboratory
Donner Laboratory, Rm A66
University of California
Berkeley, CA 94720

J. Simmons
Bioeffects Analysis Branch
U.S. Environmental
Protection Agency
401 M Street, S.W.
Washington, DC 20460

W. K. Sinclair
National Council on
Radiation Protection
and Measurements
Suite 1016
7910 Woodmont Avenue
Bethesda, MD 20814

D. H. Slade
ER-74, GTN
U.S. Department of Energy
Washington, DC 20545

J. Snow
ER-6, FORS
U.S. Department of Energy
Washington, DC 20585

No. of
Copies

C. Spicer
Battelle Columbus
Division
505 King Avenue
Columbus, OH 43201

J. N. Stannard
17441 Plaza Animado #132
San Diego, CA 92128

R. W. Starostecki
NE-40, GTN
U.S. Department of Energy
Washington, DC 20545

R. J. Stern
EH-10, FORS
U.S. Department of Energy
Washington, DC 20585

J. F. Stevens
Dayton Area Office
DOE - Albuquerque
Operations Office
P.O. Box 66
Miamisburg, OH 45342

E. T. Still
Kerr-McGee Corporation
P.O. Box 25861
Oklahoma City, OK 73125

G. M. Sverdrup
Battelle Columbus
Division
505 King Avenue
Columbus, OH 43201

J. Swinebroad
EH-12, GTN
U.S. Department of Energy
Washington, DC 20545

Technical Information
Service
Savannah River Laboratory
Room 773A
E. I. duPont de Nemours
& Company
Aiken, SC 29801

No. of
Copies

R. G. Thomas
ER-72, GTN
U.S. Department of Energy
Washington, DC 20545

C. Tiller
RG-30, FORS
U.S. Department of Energy
Washington, DC 20585

U.S. Department of Energy
Environment, Safety and
Health Division
P.O. Box 5400
Albuquerque, NM 87115

E. J. Vallario
15228 Red Clover Drive
Rockville, MD 20853

C. R. Vest
Battelle, Pacific Northwest
Laboratory
Washington Operations
370 L'Entant Promenade,
Suite 900
901 D Street, SW
Washington, DC 20024

G. J. Vodapivc
DOE - Schenectady Naval
Reactors Office
P.O. Box 1069
Schenectady, NY 12301

G. L. Voelz
Los Alamos National
Laboratory, MS K404
P.O. Box 1663
Los Alamos, NM 87545

B. W. Wachholz
Radiation Effects Branch
National Cancer Institute
EPN, Room 530
8000 Rockville Pike
Bethesda, MD 20892

No. of
Copies

M. L. Walker
EH-1, FORS
U.S. Department of Energy
Washington, DC 20585

R. A. Walters
Los Alamos National
Laboratory
MS-A114
P.O. Box 1663
Los Alamos, NM 87545

C. G. Welty, Jr.
EH-123, GTN
U.S. Department of Energy
Washington, DC 20545

I. Wender
Department of Chemical
Engineering
1249 Benedum Hall
University of Pittsburgh
Pittsburgh, PA 15261

M. L. Wesely
Argonne National
Laboratory
Building 181, ER
Argonne, IL 60439

W. W. Weyzen
Electric Power Research
Institute
3412 Hillview Avenue
P.O. Box 10412
Palo Alto, CA 92665

M. M. Williamson
DOE - Idaho Operations
Commission
550 Second Street
Idaho Falls, ID 83401

F. J. Wobber
14 Goshen Court
Gaithersburg,
MD 20879-4403

No. of
Copies

R. W. Wood
ER-74, GTN
U.S. Department of Energy
Washington, DC 20545

FOREIGN

E. L. Alpen
University of California
Study Center
21 Stratton Ground
London SW1 P2HY
ENGLAND

W. A. Asman
Laboratory for Air
Research
RIVM
P.O. Box 1
NL-3720 BA Bilthoven
THE NETHERLANDS

D. C. Aumann
Institut für Physikalische
Chemie
Der Universität Bonn
Abt. Nuklearchemie
Wegelerstraße 12
5300 Bonn 1
FEDERAL REPUBLIC
OF GERMANY

J. K. Basson
Raad Op Atomic
Atoomkrag Energy Board
Privaatsk X 256
Pretoria 0001
REPUBLIC OF SOUTH
AFRICA

A. M. Beau, Librarian
Commissariat à l'Energie
Atomique
Département de Protection
Sanitaire
BP No. 6
F-92260 Fontenay-aux-
Roses
FRANCE

No. of
Copies

G. Bengtsson
Director-General
Statens Stralskyddsinstitut
Box 60204
S-104 01 Stockholm
SWEDEN

D. J. Beninson
Gerencia de Protection
Radiologica y Seguridad
Comision Nacional de
Energia Atomica
Avenida del Libertador
8250
1429 Buenos Aires
ARGENTINA

R. Berkowicz
Air Pollution Laboratory
National Agency for
Environmental Protection
Risø National Laboratory
DK-4000 Roskilde
DENMARK

A. Brink
SASOL-One Limited
P.O. Box 1
Sasolburg 9570
REPUBLIC OF SOUTH
AFRICA

N. Busch
Risø National Laboratory
DK-4000 Roskilde
DENMARK

Cao Shu-yuan, Deputy
Head
Laboratory of Radiation
Medicine
North China Institute of
Radiation Protection
Tai-yuan, Shan-xi
THE PEOPLE'S
REPUBLIC OF CHINA

No. of
Copies

M. Carpentier
Commission of the E.C.
200 Rue de la Loi
J-70 6/16
B-1049 Brussels
BELGIUM

CEC
DG XII Library
SDM8 R1
200 Rue de la Loi
B-1049 Brussels
BELGIUM

Chen Xing-an, M.D.
Laboratory of Industrial
Hygiene
Ministry of Public Health
2 Xinkang Street
Deshengmanwai, Beijing
THE PEOPLE'S
REPUBLIC OF CHINA

G. H. Clark
Australian Nuclear Science
and Technology
Organization
Environmental Science
Division
Private Mail Bag 1
Menai NSW 2234
AUSTRALIA

R. Clarke
National Radiological
Protection Board
Harwell, Didcot
Oxon OX11 0RQ
ENGLAND

P. Crutzen, Director
Atmospheric Chemistry
Max-Planck-Institut
für Chemie
Postfach 3060
D-6500 Mainz
FEDERAL REPUBLIC
OF GERMANY

No. of
Copies

Deng Zhicheng
North China Institute of
Radiation Protection
Tai-yuan, Shan-xi
THE PEOPLE'S
REPUBLIC OF CHINA

Director
Commissariat à l'Energie
Atomique
Centre d'Etudes
Nucléaires
Fontenay-aux-Roses
(Seine)
FRANCE

Director
Commonwealth Scientific
and Industrial Research
Organization
Aspendal, Victoria
AUSTRALIA

Director
Laboratorio di
Radiobiologia Animale
Centro di Studi Nucleari
Della Casaccia
Comitato Nazionale per
l'Energia Nucleare
Casella Postale 2400
00100 Roma
ITALY

D. Djuric
Institute of Occupational
and Radiological Health
11000 Beograd
Deligradoka 29
YUGOSLAVIA

H. Dovland
Director
Norwegian Institute for
Air Research
Elvegaten 52
N-2001 Lilleström
NORWAY

No. of
Copies

H. J. Dunster
National Radiological
Protection Board
Harwell, Didcot
Oxon QX11 ORQ
ENGLAND

L. Feinendegen, Director
Institut für Medizin
Kernforschungsanlage
Jülich
Postfach 1913
D-5170 Jülich
FEDERAL REPUBLIC
OF GERMANY

R. M. Fry
Office of the Supervising
Scientist for the
Alligator Rivers Region
P.O. Box 387
Bondi Junction NSW 2022
AUSTRALIA

G. B. Gerber
Radiobiology Department
Commission of European
Communities
200 Rue de la Loi
B-1049 Brussels
BELGIUM

A. R. Gopal-Ayengar
73-Mysore Colony
Mahul Road, Chembur
Bombay-400 074
INDIA

P. Grennfelt
Swedish Water and Air
Pollution Research
Institute (IVL)
Dagjämningssgatan 1
P.O. Box 47086
S-402 58 Göteborg
SWEDEN

No. of
Copies

S. E. Gryning
Physics and Meteorology
Risø National Laboratory
DK-4000 Roskilde
DENMARK

G. F. Guadrini
C.N.E.N.
V. Mazzini 2
J-40138 Bologna
ITALY

O. Hov
Norwegian Institute for
Air Research
Elvegaten 52
N-2001 Lillestrøm
NORWAY

D. Irwin, Librarian
Supervising Scientist
for the Alligator
Rivers Region
P.O. Box 387
Bondi Junction 2022
AUSTRALIA

K. E. Lennart Johansson
National Defense Research
Institute
FOA 45 1
S-901 82 Umeå
SWEDEN

V. A. Kamath
Library & Information
Service
Atomic Energy
Establishment, Trombay
Apollo Pier Road
Bombay-1
INDIA

No. of
Copies

H. J. Klimisch
BASF Aktiengesellschaft
Abteilung Toxikologie
Z470
D-6700 Ludwigshafen
FEDERAL REPUBLIC
OF GERMANY

L. Kristensen
Physics and Meteorology
Risø National Laboratory
DK-4000 Roskilde
DENMARK

T. Kumatori
National Institute of
Radiological Sciences
9-1, Anagawa 4-chome
Chiba-shi 260
JAPAN

A. Lacser
Israel Institute of
Biological Research
Department of Mathematics
P.O. Box 19
7004 50
Ness-Ziona
ISRAEL

J. R. A. Lakey
Department of Nuclear
Sciences & Technology
Royal Naval College,
Greenwich
London SE10 9NN
ENGLAND

S. E. Larsen
Physics and Meteorology
Risø National Laboratory
DK-4000 Roskilde
DENMARK

<u>No. of Copies</u>	<u>No. of Copies</u>	<u>No. of Copies</u>
H. P. Leenmouts National Institute of Public Health and Environmental Hygiene P.O. Box 1 NL-3720 BA, Bilthoven THE NETHERLANDS	Librarian Commonwealth Scientific and Industrial Research Organization 314 Albert Street P.O. Box 89 East Melbourne, Victoria AUSTRALIA	Librarian HCS/EHE World Health Organization CH-1211 Geneva 27 SWITZERLAND
Li De-ping Professor and Director of North China Institute of Radiation Protection, NMI Tai-yuan, Shan-xi THE PEOPLE'S REPUBLIC OF CHINA	Librarian Commonwealth Scientific and Industrial Research Organization Div. of Atmospheric Research Station Street Aspendale, Vic. 3195 AUSTRALIA	Librarian Kernforschungszentrum Karlsruhe Institut für Strahlenbiologie D-75 Karlsruhe 1 Postfach 3640 FEDERAL REPUBLIC OF GERMANY
Librarian Atomic Energy Research Establishment Building 465 Harwell, Didcot Oxon OX11 ORD ENGLAND	Librarian Commonwealth Scientific and Industrial Research Organization Rangelands Research Centre Private Mail Bag, P.O., Deniliquin, New South Wales 2710 AUSTRALIA	Librarian Max-Planck-Institut für Biophysics Forstkasstrasse D-6000 Frankfurt/Main FEDERAL REPUBLIC OF GERMANY
Librarian Australian Atomic Energy Commission Riverina Laboratory P.O. Box 226 Deniliquin, New South Wales 2710 AUSTRALIA	Librarian ECN 3 Westerdijkweg NL-1755 ZG Petten THE NETHERLANDS	Librarian Ministry of Agriculture, Fisheries and Food Fisheries Laboratory Lowestoft, Suffolk NR33 OHT ENGLAND
Librarian Centre d'Etudes Nucléaires de Saclay P.O. Box 2, Saclay Fig-sur-Yvette (S&O) FRANCE	Librarian ENEA (OECD) Health and Safety Office 38, Blvd. Suchet Paris FRANCE	Library Risø National Laboratory DK-4000 Roskilde DENMARK
		Library, Periodicals Atomic Energy Commission of Canada, Ltd. Pinawa, Manitoba ROE 1L0 CANADA

No. of
Copies

Library
Department of
Meteorology
University of Stockholm
Arrhenius Laboratory
S-106 91 Stockholm
SWEDEN

A. M. Marko
Atomic Energy Commis-
sion of Canada, Ltd.
Biology and Health Physics
Division
Chalk River Nuclear
Laboratories
P.O. Box 62
Chalk River, Ontario
K0J 1J0
CANADA

K. Morita
Librarian
National Institute of
Radiological Sciences
9-1, Anagawa 4-chome
Chiba-shi 260
JAPAN

J. C. Nénot
Département de Protection
Centre d' Etudes
Nucléaires
BP No. 6
F-92260 Fontenay-aux-
Roses
FRANCE

J. P. Oliver
ENEA (OECD) Health and
Safety Office
38, Blvd. Suchet
Paris
FRANCE

No. of
Copies

N. Parmentier
Département de Protection
Centre d'Etudes
Nucléaires
BP No. 6
F-92260 Fontenay-aux-
Roses
FRANCE

L. Prahm
Danish Meteorological
Institute
Lyngbyvej 100
DK-2100 Copenhagen East
DENMARK

V. Prodi
Department of Physics
University of Bologna
Via Imerio 46
I-40126 Bologna
ITALY

H. Rodhe
Meteorological Institute
Stockholm University
S-106 91 Stockholm
SWEDEN

P. J. A. Rombout
Inhalation of Toxicology
Department
National Institute of
Public Health and
Environmental Hygiene
P.O. Box 1
NL-3720 BA, Bilthoven
THE NETHERLANDS

No. of
Copies

M. Roy
Institut de Protection et
de Sureté Nucléaire
Département de Protection
Sanitaire
Service d'Etudes
Appliquées de Protection
Sanitaire
BP No. 6
F-92260 Fontenay-aux-
Roses
FRANCE

M. Rzekiecki
Commissariat à l'Energie
Atomique
Centre d'Etudes
Nucléaires de Cadarache
BP No. 13-St. Paul
Les Durance
FRANCE

G. Schnatz
Battelle-Europe eV
Am Römerhof 35
P.O. Box 900160
D-6000 Frankfurt a.M.
FEDERAL REPUBLIC
OF GERMANY

W. Seiler
Fraunhofer Institute
for Atmospheric
Environmental Research
Kreuzeckbahnstr. 19
D-8100 Garmisch-
Partenkirchen
FEDERAL REPUBLIC
OF GERMANY

G. Silini
Secretary, UNSCEAR
Vienna International
Center
P.O. Box 500
A-1400 Vienna
AUSTRIA

No. of
Copies

R. Skogstrom
Meteorological Institute
University of Stockholm
Arrhenius Laboratory
S-106 91 Stockholm
SWEDEN

J. Slanina
ECN
3 Westerduinweg
NL-1755 ZG Petten
THE NETHERLANDS

H. Smith
Biology Department
National Radiological
Protection Board
Chilton, Didcot
Oxon OX11 0RQ
ENGLAND

R. Söderlund
Air Pollution Laboratory
National Environmental
Protection Board
P.O. Box 1302
S-171 25 Solna
SWEDEN

J. W. Stather
National Radiological
Protection Board
Building 383
Harwell, Didcot
Oxon OX11 0RQ
ENGLAND

M. J. Suess
Regional Officer for
Environmental Hazards
World Health Organization
8, Schertigsvej
DK-2100 Copenhagen
DENMARK

No. of
Copies

Sun Shi-quan, Head
Radiation-Medicine
Department
North China Institute
of Radiation Protection
Tai-yuan, Shan-xi
THE PEOPLE'S
REPUBLIC OF CHINA

J. W. Thiessen
Radiation Effects Research
Foundation
5-2 Hijiyama Park
Minami - Ward
Hiroshima 732
JAPAN

M. Thorne
International Commission
on Radiological
Protection
Clifton Avenue
Sutton, Surrey
ENGLAND

United Nations Scientific
Committee on the Effects
of Atomic Radiation
Vienna International
Center
P.O. Box 500
A-1400 Vienna
AUSTRIA

R. Van Aalst
Laboratory for Air
Research
RIVM
P.O. Box 1
NL-3720 BA Bilthoven
THE NETHERLANDS

D. Van As
Atomic Energy Board
Private Bag X256
Pretoria 0001
REPUBLIC OF SOUTH
AFRICA

No. of
Copies

Vienna International
Centre Library
Gifts and Exchange
P.O. Box 100
A-1400 Vienna
AUSTRIA

Wang Renzhi
Institute of Radiation
Medicine
11# Tai Ping Road
Beijing
THE PEOPLE'S
REPUBLIC OF CHINA

Wang Ruifa
Laboratory of Industrial
Hygiene
Ministry of Public Health
2 Xinkang Street
Deshengmanwai, Beijing
THE PEOPLE'S
REPUBLIC OF CHINA

Wang Yibing
North China Institute
of Radiation Protection
P.O. Box 120
Tai-yuan, Shan-xi
THE PEOPLE'S
REPUBLIC OF CHINA

Wei Luxin
Laboratory of Industrial
Hygiene
Ministry of Public Health
2 Xinkang Street
Deshengmanwai, Beijing
THE PEOPLE'S
REPUBLIC OF CHINA

B. C. Winkler
Raad Op Atomic
Atoomkrag Energy Board
Privaatsk X256
Pretoria 0001
REPUBLIC OF SOUTH
AFRICA

No. of
Copies

Wu De-Chang
Institute of Radiation
Medicine
11# Tai Ping Road
Beijing
THE PEOPLE'S
REPUBLIC OF CHINA

Yao Jiaxiang
2 Xinkang Street
Deshengmenwai
Beijing 100011
THE PEOPLE'S
REPUBLIC OF CHINA

Zhu Zhixian
North China Institute
of Radiation Protection
P.O. Box 120
Tai-yuan, Shan-xi
THE PEOPLE'S
REPUBLIC OF CHINA

ONSITE

3 DOE Richland Operations
Office

E. C. Norman/D. L. Hoff
J. J. Sutey
M. W. Tiernan

2 Tri-Cities University
Center

J. Cooper
B. Vallet

2 Hanford Environmental
Health Foundation

L. J. Maas
M. J. Swint

2 Westinghouse Hanford Co.

C. J. Perkins
D. E. Simpson

No. of
Copies

112 Pacific Northwest
Laboratory

O. B. Abbey
K. J. Allwine
R. W. Baalman
D. C. Bader
J. F. Bagley
W. J. Bair (15)
M. Y. Ballinger
W. R. Barchet
N. S. Bloom
C. J. Brandt
K. M. Busness
D. B. Cearlock
E. G. Chapman
T. D. Chikalla
G. A. Crecelius
D. S. Daly
M. T. Dana
J. M. Davidson
W. E. Davis
G. W. Dennis
J. C. Doran
J. G. Droppo
R. C. Easter
C. E. Elderkin (5)
J. W. Falco
R. M. Fleischman
C. S. Glantz
W. A. Glass
J. A. Glissmeyer
D. W. Glover
R. H. Gray
R. K. Hadlock
J. M. Hales (3)
R. V. Hannigan
L. C. Harrison
P. C. Hays
G. R. Hilt
D. J. Hoitink
T. W. Horst
J. M. Hubbe
R. A. Keefe

No. of
Copies

B. J. Kelman
E. W. Kleckner
N. S. Laulainen
G. L. Laws
R. N. Lee
A. C. Leslie
D. J. Luecken
J. A. Mahaffey
J. Mishima
J. M. Nielsen
E. L. Owczarski
P. C. Owczarski
J. F. Park
W. T. Pelroy
W. T. Pennell (2)
R. W. Perkins
A. M. Platt
J. V. Ramsdell
D. S. Renne
W. D. Richmond
D. R. Roth
G. F. Schiefelbein
L. C. Schmid
B. C. Scott
G. A. Sehmel
D. S. Sharp
R. L. Skaggs
E. D. Skillingstad
W. G. N. Slinn
G. M. Stokes
J. A. Stottlemeyer
D. L. Streng
J. M. Thorp
L. H. Toburen
B. E. Vaughan
L. L. Wendell (2)
C. D. Whiteman
R. E. Wildung
W. R. Wiley
R. K. Woodruff
Health Physics Library
Life Sciences Library (2)
Publishing Coordination
Technical Report Files (5)