AIR RESOURCES LABORATORY

1994 REPORT

ARL
Air Resources Laboratory

U.S. Department of Commerce

National Oceanic and Atmospheric Administration
Environmental Research Laboratories
Air Resources Laboratory
Silver Spring, Maryland

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Notice

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From the Director

The Air Resources Laboratory (ARL) is a scientific organization with a rich history and a keen eye towards the future. We now step into our 47th year as leaders in various aspects of applied air quality and climate research with increased recognition that national needs are changing, and in anticipation of emerging scientific questions that will challenge our skills and resources. We look forward to these challenges, with awareness that new environmental issues will tend to be cross-disciplinary, and multi-media. A conclusion that might follow remains to be tested — that the days of ever-narrowing environmental specialization are possibly over. Certainly, the Air Resources Laboratory will continue in its historic role of stretching the ability to predict, forecast, and/or assess, in all areas where the air interacts with other components of the environment.

This report presents some of our recent accomplishments and our vision for the future. There has been no attempt to be exhaustive; rather the goal has been to focus on areas of significant activity specifically related to the NOAA Strategic Plan or involving more than one of the ARL divisions. As in the past, each item that is summarized is not intended to answer all of the readers' questions, but instead to whet their appetite for more information, which we would be happy to provide.

Much of our effort involves collaborative research and supports other government agencies and programs. So we are particularly sensitive to trends in, and the requirements of, the community with which we interact. Your comments about ARL or this report are always welcome.

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In Memoriam

TERRY L. CLARK (1950-1994)

Terry Lee Clark, 43, of Cary, NC passed away on January 28, 1994, from complications of Acquired Immune Deficiency Syndrome. Born in Baltimore, MD, Terry graduated with a BS and MS in Meteorology from Texas A&M. Since 1975, Terry had been with NOAA/ARL as a research meteorologist assigned to ASMD in Research Triangle Park, NC. During this period, he was very active in scientific research, developing and applying models of air pollution dealing with a wide range of issues including visibility, and acid and toxics deposition. Terry developed and applied the Regional Lagrangian Model for Air Pollution (RELMAP). During the NAPAP years, he led the working group "International Sulfur Deposition Model Evaluation" (ISDME) program. He also played a key role in designing and implementing an EPA toxics modeling effort in response to the Great Waters Study which was mandated in the 1990 Clean Air Act Amendments. Terry earned the respect and admiration of his colleagues and of the international air pollution modeling community.

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An Overview of ARL

Mission:

Although ARL, probably more than most other NOAA laboratories, works closely with other government agencies, we are first and foremost a NOAA research laboratory. As stated in the NOAA 1995-2005 Strategic Plan, *"NOAA's mission is to promote global environmental stewardship and to describe and predict changes in the Earth's environment."* The ARL contribution to that goal can be summarized in the ARL mission statement:

The Air Resources Laboratory carries out research on processes that relate to air quality and climate, concentrating on the transport, dispersion, transformation and removal of trace gases and aerosols, and the exchange between the atmosphere and biological and non-biological surfaces. The time frame of interest ranges from minutes and hours to that of the global climate. Research in all of these areas involves physical and numerical studies, leading to the development of air quality simulation models. The Laboratory provides scientific advice to elements of NOAA and other Government agencies on environmental problems, emergency assistance, and climate change.

The specific goal of ARL research is to improve and eventually to institutionalize forecasting of air quality, deposition, and related atmospheric environmental variables. This is in support of concerns related to effects on human health, ecosystem viability, sustainable development, and international competitiveness.

Personnel and Divisions:

The Air Resources Laboratory started as the Special Projects Section of the U.S. Weather Bureau, in 1948. In 1963 (and until 1965), its name was changed to the Meteorological Research Projects Branch of the Weather Bureau. In 1965, the organization (including its field offices) was reconstituted as the Air Resources Laboratories, and most recently (1981) was redefined as a single Air Resources Laboratory with several field divisions. Thus, ARL is not a single, centrally-located laboratory, but a consolidation of spatially distributed laboratories that focus on specific aspects of research related to the overall ARL air quality mission.

On 22 January, 1994, the formal transfer of the National Weather Services Nuclear Support Office in Las Vegas to ARL was completed. The new ARL Las Vegas group is known as the Special Operations and Research Division.

ARL's approximately 130 federal employees work in laboratories in six states, as follows.

Headquarters Division
(Silver Spring, MD)
Focus: Transport, wet deposition, and climate change

Atmospheric Sciences Modeling Division
(Research Triangle Park, NC)
Focus: Integrated modeling
Director: Frank Schiermeier

Atmospheric Turbulence and Diffusion Division (Oak Ridge, TN)
Focus: Turbulent dispersion and exchange
Director: Ray Hosker

Field Research Division
(Idaho Falls, ID)
Focus: Air quality transport and model evaluation
Acting Director: Gene Start

Special Operations and Research Division
(Las Vegas, NV)
Focus: Particle dispersion and deposition, emergency response
Director: Darryl Randerson

In 1994, the Aerosol Research Section in Boulder was disbanded, and a new Surface Radiation Research Branch was formed under the leadership of Dr. John DeLuisi and as a field component of the Headquarters Division.

Major Awards

ASMD scientists Alan Huber, John Streicher, and Gennaro Crescenti were awarded NOAA Bronze Medals for their work in Thailand. Their project provided the Royal Thai Government with modeling and monitoring results to assist in managing air quality at the Mae Moh Power Plant to minimize the possibility of future acute effects on health and vegetation. At an EPA Awards Ceremony on November 22, Ken Schere of ASMD was awarded two EPA Bronze Medals, one for his earlier work in developing the case for NO_x as well as VOC controls for ozone reduction, and another for his assistance in organizing the North American Research Strategy for Tropospheric Ozone (NARSTO).

Research Philosophy:

Scientific investigations conducted by ARL locations are coordinated and organized in three themes. The accomplishments described in the body of this report are organized according to these themes:

Air Quality and Dispersion (air-surface exchange; acid deposition; ozone and oxidants; aerosols and visibility)

Climate Trends and Variability (solar radiation, including infrared and ultraviolet; meteorological trends; desertification)

Emergency Preparedness (nuclear; volcanoes; toxics; dense gases)

In every case, the end product of ARL research is an improved capability to predict some aspect of air quality. This capability will necessarily take the form of a computer model of some kind, driven by meteorological information and emission data, and containing the best available descriptions of all relevant processes. To this end, ARL conducts research involving both modeling and measurements, with an emphasis on integration of these activities. It is recognized that modern models are invariably data assimilative, and that modern monitoring programs require coupled modeling activities for data interpretation.

The applications of these capabilities range from assessment, typically using climatological or "characteristic" inputs, to short-term prediction, based on the use of meteorological forecast data. The current state of this science is that different applications require different mixes of the processes to be considered, and it is anticipated that future products will retain much of this specialization. In this context, however, there is an over-riding recognition of the need for model products to be as simple as satisfies the demands placed on them, while being adequately complete in their formulation. The models are intended to be parsimonious, data assimilative, and regularly benchmarked against observations made with coupled observing networks. To this end, the organizational components of ARL contribute in the following fashion.

Developing Models

- Improving model assessment capabilities for support of regulations and controls — Research Triangle Park

- Enhancement of site-specific, air-quality models — Oak Ridge

- Determining the relationship between pollutant concentrations and deposition — Oak Ridge

- Linking air quality and deposition models with routine forecast products — Silver Spring

- Extending modeling and assessment work to radioactivity — Las Vegas

- Providing emergency response capability for nuclear and toxic materials — Las Vegas, and Silver Spring

- Field testing and evaluating models — Idaho Falls

<u>**Provision of Data**</u>

- Ensuring the compatibility of international data sets — Silver Spring

- Accounting for poor measurement fidelity — Silver Spring

- Operating integrated networks to couple monitoring observations with model predictions (AIRMoN) — Silver Spring, Oak Ridge

- Operating networks to characterize data fields required as input for air quality, surface energy balance, solar radiation, and deposition models — Oak Ridge, Boulder, Research Triangle Park

- Providing quality assurance on national radiation data (solar, surface, UV-B) — Boulder

ARL's Role in the Federal Government:

ARL conducts research as needed to answer questions of urgency related to regulatory controls and policy, public safety, and the environment (as it involves atmospheric considerations). **ARL serves as a provider of scientific information to the administration, the Congress, various state and federal agencies, the public, private industry, and the scientific community.**

In this regard, ARL strives to be a full-service organization, supporting necessary research at selected universities, maintaining a long-term monitoring and analysis infrastructure around which the research is concentrated, and representing NOAA and the national interest in policy debates and scientific discussions on related matters.

A central issue is the relationship of ARL with other laboratories in NOAA, especially among the Environmental Research Laboratories. But equally important is the role that has developed involving other agencies. **In practice and by intent, ARL is the major point of interaction between NOAA atmospheric research and the related informational and scientific requirements of several other agencies.**

- NOAA is viewed by other agencies as a provider of high-quality and independent advice regarding matters of atmospheric transport, dispersion, air quality, and deposition, and ARL is perceived to be the agent providing access to this advice.

- NOAA values independence from agencies that are more closely influenced by policy and regulatory considerations, and attributes (in part, at least) the high quality of its science to the opportunity to conduct and promote research independently of policy and regulatory processes.

Much of the contribution made by ARL can be viewed as provision of independent atmospheric expertise to assist other agencies in fulfilling their own federal mandates. This provision of scientific information and advice to other agencies can be considered to be a component of

NOAA's service function. Financial support for work intended to permit another agency to perform its own function, in its own jurisdictions, with improved credibility and defensibility is normally provided by the other agency concerned. At this time, the major agencies involved are the Environmental Protection Agency and the Department of Energy. ARL is roughly equally supported by NOAA, EPA, and DOE.

- The Environmental Protection Agency provides almost complete support for the ARL team at Research Triangle Park, established specifically to provide meteorological expertise and services to EPA, related to atmospheric dispersion and air quality modeling.

- The Department of Energy provides about 25% of the funding for the ARL team at Oak Ridge, set up to provide a collaborative NOAA/DOE capability to address questions on dispersion, deposition and air quality of relevance to the DOE Oak Ridge Field Office.

- The Department of Energy also provides about 25% of the funding at Idaho Falls, for maintenance and improvement of emergency assistance services to the Idaho National Engineering Laboratory.

- The Department of Energy provides almost all of the funding of the ARL Special Operations and Research Division, in Las Vegas, to support the DOE defense programs of the Nevada Operations Office.

ARL's Contribution to the NOAA Strategic Plan:

The NOAA Strategic Plan focuses on needs that are related to the performance of NOAA's own mission. The activities of ARL contribute to the goals of the Strategic Plan, but also interject the requirement to consider a higher plane of consideration — NOAA's role as a source of atmospheric and aquatic environmental guidance to other elements of society and especially to other federal agencies, independent of their own regulatory and control functions. ARL research contributes directly in several NOAA Strategic Plan components, as follows.

<u>Coastal Ecosystems Health</u>

(a) The role of atmospheric deposition as a contributor to coastal ecosystem eutrophication and decay.

ARL is conducting research to develop objective methods for quantifying atmospheric deposition, as it affects coastal ecosystems, with emphasis on nutrients and toxics. Current research is directed specifically to the roles of nitrates and airborne toxic chemicals. ARL is focussing initially on East Coast ecosystems — mainly the Chesapeake Bay and Albermarle/Pamlico Sound. State-of-the-art models are being developed by ARL (Research Triangle Park), and advanced measurement systems are being deployed by ARL (Oak Ridge and Silver Spring). Initial estimates for the Chesapeake Bay indicate that about 30-40% of the nitrogen loading is derived from the atmosphere. ARL chairs the Chesapeake Bay Air Quality Coordination Committee, an officially-endorsed body for consolidating activities among federal and state agencies.

(b) Monitoring of Causative Factors.

ARL is leading a national thrust towards "integrated monitoring," a new multi-disciplinary approach to monitoring to address complex questions. Since monitoring of the actual health of ecosystems only provides indications of damage *after* the damage has occurred, responsible ecosystem monitoring requires attention to those factors that cause the damage to occur, specifically input rates of toxic materials and nutrients. The present objective is to develop cost-effective and proven methodologies for conducting such monitoring.

ARL operates exploratory monitoring stations in coastal areas, where interpretation of atmospheric data is presently difficult and agreement on the results is rare. Techniques are being developed to account for the roles of terrain complexity in the models used to interpolate among monitoring sites and in the simulations used to assess likely inputs in the absence of field data. In particular, techniques to account for moderate terrain complexity have been developed and are now being included in assessment models being developed by ARL for EPA. As yet, there has been no opportunity to test the predictions of these models against field data, however steps to provide a platform suitable for collecting such data have been initiated.

Advance Short-Term Warning and Forecast Services

(a) Air Quality Predictions

A major goal of ARL is to develop the basis on which to extend current prediction services to other environmental variables, necessitated by increasing population and societal pressure. The long-term goals of this research are related to assessing air quality (ozone, particulates, etc.) and to UV-B radiation.

In this context, it is apparent that the focus of most atmospheric predictive models is on those layers of the atmosphere that move weather systems. For air quality, more attention must be directed to the lower atmosphere (where people live and where pollution is greatest). Relevant models are now available, and are slowly being coupled with weather forecasting models. In the future, data assimilation methods must be extended, to focus on areas where forecasts are specially needed.

(b) Emergency Planning and Response

ARL serves as a center of activity for the provision of specialized meteorological assistance in the event of large releases of hazardous materials into the atmosphere, such as from volcanoes, nuclear accidents, and industrial disasters. In general, NOAA provides basic meteorological support in all such cases, but is also expected to provide related guidance to other agencies and warnings to the public. For this purpose, ARL (as a joint activity with the National Meteorological Center) operates a Regional Specialized Meteorological Center for the World Meteorological Organization (WMO), to provide emergency response assistance to the nations of North and Central America in the event of a disastrous atmospheric accident. Throughout the entire nuclear era, ARL has provided emergency preparedness and response services to DOE and the Nuclear Regulatory Commission (NRC), relating to nuclear accidents and explosions and to the underground testing of nuclear weapons.

As components of this activity, ARL coordinated much of the multi-agency and multi-national atmospheric research response to the Kuwait oil fires emergency. ARL developed the techniques now in routine use for forecasting the spread of volcanic ash. ARL also developed the methodologies now in place to advise NRC (and several components of DOE) in the event of a nuclear accident. In the distant past, ARL research led to the generation of the now famous "Gaussian plume" dispersion methodology, now routinely used for warning the nearby public in the event of a leak of trace quantities of hazardous gases into the atmosphere.

Seasonal to Interannual Climate Forecasts

(a) Air Quality and Environmental Assessments

As a longer-term extension of ARL's work on air quality prediction, ARL provides objective and independent guidance to policy-makers concerning specific environmental concerns and corresponding regulatory strategies, related to national and global air quality and climate. Specific examples of recent issues include acid rain, tropospheric ozone, visibility, and airborne toxics.

NOAA/ARL provides independent guidance on alternative regulatory and control strategies to the EPA through its Research Triangle Park operation. ARL also conducts extensive field tests of the models developed for such purposes, through its Idaho Falls group.

For more than a decade, NOAA has provided the scientific direction of the National Atmospheric Precipitation Assessment Program, an interagency body to provide necessary cross-agency mechanisms to coordinate research, consolidate knowledge, integrate assessments, and implement national strategies. ARL has been the principal NOAA representative.

In collaboration with scientists from many other agencies, ARL has led scenario-based assessments of toxic chemicals, ozone, and NO_x control options, etc. The importance of this activity is rapidly growing. NOAA is widely viewed as an independent source of expert information on matters of environmental and air quality policy, both nationally and globally. As time progresses, environmental quality is becoming less of a local problem and more of a global concern. Air quality scenario and assessment models will need to broaden their scope from countries to continents.

Predict and Assess Decadal-to-Centennial Change

(a) Detection and Attribution of Change in Air Quality

A major component of ARL research relates to the need to detect the consequences of imposed emission controls in a timely and unequivocal manner, so as to permit remedial adjustments in control strategies. For this reason, ARL has operated a research-grade national monitoring network since about 1984, concentrating on chemicals indicative of industrial and societal emissions — primarily sulfur and nitrogen oxides. Recently the longest-running precipitation chemistry network in the world has been consolidated with this ARL program. Now, we have an ongoing, broad-based network that is specifically designed to reveal changes in the atmospheric environment, with rapidity.

At this time an Atmospheric Integrated Research Monitoring Network (AIRMoN) exists, although in embryonic form. The models that are needed to interpret the data obtained are also on hand, although only as first-generation attempts as yet. The existing AIRMoN program is designed primarily to provide accurate information on the rate of deposition of air chemicals to the surface; present planning is to add a rapid detection component to the AIRMoN program, under funding through the new Health of the Atmosphere program. The intentions are that the AIRMoN will be refined and coupled with real-time analysis and modeling so as to reveal those changes that can be attributed to changes in pollution emissions.

(b) Quality Assurance of Global Data

ARL leads a multi-national effort to ensure that air quality data sets collected by national monitoring networks can be brought together in an objective and seamless manner. A WMO Quality Assurance/Science Activity Center for the Americas is presently being inaugurated, to serve North, Central, and South America. The center will work directly with member nations, and with site operators, to ensure the highest possible integrity of monitored data. A three-agency consortium has been established to provide the necessary support — DOE, EPA and NOAA.

Recent Organizational Highlights

In keeping with government-wide efforts to streamline programs and provide higher quality and more cost-effective service to the nation, the Air Resources Laboratory has recently re-aligned its research capabilities, facilities and personnel to strengthen operations in areas where we are widely seen to have special skills and to refocus efforts towards scientific issues of national and international importance. Major changes involved restructuring the ARL presence in Boulder and establishing an integrated surface radiation program there; centralizing surface dust activities in Research Triangle Park, and aircraft activities in Oak Ridge; and welcoming back into the ARL family the NOAA/NWS Nuclear Support Office in Las Vegas, Nevada.

Outreach and Community Service

The Air Resources Laboratory promotes the ideals of equality of opportunity, good neighborliness, and community service in its official activities and the private lives of its staff members. Here we list just a few of the contributions of the laboratory and its employees during 1994. The heavy emphasis on science education is not accidental, as we try to use our collective scientific experience and training to encourage young people's interest in the natural world.

ARL scientists serve as Adjunct Professors at the following universities and colleges:

- Duke University
- Georgia Institute of Technology
- Hebrew University (Jerusalem)
- North Carolina State University
- University of Nevada at Las Vegas
- University of North Carolina
- University of Tennessee at Knoxville

Carlos Alicea, a Hispanic summer intern, worked with ARL/HQ from 6 June to 12 August. Carlos' background is in Environmental Science.

Veronique Bugnion visited SRRB as part of the DOC/NOAA Exchange Visitor Program (a program of the DOC/NOAA to provide courses of study at selected universities, etc., for qualified foreign students.)

Two high school students were supported by ATDD through the Anderson County school system vocational education program. Two additional students were added for the summer.

Glenn Rolph and Rick Artz continued to participate in the National Geographic Kids Network on Acid Rain. Glenn and Rick provide assessments of the data collected in North America and abroad by elementary school students. Students learn about atmospheric deposition, collect observations, and analyze the results.

The following schools were involved in ARL outreach programs —

- Kirk of Kildaire Preschool, Cary, NC
- Cresthaven Elementary, Washington, DC
- Eno Valley Elementary, Durham, NC
- Memorial Elementary, Paris, IL

- West Hills Elementary, Knoxville, TN
- Woodland Elementary, Oak Ridge, TN
- Linden Elementary, Oak Ridge, TN
- Clark County School District, Las Vegas, NV
- Bonneville School District, Idaho Falls, ID
- Boulder Junior High, Boulder, CO

SORD employees participated in Native American Program in November, Veterans Day Program in November, and Angel Tree Project in December. In addition, SORD (Las Vegas) participated in the Partnership in Education program, involving visits to eight schools.

SORD also participated in the DOE sponsored "Science Now" program in Las Vegas. This focused on outstanding high school students from the Las Vegas area. Students were given the opportunity to operate NOAA equipment and to interact with NOAA meteorologists.

ATDD (Oak Ridge) again participated in the annual DOE and Martin Marietta Energy Systems-sponsored "Environmental Fair." Local businesses and organizations participated in an effort to educate grade school students about various environmental issues. ATDD's booth presented information about current global climate change studies, and contained several "hands-on" demonstrations.

ATDD also hosted about 100 local fourth grade students at a presentation on latitude, longitude, and use of the Global Positions System (GPS) to determine location, as part of the National Geographic program for students to determine their "global address" for inclusion in an Internet-accessible database.

At Research Triangle Park, Dr. Sharon LeDuc gave a Career presentation to seventh grade students, at the University of North Carolina, Chapel Hill, NC.

List of Acronyms

AEROCE — Atmosphere-Ocean Chemistry Experiment
AIRMoN — Atmospheric Integrated Research Monitoring Network
ANATEX — Across North America Tracer Experiment
ANICA — Atmospheric Nutrient Input to Coastal Areas
AQSM — Air Quality Simulation Models
ARL — Air Resources Laboratory
ARM — Atmospheric Radiation Measurement program
ASMD — Atmospheric Sciences Modeling Division
ATDD — Atmospheric Turbulence and Diffusion Division
BAPMoN — Background Air Pollution Monitoring Network
BOREAS — Boreal Ecosystem-Atmosphere Study
CAPTEX — Cross-Appalachian Tracer Experiment
CART — Cloud and Radiation Testbed
CASTNET — Clean Air Status and Trends Network
CORE — Collocated Operational Research Establishments
CRAFT — Cray Research Adaptive ForTran
CTDM — Complex Terrain Dispersion Model
DDIM — Dry Deposition Inferential Monitoring
DOE — Department of Energy
EPA — Environmental Protection Agency
EPS — Emission Processing System
ETEX — European Tracer Experiment
FAA — Federal Aviation Administration
FRD — Field Research Division
FREDS — Flexible Regional Emissions Data System
GAW — Global Atmosphere Watch
GEMAP — Geocoded Emission Modeling and Projection
GPS — Global Positioning System
GTS — Global Telecommunications System
HPCC — High Performance Computing and Communications
HYSPLIT-ACID — Hybrid Simple Particle Lagrangian Integrated Trajectory model with Atmospheric Chemistry Including Deposition
IAEA — International Atomic Energy Agency
IGAC — International Global Atmospheric Chemistry
IPCC — Intergovernmental Panel on Climate Change
IRGA — Infrared gas analyzer
ISC-COMPDEP — Industrial Source Complex - COMPlex terrain DEPosition
ISIS — Integrated Surface Irradiance Study
MAP3S — Multistate Atmospheric Power Production Pollution Study
MAS — Mobile Atmospheric Spectrometer
MFP — Mobile Flux Platform
MRF — Medium Range Forecast
NAAQS — National Ambient Air Quality Standards
NADP — National Atmospheric Deposition Program
NAPAP — National Acid Precipitation Assessment Program
NARE — North Atlantic Regional Experiment
NASA — National Aeronautics and Space Administration

NARSTO	— North American Research Strategy for Tropospheric Ozone
NAWC	— Navy Air Warfare Center
NESDIS	— National Environmental Satellite, Data, and Information Service
NIST	— National Institute of Standards and Technology
NMC	— National Meteorological Center
NMFS	— National Marine Fisheries Service
NOAA	— National Oceanic and Atmospheric Administration
NRC	— Nuclear Regulatory Commission
NSF	— National Science Foundation
NTS	— Nevada Test Site
NWS	— National Weather Service
PBL	— Planetary Boundary Layer
PERF	— Petroleum Industry Environmental Research Forum
PVM	— Parallel Virtual Machine
QA/SAC	— Quality Assurance/Science Activity Center
QAPJP	— Quality Assurance Project Plan
QBO	— Quasi-Biennial Oscillation
RADM	— Regional Acid Deposition Model
RAMAN	— Regional Atmospheric Measurement and Analytical Network
RAMS	— Regional Atmospheric Modeling System
RELMAP	— Regional Lagrangian Model of Air Pollution
ROM	— Regional Oxidant Model
ROSE	— Regional Oxidants in the SouthEast
RSMC	— Regional Specialized Meteorological Centre
RTP	— Research Triangle Park
SORD	— Special Operations and Research Division
SPARC	— Stratospheric Processes And their Role in Climate
SRRB	— Surface Radiation Research Branch
SURFRAD	— Surface Radiation monitoring network
TOGA/COARE	— Tropical Ocean Global Atmosphere/Coupled Ocean-Atmosphere Response Experiment
USGS	— U.S. Geological Survey
UV-B	— Ultraviolet-B
VAFTAD	— Volcanic Ash Forecast Transport and Dispersion
WATOX	— Western Atlantic Ocean Experiment
WBW	— Walker Branch Watershed
WMO	— World Meteorological Organization
WTI	— Waste Technology Industries

A NEW NOAA AIRCRAFT CAPABILITY

The Twin Otter Airborne Mobile Flux Platform

Background.

The NOAA Strategic Plan promotes the need to predict with accuracy short-term environmental changes, and recognizes that current understanding is restricted by observations that are temporally and spatially incomplete. Purchase during 1994 of a de Havilland Twin Otter aircraft by the NOAA Aircraft Operations Center, using funds from ERL, ARL and the National Marine Fisheries Service, is intended to allow the Air Resources Laboratory to address this issue by improving our current flux measurement capability and by providing a slow, stable platform for the collection of atmospheric chemistry data. It is expected that the Twin Otter will occupy a unique niche in NOAA's atmospheric research capabilities--an aircraft suited for flux and atmospheric chemistry missions in the lower troposphere at a low operational cost.

Tower and Aircraft Platforms.

Measurements of surface exchange (turbulent flux) processes constitute a major research activity of NOAA's Air Resources Laboratory (ARL). A "first principles" method for turbulent flux measurements is eddy covariance, or eddy correlation. In this method fast response measurements of trace species (e.g., H_2O, CO_2, O_3) are combined with fast response micrometeorological measurements (3-dimensional winds, temperature) to directly determine the species flux to or from the surface. While the technique is simple in concept, in reality it places stringent demands on the measurement system. Chief among these is the requirement that streamline deformation caused by the sensors themselves be minimized. This places severe constraints on the design and deployment of the appropriate sensors.

Due to the complexities involved, eddy flux measurement campaigns often use stationary sensors affixed to ground-based meteorological towers. While these tower-based measurements yield detailed information on the surface exchange processes at a single location, they reveal little about the representativeness of the measurements in the larger geographical context, or about the spatial variability of the exchange process. For spatially resolved information, measurements from instrumented research aircraft are required. Flux measurements from aircraft, however, are rendered more complicated by streamline deformation considerations, coupled with the requirements to accurately measure air motions relative to the airframe and aircraft motions relative to the ground.

These measurement demands have been met by ARL's development of a Mobile Flux Platform (MFP). The MFP offers considerable advantages over traditional flux measurement packages, which are expensive and require significant space and power, limiting their use to larger aircraft with attendant increases in flow disturbance. The miniaturized sensors in the MFP allow collocation of the motion and velocity sensors in the instrument probe affixed to the aircraft, which centers the frame of reference in the probe (rather than in the aircraft), simplifying the mathematics required to separate probe and air motions. Its light weight and low power consumption allow the MFP to be installed in small aircraft and other low operating cost vehicles.

ARL Aircraft Programs.

Two aircraft have been used in recent years to support ARL's research programs. The prime demonstration platform for the MFP has been a staff-owned variant of the Rutan-designed "Long-EZ" airplane. The Long-EZ is a high efficiency airframe with a "pusher" engine configuration which leaves the nose of the airplane free from propeller-induced flow disturbances, engine vibration, and exhaust. The aircraft's superior pitch stability and low wing loading allow safe, low speed flight at 50 m/s, reducing flow compressibility disturbances far below those typical of fast twin engine aircraft. The Long-EZ, however, is a developmental airframe with minimal (70 kg) instrument payload capacity, and is capable of carrying only those sensors which are compact, lightweight, and completely automated. ARL's second aircraft, a Beechcraft King Air C-90, has been used extensively in the past for air quality and atmospheric chemistry studies. While the King Air is an excellent platform for weather modification and some air quality experiments, its payload capacity is frequently insufficient for detailed studies of tropospheric photochemistry. In addition, the King Air is inadequate for turbulent flux measurements, as its less streamlined design and faster flight speeds result in unacceptable flow distortion around the airframe.

The aircraft of choice for many eddy flux and gradient studies is a DeHavilland Twin Otter, a twin engine, non-pressurized, high wing aircraft that combines the slow, streamlined flight characteristics of the Long-EZ with a payload capacity more than twice that of the NOAA King Air. Thus the aircraft will be uniquely suited to permit accurate eddy flux measurements of a variety of trace species, including those which require heavy and complex detection instrumentation. Trace gas and aerosol photochemistry studies will benefit from the payload capacity of the Twin Otter, which will allow the deployment of more complete measurement suites. The major drawbacks of the Twin Otter include a limited range (< 1000 km) and ceiling (5.5 km). These limitations will not pose serious problems for atmospheric research in the boundary layer and lower free troposphere, the regions of interest for the majority of ARL programs.

The 1994 Purchase.

The 1994 purchase of a previously-leased Twin Otter by NMFS and ERL will allow the deployment of the aircraft in FY 1995 for use in a variety of atmospheric research programs involving several ERL laboratories. Flux measurements and atmospheric chemistry studies are currently required for several broad-based programs supported by NOAA and other scientific organizations. Programs which require the use of the Twin Otter include the Atmosphere-Ocean Chemistry Experiment (AEROCE), and various programs of the North American Research Strategy on Tropospheric Ozone program (specifically during 1995, the Southern Oxidants Study). In addition, participation in BOREAS, GEWEX, and wake turbulence studies is anticipated. Other ERL laboratories which have expressed interest in the Twin Otter include the Environmental Technology Laboratory and the National Severe Storms Laboratory.

At the end of 1994, work started in earnest on modifying the aircraft for use as a flux platform (both eddy fluxes and PBL gradients). Some of the modifications (to the airframe, power, navigation systems, etc.) were performed by staff of the Navy Air Warfare Center (NAWC) in Warminster, PA. Most of the ARL effort was provided through the groups at Oak Ridge, Boulder, Silver Spring, and Idaho Falls.

ARL HIGH-LATITUDE STUDIES

BOREAS, and the Alaskan North Slope

Background.

There is considerable uncertainty about the way in which high-latitude ecosystems are described in numerical models. For example, it is not clear how much carbon dioxide is sequestered in Arctic ecosystems, or how much methane or nitrogen oxides emanate from them. Moreover, even the simplest considerations of surface energy budget become complicated for a frozen landscape, and especially so for seas with broken ice. ARL/ATDD has been engaged in two separate research programs addressing related issues, one funded by the NOAA Office of Global Programs and collaborative with NASA ("BOREAS," in northern Saskatchewan, Canada), and the other conducted with National Science Foundation and Department of Energy funding and cooperative with San Diego State University (on the Alaskan northern slopes).

BOREAS 1994.

ATDD provided continuous tower measurements of heat, moisture, and CO_2 fluxes from a 45 m tower in a Saskatchewan jack pine forest throughout the whole growing season. However, most 1994 activity took place in three intensive study periods — May/June, mid-July, and August/September.

A new global positioning system (GPS) ground station and software, purchased for the airborne flux system, was used for the first time in these intensive campaigns. It functioned exceptionally well; airplane position error appeared to be within ± 2 m; velocity accuracy was about ± 0.03 m s^{-1}.

During the second field campaign, a 100 mm rainfall event was followed by several weeks of warm dry weather. After the available surface water evaporated, high temperatures and high vapor pressure deficits forced stomata to restrict transpiration. Hence, most energy appeared as sensible heat. Net daily carbon fluxes were small and sometimes represented a loss from the ecosystem. The factors that limit daytime transpiration also restricted rates of carbon uptake by the forest.

The ATDD Long-EZ experimental aircraft concentrated on measuring fluxes over the boreal forest near Candle Lake, Saskatchewan during the second study period. Aircraft flux measurements provided a measure of the spatial distribution and areal average of air-surface exchange, and correlated well with the temporal statistics from the tower measurements. The Long-EZ was one of four airplanes measuring fluxes at this time. Its flight altitude was the lowest of the four and it is expected to have sampled fluxes well within the region where surface heterogeneity still has strong influence. The forest was very patchy, with stands of trees alternating with fens, barrens, cut and burned areas, and lakes, all on kilometer scales or less.

During the third period, heat, moisture, and CO_2 flux data were once again collected from the tower, in and above a stand of old jack pine, and at 25 - 30 m above ground using the aircraft.

The ATDD Long-EZ was the only aircraft to participate in all of the BOREAS field campaigns. Early analyses of the airborne data set are very encouraging. When viewed together with the tower data, it is clear that there are substantial differences between the partitioning of energy of a boreal jack pine stand and that of a temperate deciduous forest. Most of the incident solar energy absorbed by the temperate forest is converted to latent heat; most net radiation over the boreal jack pine stand becomes sensible heat. (On first principles, this is as must be expected, since the ratio of sensible to latent heat flux is doubtlessly a strong negative function of temperature.) These differences in energy partitioning impact the rate of growth of the PBL.

Huge differences in CO_2 exchange rates were also found. Greater uptake was observed over the temperate forest, because its more benign climate and greater nutrients and moisture availability permit more rapid photosynthesis.

A BOREAS Data Workshop in Williamsburg, VA, 14-16 December, was the first opportunity for BOREAS participants from all disciplines to present preliminary analyses from summer 1994, and to consider the emerging picture of carbon exchange between the atmosphere and the Boreal Forest. Winter net CO_2 flux is upward, increasing in the spring until leaves appear. Net daytime growing season exchange is only a small difference between photosynthesis and respiration, in contrast to lower latitudes, where photosynthesis dominates. Latent heat flux was unexpectedly low, relative to sensible heat flux, producing deeper mixed layers and lower rainfall than models predict.

The most notable feature of the aircraft transects was the repeatability of the measurements. Using averaging lengths as short as one kilometer, the Bowen ratio was virtually identical during three days in July, and agreed with tower-based flux measurements. Figure 1 illustrates the heat flux data obtained.

There were also several aircraft intercomparison runs, in which pairs of flux-measuring airplanes flew in close formation during the 1994 summer campaigns. The ATDD Long-EZ flew primarily with the National Research Council (Canada) Twin Otter, although some runs were flown with the considerably faster University of Wyoming King Air. Comparison with the NCAR Electra was impossible because of the disparity of flight speeds.

***North Slope (Alaska) Flux Studies*.**

This work focuses on the ways in which north slope ecosystems serve as sources or sinks for a variety of air chemicals known to affect global climate change, such as carbon dioxide, methane, and most importantly water vapor. The work is collaborative with San Diego State University; ARL is involved because of its unique capability to measure the rates of exchange of carbon dioxide and water between the air and the surface.

From the local perspective, the work is designed to provide information on how the ground and the atmosphere interact, so that future industrial activities in the region can be organized and implemented to have minimal adverse environmental consequences. From the global perspective, the work is intended to refine the way in which the high-latitude terrestrial biosphere is described in models as a sink for atmospheric carbon dioxide.

A preliminary study was conducted in 1993. San Diego State University conducted tower-based flux studies, and the ARL/ATDD Mobile Flux Platform (MFP) provided path-averaged airborne fluxes, and an indication of their variability, using the Long-EZ test aircraft. In a subsequent experiment, in 1994, the Long-EZ also carried a downward-looking four-channel radiometer. The four channels were set to mimic satellite thematic mapper bands; it was intended to use the data collected to calibrate satellite techniques that use thematic imager observations. A high-performance video camera was also fitted, to assist image-processing.

The aircraft flew along a north-south transect starting over the ocean and extending to about 100 km inland. Exceedingly complex meteorological and flux conditions were encountered. Over the ice-covered Arctic Ocean, the sensible and latent heat fluxes and CO_2 flux were all very small. The influence of the ice surface on radiation and on the temperature of the air and surface was found to be dramatic. Inland from the coast, the air was observed to warm rapidly as more of the net radiation was partitioned into sensible and latent heat, rather than being stored in the soil. Further south but still within the coastal flood plain, mean ambient CO_2 concentrations were found to increase sharply, presumably because of numerous oil-field flares. These flares complicated CO_2 exchange rate computations, however, the data indicated increased CO_2 uptake by the underlying surface, as would be expected along the biologically more productive coastal flood plain. Further inland, CO_2 fluxes continued to indicate surface uptake, but not as rapidly as in the coastal regions. The effects of patchy clouds and numerous lakes became apparent in the increased variability of surface temperature and solar radiation along the transect (from north to south). Although the sensible and latent heat fluxes were quite variable, they correlated well with the available net radiation.

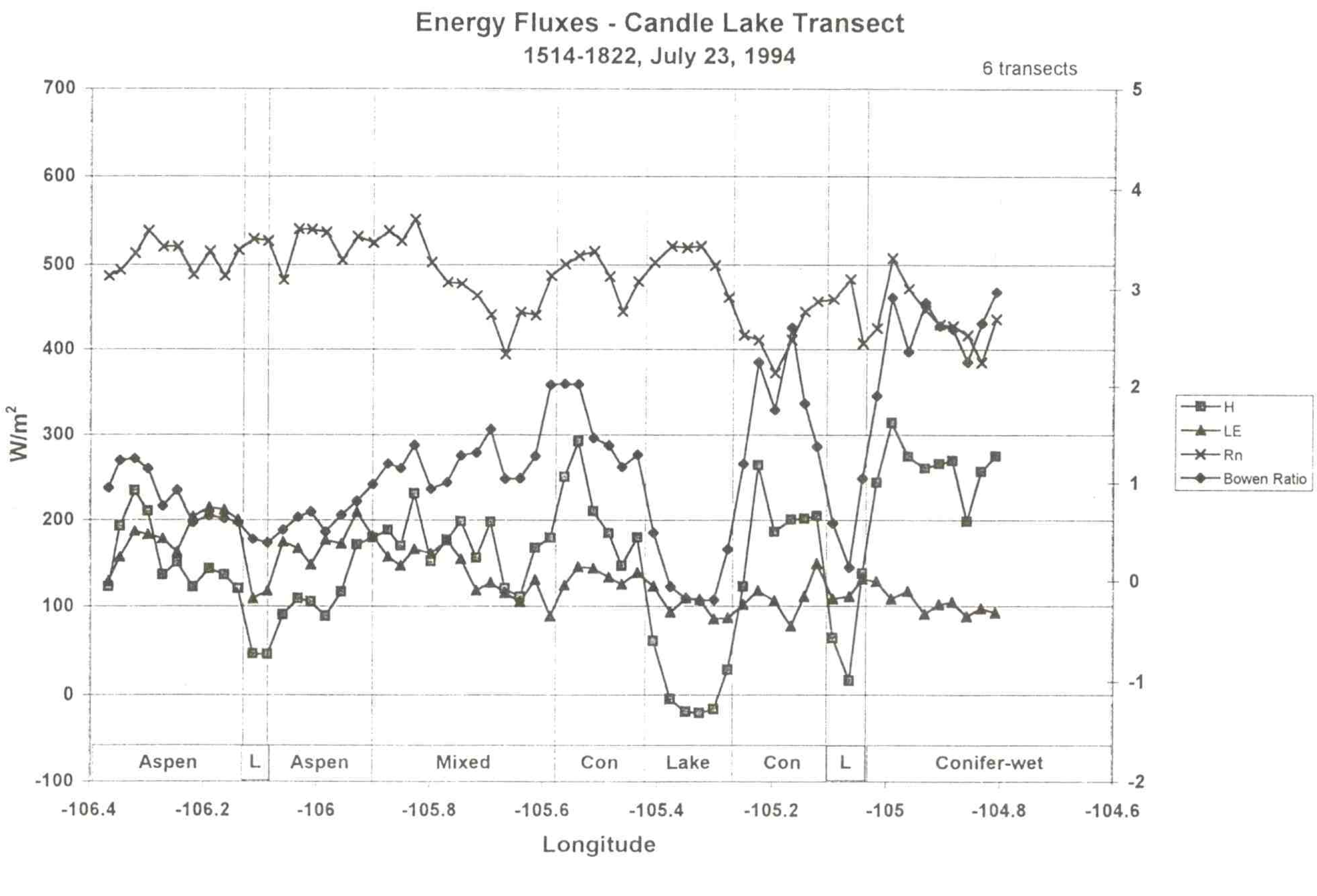


Figure 1. Heat fluxes (and Bowen ratio) from a BOREAS transect on July 23, 1994. From the left, the distinct areas are Aspen forest, a small lake, Aspen, mixed forest, coniferous forest, a lake, coniferous forest, another lake, and more coniferous forest.

AIR-SURFACE EXCHANGE

Heat, Momentum, Water, and CO_2 Transfer at the Earth Surface

Background.

ARL conducts basic research on methods for predicting and measuring exchange of meteorological quantities (heat, moisture, and momentum) as well as of trace gases and particles (e.g. ozone, carbon dioxide, sulfur and nitrogen oxides, base cations, nutrients, and radioactive and toxic chemicals) between the atmosphere and various surfaces. The study of trace gas and particle deposition is addressed elsewhere in this document (see "AIRMoN-Dry"). In general, however, the trace gas and particle question is not limited to deposition, but also involves emission and resuspension.

Presently, ARL focuses its attention on the development of systems for measuring fluxes at specific locations, and the extension of local measurements and understanding to describe areal average exchange in numerical models.

Tower Studies.

Two portable eddy flux systems have been developed, each providing a new tower capability to monitor all eddy fluxes for which appropriate sensors are available. It is standard operating procedure to measure routinely the momentum, sensible and latent heat, and carbon dioxide fluxes in all applications of these new systems.

At Oak Ridge, and as part of a continuing effort to improve and streamline flux measurement systems, a tower-based eddy correlation system powered by a 12 volt battery with solar panel (and/or wind generator) recharging was deployed in a local test program and subsequently installed for extensive testing at the Walker Branch Watershed. The system is specifically designed to provide uninterrupted monitoring of momentum, heat, water vapor, and carbon fluxes.

At Research Triangle Park, and in cooperation with Oak Ridge, a separate portable flux-measuring system was developed, this time designed for direct measurement of trace gas fluxes. This system is also described elsewhere (see AIRMoN-Dry). The system provides for direct eddy correlation measurements of sulfur dioxide, ozone, and carbon dioxide fluxes, and of nitric acid by filter pack gradient analysis, as well as the important components of the surface energy budget. The system was tested in field programs at Beaufort, NC, and at Bondville, IL.

Also at Research Triangle Park, planning started on a project to obtain a better understanding of nitrogen oxide (NO_x) emissions from soils (through a cooperative agreement with the NC State University). Estimates of these emissions are needed for models like the Regional Oxidant Model (ROM) and the Regional Acid Deposition Model (RADM). Nitric oxide emissions are thought to arise from microbial activity, which is enhanced when nitrogen-based fertilizer is applied. A planning workshop for a pilot experiment was held in Raleigh during March 1994. Representatives from NASA, Argonne National Laboratory, University of Maryland, ARL-Oak Ridge, and ARL-Silver Spring participated. The study was tentatively planned for May 1995 on a farm in eastern North Carolina.

In-Canopy Studies.

During 1994, flux monitoring activities expanded at the Walker Branch Watershed

(WBW) in Oak Ridge, with a new emphasis on distinguishing between the flux contributions of the forest floor and the trees themselves. Two eddy-correlation measurement systems continuously measured energy and CO_2 exchange both at the forest floor and above the canopy, to evaluate the separate (ground and in-canopy) sources of latent heat and CO_2. Experience gained in this effort will be important for anticipated surface-layer model testing and evaluation studies (under NOAA/GEWEX/GCIP). Computers at the field site are now linked in a network, which will be used to retrieve data daily from the flux systems and from standard meteorological arrays, to facilitate quality control and data processing.

The Mobile Flux Platform, and GPS.

A major ARL development has been that of the Mobile Flux Platform (MFP), a system that corrects velocity records for the effects of using a sampling platform that is not rigidly fixed to the earth's surface. During 1994, the use of new Global Positioning System (GPS) technology was evaluated, and the newest available GPS systems were adopted. The MFP GPS systems were upgraded, and a post-processing software from the University of Calgary was implemented to allow GPS Doppler velocities to be corrected to ± 2 cm/s (while flying on an aircraft at 50 m/s). Before this modification, platform velocity accuracy was limited to about ± 20 cm/s. No other airborne systems are known that have a position accuracy of ± 3 m, angular accuracy of ± 1 milliradian, and velocity accuracy of ± 2 cm/s.

Large-Area Exchange.

The Oak Ridge group deployed both tower and aircraft eddy correlation systems during a 1971 study of areal fluxes over a heterogenous but flat surface at Boardman, Oregon (as part of the DOE ARM program). The site was a farm, using mechanical systems to irrigate 800 m diameter circles. Analysis of tower eddy correlation fluxes of heat and moisture continued through 1994. Differences in the fluxes among alfalfa, corn, and wheat crops were found to be significant. During daytime conditions, transpiration rates differed by 20% to 50%.

Measurements of momentum, heat, and moisture fluxes from the ATDD Long-EZ research airplane were analyzed to quantify spatial variabilities in the fluxes. Fluxes from an 800 m crop circle were compared to average fluxes from transects across the whole farm. On average, a 50 to 100 W/m^2 difference from field to field has been found during daytime hours. A similar assessment has been planned for the ARM Southern Great Plains (Oklahoma) CART site using modeled sensible and latent heat fluxes. The model will be tested with measurements recently obtained from the Oklahoma site.

Carbon Dioxide.

Continuous eddy correlation measurement of CO_2 flux over the Walker Branch (Oak Ridge) forest continued through 1994, along with associated data analysis and model calculations. For the full year, the net carbon exchange was 945 g m^{-2}. This is about three times the value measured by others over the older and more northern Harvard forest.

The eddy flux measurement of CO_2 exchange is now a mature technology. ATDD organized (collaboratively with the University of Tuscia, Italy) an international workshop on Strategies for Monitoring CO_2 Fluxes over Terrestrial Ecosystems. The workshop was conducted in December, 1994, in Italy. The goal was to take a first step towards establishing a global network that can directly address the issue of the "missing sink" in the global carbon balance.

THE ATMOSPHERIC INTEGRATED RESEARCH MONITORING NETWORK (AIRMoN)

A Research Monitoring Array for Early Detection and Deposition

Background.

The Atmospheric Integrated Research Monitoring Network is an array of stations designed specifically to detect the benefits of emissions controls mandated by the Clean Air Act Amendments of 1990, and to quantify these benefits in terms of deposition to sensitive areas. AIRMoN combines two previously-existing deposition research networks that have appropriate characteristics (previously known as the MAP3S precipitation chemistry network and the CORE/satellite dry deposition inferential method network) under a single operational umbrella, so as to provide a new monitoring activity to which on-line modeling and analysis can be easily applied. An additional air-sampling component of AIRMoN is anticipated, to augment the sampling already taking place under the dry deposition activity and to provide additional rapid-detection capabilities.

The techniques of AIRMoN are specifically designed to quantify the extent to which changes in emissions affect air quality and deposition at selected locations. A small array (about 20 to 30) such locations are presently intended for attention of this kind. These locations will be chosen to optimize the probability for detecting the change that is sought, and to serve related needs of effects researchers. Specific sites are (and will be) emphasized, where operations of different observing arrays can be collocated. Such Collocated Operational Research Establishments ("CORE sites") will serve two additional distinct purposes: (a) to provide linkages among network programs operating to address different needs with different protocols and (b) to provide the detailed measurements necessary to understand important processes.

Early Detection.

The specific goals of the AIRMoN rapid detection monitoring program are

— *to provide regular, timely reports on the atmospheric environment consequences of emission reductions, as imposed under the Clean Air Act Amendments,*

— *to extend these observations to wet and dry deposition rates that affect sensitive ecosystems, and*

— *to provide a direct linkage between the monitoring and modeling communities that are involved.*

The overall design target for AIRMoN is to detect, with 95% confidence, the atmospheric concentration and deposition consequences of a 5% reduction in emissions, over a two-year period.

As currently planned, AIRMoN will be made up of 20 to 30 measurement sites in total. These sites will be arranged in three subnetworks. The wet deposition component (AIRMoN-wet) already exists in preliminary form, with 7 sites currently operating; eventually, it is planned to contain about 20 sites. The dry deposition component (AIRMoN-dry) is planned to be of similar size, although with as many as possible of its sites collocated with AIRMoN-wet. There are presently 13 such sites.

A smaller array of air chemistry observatories (approximately five such stations; AIRMoN-air) will provide the detailed chemical data required by some specific rapid detection techniques.

AIRMoN is intended to provide data needed by several alternative methodologies for providing the rapid detection characteristics that are sought. These techniques are described in detail in the following summary; a combination of cluster analysis and prediction differencing methods will probably be used.

Status.

AIRMoN has been endorsed, in principle, by both the National Acid Precipitation Assessment Program (NAPAP) and NOAA. To get started on the endeavor, the daily-sampling precipitation chemistry research program, previously operated under the auspices of the Department of Energy was transferred to NOAA (the MAP3S program). Plans for AIRMoN were endorsed during 1992 by NOAA and by the Department of Commerce, and were accepted by OMB as an important contribution to NAPAP and to the debate about the consequences of the Clean Air Act Amendments controls. The activity was subsumed into a funding package now well recognized — NOAA's "Health of the Atmosphere" initiative.

The overall philosophies of the AIRMoN network have been enthusiastically received elsewhere. In particular, a trial application of the general principles is now being planned for Central and Eastern Europe, where monitoring programs are currently in some disarray.

AIRMoN -- Wet.

Field sampling continued without interruption at the seven AIRMoN-wet daily sampling sites during 1994. At the National Atmospheric Deposition Program Technical Committee Meeting (October 24-27) final decisions were made regarding the AIRMoN-wet quality assurance plan and site operator protocols. The basic philosophy remained unaffected by these negotiations with other networks: report all of the data as fast as possible, give them to anyone who wants them in an electronic format, and attach a simple screening code to allow the user to avoid relevant contamination problems.

AIRMoN -- Dry.

Interest, both national and international, continues in the NOAA Inferential Method, initially developed under NAPAP auspices for estimating dry deposition fluxes from simple field measurements. Several foreign networks are contemplating adopting the AIRMoN approach, specifically South Africa, Spain, and a number of central and eastern European countries (as mentioned above).

Improved estimates of dry deposition rates for AIRMON-dry sites were generated during 1994. The network is arranged so that flux estimates obtained throughout the entire program can be periodically refined as more is learned about the ways in which airborne pollutants are deposited.

Existing dry deposition algorithms for gaseous pollutants were examined, with prime attention to O_3, SO_2, and HNO_3. Sensitivity tests showed that models were most sensitive to land-use type and time of day. Accordingly, the data sets were stratified based on these classifications for use in the future evaluations.

AIRMoN-Wet

A Nested Array of Daily and Weekly Sampling

Background.

The longest U.S. network record of precipitation chemistry in the modern era is that which started as the Department of Energy's Multistate Atmospheric Power Production Pollution Study (MAP3S) in 1976. With the end of the acid deposition decade, and with the cessation of a formal research program under the National Acid Precipitation Assessment Program, the MAP3S network was terminated by DOE and was eventually transferred to NOAA where it remains a program of ARL, constituting one tier of the AIRMoN-Wet program.

The major wet deposition network of the U.S. is the National Atmospheric Deposition Program (NADP), a large array of about 200 stations that collect weekly samples of precipitation and have the chemical analysis performed at a single central laboratory. The weekly samples have two severe drawbacks: their chemistry can be affected by biological activity in samples that sit in the field for several days before collection, and their week-long averaging means that several rainfall events can be combined into a single sample. Both of these drawbacks are important considerations for NOAA. The first means that accurate quantification of ammonium and nitrate ion deposition is not possible; the AIRMoN wet approach is to collect daily samples and to keep them chilled so as to minimize biological activity between collection and analysis. The second complicates any interpretation or analysis that involves a coupling with meteorology. In order to relate specific deposition events to specific source areas, source-receptor calculations require daily (or shorter) time resolution of the samples. ARL also operates a small array of weekly sampling sites, as a contribution to the NADP. The accompanying figure shows the AIRMoN-Wet array.

Routine aspects of the AIRMoN program continued throughout 1994. The AIRMoN field program continued uninterruptedly, with samples collected on a routine daily basis at all seven stations. Analysis by the same central laboratory as services NADP is now routine. As many quality assurance steps as possible are shared between the two arrays, but clearly the demand for nitrogen species integrity imposes more stringent requirements on sample-handling for AIRMoN, and the onorous collection protocols encourages rapid automation of many of the data gathering chores.

AIRMoN -- NADP Interactions.

The NADP sampling program is receptor-oriented; it is based on requirements by ecologists, agriculturists, foresters, etc., to quantify the input of chemicals from the atmosphere to potentially sensitive areas. For such biologically-oriented purposes, weekly sampling is quite adequate. The daily sampling of AIRMoN, as required to meet the unique purposes of ARL, is frequently an item of some contention in the NADP community. During 1994, special effort was made to explain the ARL interests and data needs to the NADP community. The effort was largely successful. A measure of the success is that AIRMoN-Wet is now accepted as a formal sub-program of NADP.

Use for "Early Detection."

The requirement for daily sampling in order to meet the demands of "early detection" analyses was also explained at the NADP Technical Committee meeting. An analysis was presented that shows a comparison of some of the methods proposed under the AIRMoN rapid detection program (see separate documentation here) to detect cleaner air due to mandated emissions reductions at selected locations before it is detectable by the larger array of weekly-sampling stations. Examples were shown of receptor based methods, such as computation of back trajectories in combination with cluster analysis and gridded tabulations of trajectory frequencies. Two source-based methods were illustrated. One was a matrix approach showing all combinations of sources contributing to all potential receptors, while the second aggregated all the sources together, and in combination with a chemical model, made actual predictions of deposition at each sampling location. These techniques, either individually, or in combination, will be used to segregate the sampling data into smaller subsets that have less variability. Downward trends in these subsets should be easier to confirm and attribute only to the reductions in emissions.

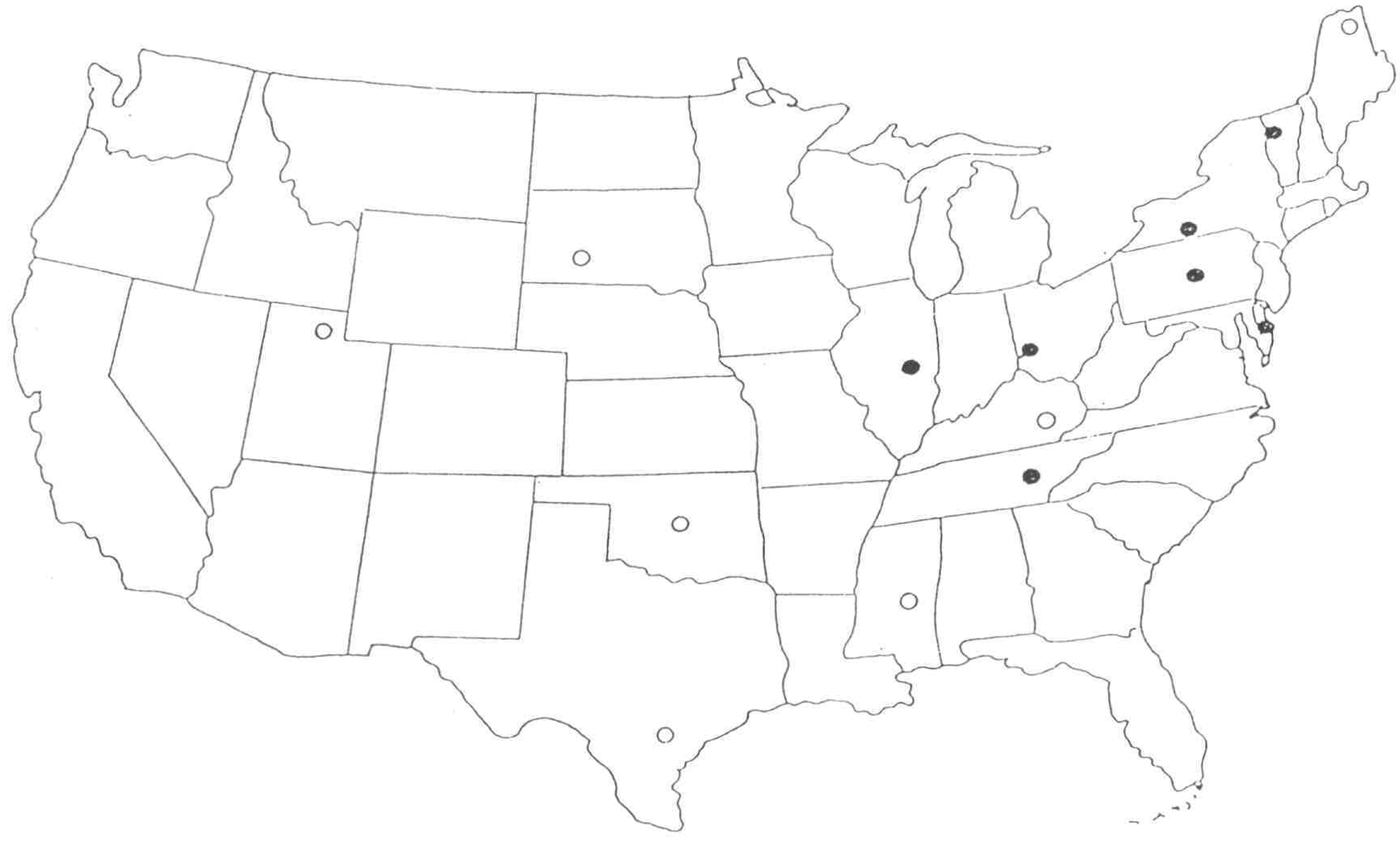


Figure 1. The AIRMoN-Wet array, showing both daily (solid) and weekly (open) sampling sites. The daily sites are the continuation of six sites of the MAP3S precipitation chemistry network previously sponsored by the DOE, plus an additional site near Burlington, Vermont.

AIRMoN-Dry

Network Investigations of Dry Deposition

Background.

ARL is a leader in the development and operation of dry deposition networks. Since 1984, the Atmospheric Turbulence and Diffusion Division in Oak Ridge has been operating a network specifically designed to get around the major problem confronting dry deposition monitoring activities -- there is no existing method suitable for routine direct measurement. The nested network that was developed consisted of a small number of research sites supporting a larger array of stations making simpler but more routine observations. The Dry Deposition Inferential Method (DDIM) that was developed remains the central routine analytical tool of the ongoing NOAA dry deposition trial network, now identified as the dry deposition component of the Atmospheric Integrated Research Monitoring Network (AIRMoN). This network started with six sites; thirteen stations are now operating (as shown in the accompanying figure).

The Atmospheric Sciences Modeling Division in Research Triangle Park plays a central role in the operation of the EPA Clean Air Status and Trends Network (CASTNET), which is the present-day continuation of the EPA National Dry Deposition Network initiated under the National Acid Precipitation Assessment Program. The same inferential methodology mentioned above is the underpinning of the CASTNET dry deposition program. The EPA and the NOAA activities are wholly collaborative: both operations are structured to apply new understanding as rapidly as possible, and to quantify the uncertainty associated with the indirect (inferential) estimates that the routine monitoring networks produce. In simple concept, the Collocated Operational Research Establishments ("CORE" stations) of AIRMoN-Dry provide a continuing infrastructure for exploratory research. The much larger CASTNET array of the EPA is the routine network in which the results are applied. The tier of simpler stations of the NOAA AIRMoN-Dry array serves as a transition, testing the transferability from the research environment to routine application.

The Dry Deposition Inferential Method.

Interest, both national and international, continues in the NOAA Inferential Method, initially developed under NAPAP auspices for estimation of dry deposition fluxes. Requests have been received for details of the technique and for the latest version of the inferential model for dry deposition velocity from the U.S. Forest Service, from a NOAA group designing a collaborative study of deposition in Central Europe, and from a South African electric utility.

During 1994, a new multi-layered model was adapted for dry deposition inferential application, replacing the initial "big leaf model" that had its origins in agricultural meteorology. The new model provides a greatly improved capability to simulate the effects of several natural variables known to be important in the dry deposition context. However, some tests comparing the two models indicated little improvement while the newer model was in its early stages of development (for example, results obtained in Europe as part of the EUROTRAC program).

Research Activities.

The major goal of dry deposition research conducted under the AIRMoN-Dry program relates to the need to identify and understand the processes that cause dry deposition, in order to quantify dry deposition rates at locations where direct measurement is not possible. ARL presently focuses its attention on

- the development of systems for quantifying dry deposition,

- the measurement of dry deposition using micrometeorological methods,

- the development of techniques for assessing air-surface exchange in areas (such as specific watersheds) where intensive studies are not feasible, and

- the extension of local measurements and understanding to describe areal average exchange in numerical models.

Improved estimates of dry deposition rates for sites in the NOAA AIRMON-Dry network were generated.

Testing of DDIM Predictions.

The ARL team at Research Triangle Park, working with colleagues at Oak Ridge, developed a movable system for direct measurement of dry deposition fluxes. A first test of this system was conducted near Beaufort, NC. The system provides direct eddy correlation measurements of sulfur dioxide, ozone, and carbon dioxide fluxes, and gradient measurement of nitric acid flux. The system also measures the surface energy budget. The system was subsequently deployed at the Bondville CASTNET (and also AIRMoN and ISIS) site in Illinois. Deployment at other sites will occur during 1995. In essence, the flux data obtained will be used to assess uncertainty and to improve the inferential dry deposition models being widely used in analysis and modeling of dry deposition.

The ASMD team also conducted an evaluation of existing dry deposition algorithms for gaseous pollutants to identify an algorithm for implementation into the ISC-COMPDEP (Industrial Source Complex - COMPlex terrain DEPosition) model. Model predictions were compared against O_3, SO_2, and HNO_3 field data sets. Sensitivity tests showed that the models were most sensitive to land-use type and time of day (day/night), so the data sets were stratified based on these classifications for use in the evaluation.

Figure 1. The sites of AIRMoN-Dry, showing CORE (solid) and satellite (open) locations.

AIRMoN & EARLY DETECTION

Detecting the Benefits of Emissions Reductions

Background.

The Clean Air Act Amendments of 1990 impose the need to monitor the benefits of the mandated emissions reductions. At the same time, a phased implementation of new controls is imposed, together with a new emissions trading approach that complicates the normal process of benefit assessment through model development of different scenarios. The Early Detection component of the NOAA Health of the Atmosphere program is designed to detect the benefits of emissions reductions rapidly enough to guide revisions of the Act or of the way in which it is interpreted.

Classical monitoring programs are designed to monitor the current status of key components of the environment, and to detect trends in them. There is no inherent capability to relate observed changes to any specific cause, possibly not associated with changes in emissions. In practice, observed changes in concentration or in deposition may result from many causes. To detect those changes that can be attributed to emissions reductions requires new methods for coupling monitoring with analytical interpretative programs.

Variations in air quality and deposition are primarily due to meteorological, chemical, and emissions factors, all varying on diurnal, seasonal, annual, and decadal time scales. If the variance due to factors other than emissions reductions can be reduced, then the otherwise masked signal attributable to the emissions changes themselves will be left more apparent.

Lagrangian Interpretative Methods.

(a) Receptor orientation. Receptor-oriented approaches use trajectories, without considering dispersion, to define the upwind advection path from the measurement point. (Note that dispersion is not reversible.) Cluster analysis is a fairly common method applied to data from a single station (single site sectorial sampling). This method is comparatively simple and yields quick results. Cluster analysis is primarily a spatial analysis applied to a given data set, receptor by receptor. To extend this approach to an array of stations, a gridded tabulation method has been developed. Although more applicable to a network situation, this approach is not readily applicable to time series measurements.

(b) Source orientation. The effects of dispersion and atmospheric chemistry (non-linear as well as linear) can be taken into account when the methodology targets specific sources, from which pollutants are assumed to be emitted. Source-receptor matrices can be developed, using calculations performed from all source regions to all receptors. The technique offers considerable advantage: daily fractional contributions due to different sources are computed, and detailed chemical reactions are taken into account. However, the method involves management of very large data files. Differences between predictions and observations can also form the basis for analysis. This prediction differencing approach can be used to compute trends in residuals between measurements and calculations, from which the consequences of changes in emissions can be made more obvious. This method permits sequential reductions in the residual (unexplained) variance, but does not easily associate a specific receptor with a particular source.

Receptor Modeling.

Emissions from different sources carry chemical signatures that can be used to apportion observed pollution concentrations among sources that have been appropriately "fingerprinted." The specialized receptor models that result rely on trace metals carried by particles to identify smelter emissions, carbon monoxide to identify nearby automotive sources, etc. In practice, sources of special interest are identified, and emission signatures are determined by source-specific sampling programs. Statistical methods are then used to attribute as much as is possible of the variance in observed concentration data to these sources. The method has the advantage of bypassing the need for meteorological data. It has the disadvantage of requiring that all of the chemicals of relevance are affected in the same way by all of the processes involved in transport and dispersion; this is especially contentious when clouds are present or when precipitation occurs.

Recent Results.

Tests of the source-receptor matrix approach have resulted in the development of a specialized program for displaying the distribution of normalized concentration or deposition from a selected source region (source orientation) or the contributions from source regions to a selected receptor (receptor orientation). This kind of display can be used to determine which source regions have the greatest impact on a receptor. It should be noted that the highest contributions will nearly always be from the nearest sources, so that a "receptor oriented" map will look very similar to a "source-oriented" map, however the interpretation is quite different.

Tests of the matrix computational method have also been conducted, using a similar computer simulation. One problem with the simple matrix approach is that it is not always possible to combine sources linearly to obtain the total contribution at a receptor. In that case it is necessary to run the full emissions with an iterative scheme accounting for critical chemical reactions.

Trajectory clustering has also been evaluated. Grouping of trajectories into common spatial clusters is a method to classify different meteorological situations associated with pollutant transport from different source regions. Deposition samples collected at a selected AIRMoN site for the entire year of 1993 were examined in relation to the number of different meteorological clusters that were identified. For this initial data set, sample duration was typically one day, but some samples represent longer periods. This would complicate the apportionment of samples among distinct meteorological situations.

Prediction differencing involves the assumption of an appropriate emissions inventory; the model then calculates the daily deposition amount by grid node over the entire domain. Values are then interpolated to individual AIRMoN sites. When applied to observations at a selected AIRMoN site, the modeled distribution was found to compare favorably to the measurements. This enhances the confidence with which the new Early Detection program is being embraced.

In summary, tests conducted so far indicate that there is profit in combining the techniques mentioned above, for example by using cluster methods to identify sites and days appropriate for prediction differencing. The tests also indicate that improvements in the prediction of precipitation will be required to reduce variability even further.

COASTAL ECOSYSTEM ATMOSPHERIC LOADINGS

Measuring the Input of Nitrogen to Sensitive Areas

Background.

ARL has long-standing expertise in measuring the deposition of trace chemical constituents of the atmosphere to sensitive areas, both by wet deposition and by dry. Recent recognition that this atmospheric deposition can be an important contributor to eutrophication has elevated atmospheric deposition to a new level of interest, amplified by the realization that the atmospheric input is rarely taken into account in the models currently used to guide the policy process. Initial estimates for the Chesapeake Bay indicate that about 30% to 40% of the nitrogen loading is derived from the atmosphere.

ARL is currently developing methods for quantifying atmospheric deposition to coastal ecosystems, with emphasis on nutrients and toxics. Current research is directed specifically to the roles of nitrates and airborne toxic chemicals. ARL is focussing initially on East Coast ecosystems — mainly the Chesapeake Bay but with some attention to the Albermarle/PamlicoSound. State-of-the-art models are being developed by ARL (Research Triangle Park), and advanced measurement systems are being deployed by ARL (Oak Ridge and Silver Spring).

ARL co-chairs the Chesapeake Bay Air Quality Coordination Group, an officially-endorsed body for consolidating and coordinating activities among federal and state agencies. A highlight of this Group's activities in 1994 was a specialist workshop conducted at Mt. Washington, Maryland, to construct an ordered list of projects designed specifically to reduce the uncertainty surrounding current estimates of atmospheric deposition in coastal areas.

Monitoring Activities.

In the past, monitoring of deposition in coastal areas has been largely avoided, because of the well-recognized difficulties associated with the influence of airborne sea-salt. In a conscious attempt to learn more about how to measure coastal atmospheric deposition, ARL now operates several exploratory monitoring stations in coastal areas. Techniques are being developed to account for the roles of terrain complexity in the models used to interpolate among monitoring sites and in the simulations used to assess likely inputs in the absence of field data. In particular, techniques to account for moderate terrain complexity have been developed and are now being included in assessment models. As yet, there has been no opportunity to test the predictions of these models against field data, however steps to provide a platform suitable for collecting such data have been initiated.

Studies so far have concentrated on nitrogen compounds, these being key contributors to the process leading to eutrophication. Most atmospheric nitrogen compounds (excluding N_2 and N_2O, which are inert in the lower atmosphere) fall into two categories: reactive nitrogen, sometimes referred to as oxides of nitrogen or "odd nitrogen," and reduced nitrogen (typically dominated by ammonia, NH_3). Some organic nitrogen species arise in the atmosphere from the interactions involving nitrogen oxides and biogenic or anthropogenic hydrocarbons, and are thus typically referred to as a subset of reactive nitrogen.

For purposes of this discussion, the term "organic nitrogen" will refer exclusively to biogenically derived nitrogen compounds such as amines and amino acids, and will be discussed separately.

The relative abundances in air of the different forms of nitrogen — NO, NO_2, HNO_3, particulate nitrate, NH_3, organic nitrogen — vary widely based on proximity to sources and on the prevailing conditions. However, current estimates indicate that reactive nitrogen is the largest contributor to atmospheric nitrogen loads to coastal waters (40% to 60%), with ammonia (20% to 40%) and organic nitrogen (0 to 40%) also contributing significant amounts.

When considering total atmospheric deposition of nitrogen to a given watershed, the largest uncertainties are associated with the ability to estimate the spatial distribution of dry deposition. Because of its chaotic nature, wet deposition behaves ergotically - wet deposition at one site is much the same as at a neighboring site provided the averaging time is long enough. This fact allows meaningful areal isopleth maps of wet deposition and nitrogen chemistry to be constructed. However, this is not the case with dry deposition. The mechanisms that control air-surface exchange are tied to biological and surface factors that are highly variable in space.

Enough is known about the processes that control dry deposition to permit a landscape to be considered on a point-by-point basis. Results from such investigations illustrate that time-averaging does not smooth dry deposition patterns. In fact, time-averaging helps reveal differences between neighboring locations. Thus, it is not possible to extract meaningful site-specific dry deposition data from large-area, time-averaged information without consideration of the site in question. The problems with dry deposition are magnified by the fact that for nitrogen species only an inferential measurement technique is suitable for long term, continuous monitoring. Thus, most spatial estimation of dry deposition has relied heavily on a modeling approach (see the accompanying summary). Even the detailed, site-specific models developed to infer dry deposition rates from on-site field observations are limited in their ability. Comparative measurement/modeling studies have shown that these models are inconsistent in their performance. The reasons for the inadequacies are associated with surface characteristics (cuticular chemistry, leaf wetness, water stress, etc.) that are hard to quantify. These issues are not new, and they have been the subject of considerable debate. Although important advances have been made, a universally acceptable spatial model is still far distant.

Other Waterbodies.

The relative contribution of atmospheric nitrogen deposition to new nitrogen inputs to estuarine, coastal, and offshore waters around the world ranges from less than 10% up to 70%. Studies of other major East Coast estuaries have provided atmospheric nitrogen loading estimates that range between 18% and 39% of the total nitrogen load. The uncertainties of these studies make it imperative to obtain a better understanding of the processes that transport and deposit nitrogen to estuaries and coastal zones.

Future Analyses.

In an effort to coordinate scientific programs to reduce existing uncertainties in atmospheric loadings estimates, the Chesapeake Bay Program's Air Quality Coordination Group (with ARL as co-chair, shared with the State of Maryland) conducted a meeting of active scientists from different contributing disciplines was conducted at Mt. Washington, Maryland, on 29/30 June 1994. The challenge given to the workshop was simple — to construct a prioritized listing of practical studies that would make the greatest impact on reducing the current uncertainty in estimates of the contribution of atmospheric deposition to declining aquatic ecosystem health.

The listing that resulted is summarized below (extracted from the CBP report "Atmospheric Loadings to Coastal Areas: Resolving Existing Uncertainties"). It was concluded that ongoing scientific investigations are making considerable progress; in essence, any new efforts should build on existing programs rather than risk new starts that compete with them.

The emphasis of the workshop was on all of nitrogen species, toxic chemicals, trace metals, precipitation chemistry, airborne aerosols, and supporting meteorological investigation. In every one of these cases, the general call for a new focus applies, although with different weights according to the particular emphasis. The following prioritized list was developed.

1 -- Conduct intensive, coordinated integrated monitoring at special locations within the watershed, with wet deposition, dry deposition, and local catchment area characterizations. It was concluded that the single most limiting factor in assessing the adequacy of current models is the lack of high quality data on actual deposition within the target watershed.

2 -- Work to improve existing atmospheric models. In brief, there are many limitations of current models, especially including their limited grid size (smaller grid cells are desired) and their inability to handle important orographic and chemical factors.

The above top priorities reflect the recognition that current models are likely to be misleading, but that the extent of any errors cannot be judged because direct observations of deposition are not yet made.

3 -- Improve biogeochemical watershed models. The workshop recognized the important role of watershed chemical retention.

4 -- Improve emissions inventories and projections. Assessments of atmospheric deposition are necessarily at the mercy of emissions estimates; related estimates are currently highly imperfect.

5 -- Extend the vertical and spatial meteorological and chemical concentration coverage. Assessment models of today need more advanced input data than the simpler models used in early assessments. As the new models evolve further, input data requirements will increase even further.

6 -- Implement an extensive array of less intensive measurements. This item follows on from Priority 1. In essence, a nested network is envisioned, with a small number of intensive stations supporting a denser array of simple stations designed to provide improved spatial resolution for some selected variables.

NITROGEN DEPOSITION TO THE CHESAPEAKE BAY

Identifying the Airshed using RADM

Background.

Eutrophication of Chesapeake Bay has led to anoxia at the bottom and major loss of biological productivity. Eutrophication is driven by both phosphorous, P, and Nitrogen, N. However, for the main Bay and the deep trench (the saline portions of the Bay), water quality models and data analyses indicate that reduction in nitrogen loading is the best way to reduce anoxia. Thus, nitrogen is the driving pollutant for eutrophication in Chesapeake Bay.

Nitrogen input from the atmosphere represents a significant source of nitrogen to the Bay (25-35%) of the nitrogen loading. Control of nitrogen oxide air emissions should be beneficial for air (oxidants), aquatic (acid deposition), and estuarine (eutrophication) systems. Water quality models have incorporated atmospheric nitrogen, but in a very simple manner.

Estimating N Deposition.

A major objective of the RADM modeling activity is to improve current estimates of nitrogen loading from the atmosphere to the Chesapeake Bay watershed and the Bay itself. These estimates will be provided as inputs to the water quality models for the watershed (the HSPF model adapted by the Chesapeake Bay Program Office) and the Bay (the 3-D Bay Water Quality model developed by the Army Corps of Engineers).

Another objective is to determine the airshed that is primarily responsible for the atmospheric nitrogen affecting the Bay watershed. The airshed will be larger than the watershed. The overall purpose is to develop an understanding of which controls of NO_x emissions to the atmosphere will have the greatest benefit on reducing the nitrogen loading to coastal estuaries. Some NO_x controls are anticipated through requirements in the 1990 Clean Air Act Amendments.

This work is important to the success of the Chesapeake Bay Program Office's efforts to achieve a 40% reduction in controllable nitrogen loading to the Bay by the year 2000 and to the Program's deliberations regarding the 1992 renewal of the Bay Agreement.

Development of more accurate spatial fields of nitrogen loading estimates involves estimation of annual average nitrogen deposition to coastal areas. The model "of choice" is the Regional Acid Deposition Model. Deposition estimates are made starting with the new 1990 interim emissions inventory and representative meteorology.

Definition of the Airshed.

An understanding of the airshed influencing the Chesapeake Bay watershed has emerged from using RADM as a laboratory of the real world; sensitivity studies have been conducted that elucidate the contributions of different emissions sources to the Bay watershed. This source-receptor understanding is very difficult (nearly impossible) to develop from empirical data and requires the designing of sensitivity studies to extract the relevant information from a mathematical model.

Refined Deposition Maps.

To improve the linkages between the atmosphere and the Bay watershed (and the Bay itself), a new higher resolution

RADM with 20-km grids, nested within the original 80-km domain, was developed. The aggregation technique used to develop annual average deposition was adapted for the 20-km domain. The 20-km domain nested in the 80-km domain is shown in Figure 1. Higher resolution is needed to resolve urban and major point source influences better, and to reveal local and regional-scale gradients. More attention also needs to be given to subgrid photochemistry affecting nitric acid production, and to dry deposition to water surfaces.

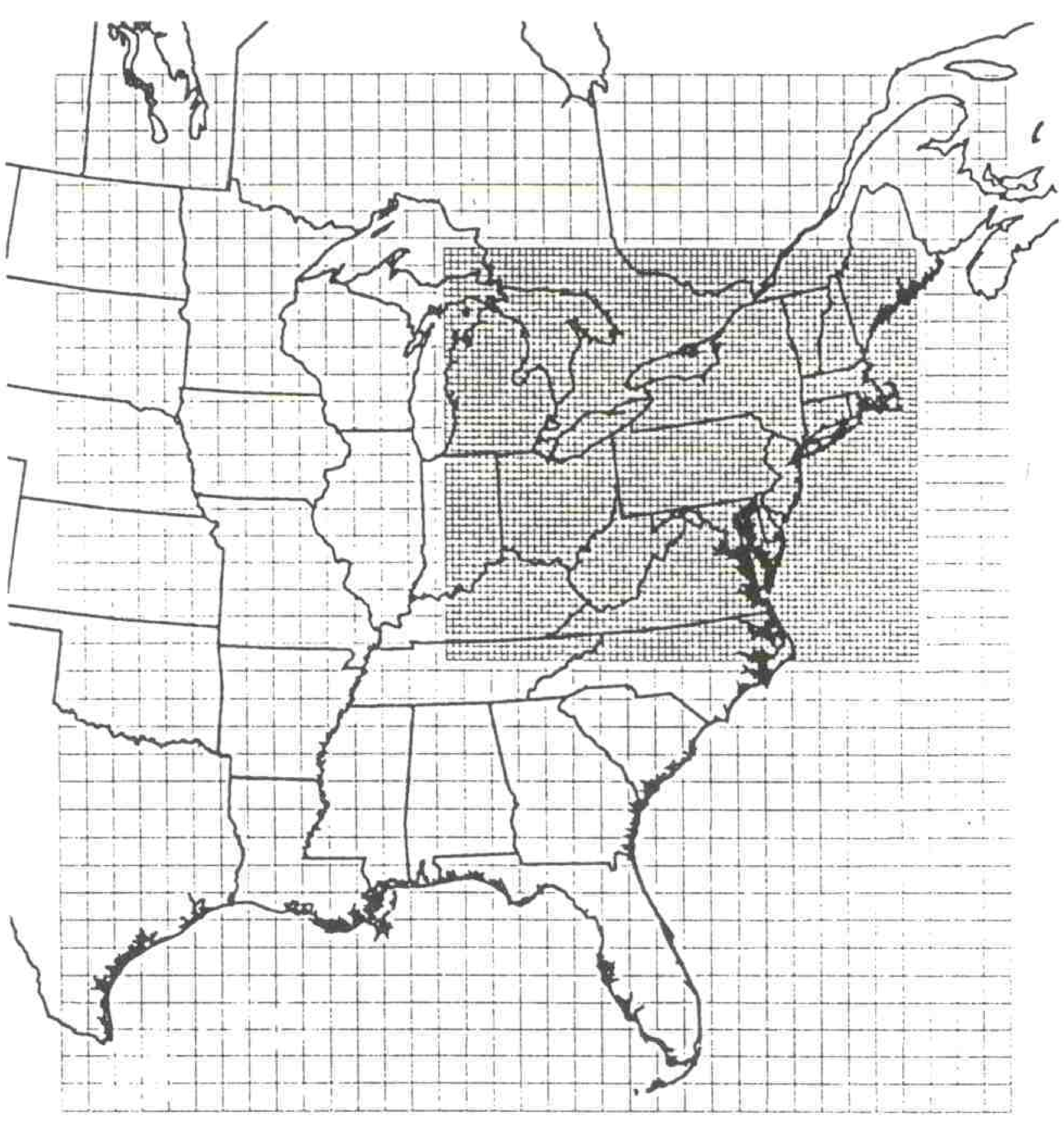


Figure 1. The computational domain of RADM, showing the smaller 20-km grid within the original 80-km grid domain.

The more resolved representations should provide an improved linkage with water quality models. However, the increase in spatial resolution quadruples the cpu requirements for each study.

As a first step, the new high-resolution RADM is being used in two major investigations addressing needs identified by the Chesapeake Bay Program Office. These relate to estimating the reductions in deposition that are expected to occur due to the 1990 Clean Air Act and to implementation of new reductions in NO_x emissions due to requirements stemming from oxidants, rather than acid rain. This work is under way.

The Chesapeake Bay Airshed.

Identification of an "airshed" first requires an assessment of the responsibility of emissions sources, as influenced by annual meteorology.

The nitrogen deposition at any one receptor area derives from a large number of sources, spread out over a large geographic area. An assessment of source responsibility or a range of influence cannot be constructed, therefore, from monitoring data. A range was determined with the RADM model through development of an operational procedure for "tagging" the NO_x emissions regions. Then it was necessary to develop a measure that normalizes for different rates of emissions. Different emissions rates influence the absolute deposition and, of course, the fraction of the total deposition contributed by a source region. A measure for identification of the airshed needs to be insensitive to emissions rates. A relative measure, based on the total deposition due to the "tagged" source summed across the entire modeling domain was developed. Using this approach, it was determined that

- *50% of the nitrogen deposition to the Bay itself is from sources 150 to 300/350 km distant, and*

- *75% of the nitrogen deposition to the Bay is from sources 250/300 to 600/800 km distant.*

In each case, the larger distance estimates represent the distance in the prevailing wind direction. These ranges clearly show nitrogen deposition is a regional problem.

A comparison of the nitrogen "tagged" sub-regions with the tagged sulfur model for the exact same sub-region indicated the range of influence of NO_X emissions is very similar to the range for NO_X. This is not what was expected, producing a surprise. This result will need to be investigated further. These ranges translate into atmospheric residence times on the order of 1 to 1.5 days. These residence times for sulfur are shorter than older literature estimates but in line with newer estimates that take clouds and aqueous chemistry into account.

The comparability of the SO_2 and NO_X ranges of influence allowed us to use both sulfur and nitrogen "tagged" results to more precisely estimate or define the airshed affecting the Bay watershed. The goal in the identification of the principal airshed was to identify the source regions contributing the majority of the deposition to the watershed and to define the perimeter of diminishing returns. That is, the perimeter beyond which it would not be cost effective to reduce emissions from the perspective of reducing nitrogen deposition to the Bay watershed. A decision rule was developed to assess the point of diminishing return. A reasonable approximation was the isocontour defining the distance at which 60% of the deposition from a source regions had fallen. Using this decision rule, source regions were examined, moving counter-clockwise around the boundary of the watershed and the decision rule used to define those regions to be included in the airshed.

Such a procedure produced a definition of the airshed affecting the Chesapeake Bay watershed that is evident in Figure 2; the airshed is significantly larger than the watershed. The airshed includes many sources along the middle and upper Ohio River and it was surprising how far down the Ohio River, to around Lexington, KY, utility sources are apparently influencing the Chesapeake Bay watershed. The airshed is roughly 900,000 km^2, more than 5.5 times the watershed's 165,000 km^2. These results are very important and effectively have set the stage for FY 95 work, as intended.

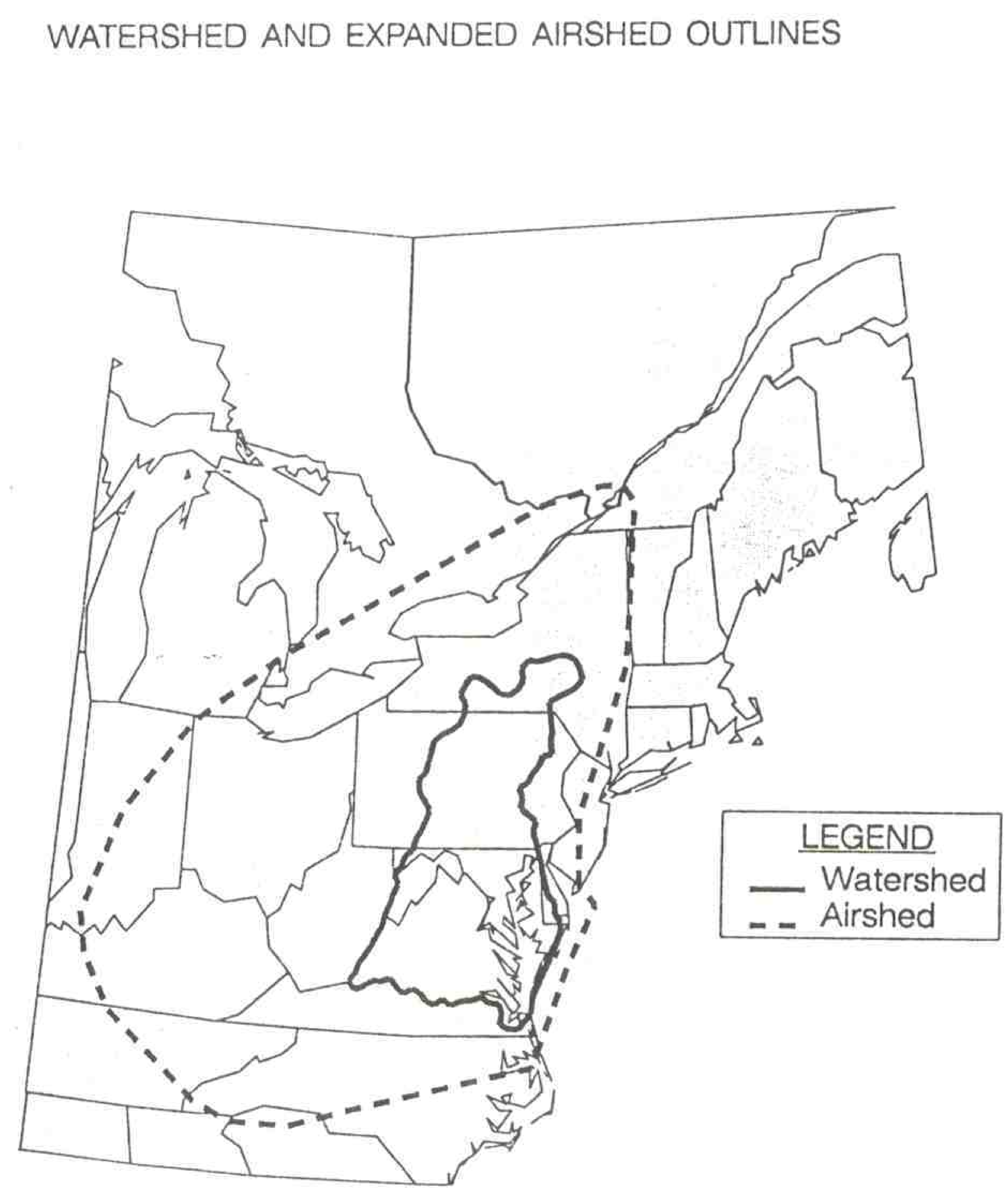


Figure 2. The watershed and the (considerably larger) airshed of the Chesapeake Bay.

MODELS-3

A Third Generation Air Quality Model

Background.

A flexible environmental modeling and decision support system, called Models-3, is being developed to provide air quality assessment and decision support tools for use direct by Federal, State, and industrial organizations engaged in a wide variety of environmental research and applications. Models-3 is a project of ARL/ASMD at Research Triangle Park. It is a joint program with the EPA to integrate not only traditional air quality modules but also the data preprocessing and postprocessing steps into a complete and efficient simulation system.

The Models-3 Framework.

The initial development effort is focused on multi-scale, multi-pollutant air quality modeling related to ozone non-attainment, acid deposition, and fine particles. However since many of the fundamental technology and science issues being addressed are directly applicable to other environmental modeling domains, the long term goal is to extend the system to handle integrated cross-media assessments and to serve as a platform for community development of complex environmental models. The modeling framework is designed to automate many of the activities associated with air quality model development, evaluation, and execution. The framework design isolates system interfaces and specific hardware/software platform solutions to ensure that advances in technology can be integrated without major revision to the structure of the system. Graphical user interfaces provide ease of use for major functions, such as planning and executing a study, managing data, or building a new model.

Atmospheric processes are treated as interchangeable science modules to enable rapid testing and integration of new science. These modules contain explicit formulations of scale and coordinate dependencies. To achieve acceptable turnaround for its users, the system incorporates high performance computing and communications technology. For example, key algorithms are being adapted to take advantage of parallel computing.

An environment layer contains a number of system "personalities" (e.g. Unix, MS Windows, etc.) that adapt Models-3 to the particular platform, system software, and platform dependent files available. Data access is through a standard Input/Output Applications Programming Interface. Numerous rapid prototypes have been developed to test the feasibility of various components of the system. Testable systems requirements have been prepared from interviews with potential users and knowledge gained through early prototypes. An early prototype which simplified the data preparation, execution, and data analysis of the Urban Airshed Model has been released to several groups for initial testing and feedback.

The initial version of Models-3 is provides state-of-the-art urban and regional ozone, acid deposition, and aerosol modeling, with user-friendly human-computer interaction and automated management of processing, data, and resources.

The HPCC Linkage.

Models-3 is closely associated with the High Performance Computing and Communications program (HPCC). This program is part of a larger multiagency Federal High Performance Computing and

Communications program sanctioned under the "High Performance Computing Act of 1991" and coordinated through the Committee on Information and Communications of the National Science and Technology Council. The major program goals are: 1) to build advanced capabilities to address multipollutant and multimedia issues; 2) to adapt environmental management tools to high performance computing and communications; and 3) to provide a modeling and decision support environment that is easy to use and responsive to environmental problem solving needs of key State, Federal, and industrial users.

The 1994 Workshop.

To help finalize design of Models-3 science components, a second Models-3 science workshop was held in September 1994. The second workshop was intended to discuss science deficiencies identified during the first workshop. About 50 scientists developed detailed tasks needed for the completion of the Models-3 Initial Operational Version (IOV). Key research areas that were identified are: soil moisture, resistance, and subgrid landuse; cloud process and aqueous chemistry; hydrostatic and nonhydrostatic modeling issues for National Weather Service and chemistry-transport models; emissions modeling; generalized coordinates and meeting technique; plume-in-grid modeling; gas-phase chemistry reader and solver; horizontal diffusion; aerosol modeling; actinic flux and radiation; and observation database for model evaluation.

Emission Data Processing.

There are three primary options for an Models-3 emission inventory processor, (1) the existing Flexible Regional Emissions Data System (FREDS), (2) the Emission Processing System (EPS) associated with the Urban Area Model, and (3) the Geocoded Emission Modeling and Projection (GEMAP) system. Primarily because of its design and GIS capability, the decision was made to use GEMAP as the basis for Models-3 emission processing.

Parallel Algorithm Research.

A highly vectorized version of the quasi-steady state approximation (QSSA) gas-phase chemistry solver was developed and implemented for the Models-3 prototype. This solver makes minimal assumptions about the type of mechanism employed and is intended to be used as a basic algorithm for the development of general gas-phase chemical mechanisms in Models-3. In addition, a simplified testbed model was developed, to provide an initial, representative chemistry-transport model as a solver development and testing environment for distributed and massively parallel computing architectures. The testbed has been implemented on a Cray T3D massively parallel processing system in both the Parallel Virtual Machine (PVM) programming model and the Cray Research Adaptive ForTran (CRAFT) model.

Future Objectives.

The detailed design specifications for the Models-3 framework will be finalized, coded and tested. Tests will also be performed to analyze communications issues between coupled meteorology and air quality models. Numerous tests will explore the advantages and limitations of distributed computing in a hardware environment that employs both vector and parallel processing components. Models-3 visualization prototypes will be tested to evaluate latency effects in a network parallel environment where functional modules are executed on distinct systems to support animation, image rendering and image display. Remote collaborative computing approaches will be evaluated for effectiveness.

OZONE RESEARCH IN ARL

Studies of Ozone, and NARSTO

Background.

Tropospheric ozone has continued to be a problem in the continental U.S. and southeastern Canada despite decades of air quality regulation and several generations of legislation. The general problem was addressed in the recent NSF report *Rethinking the Ozone problem in Urban and Regional Air Pollution*; this called for a coordinated multi-agency approach to ozone research. The North American Research Strategy for Tropospheric Ozone (NARSTO) resulted from these beginnings. Sponsors of the program include NOAA, EPA, DOE, EPRI, the American Petroleum Institute, the Motor Vehicle Manufacturers Association, and many power companies.

The goal of NARSTO is to carry out a research program which will provide data for the development and evaluation of air quality control strategies. This relates well with the dominant goal of ARL research. Effective action to control ozone levels can only be taken if the mechanisms of ozone production and transport are understood and if the effects of control measures on ozone levels can be measured. Reliable Air Quality Simulation Models (AQSMs) must be developed and tested so that the effects of control strategies can be predicted.

ARL has many relevant strengths, some of which are described elsewhere in this document (e.g. the Twin Otter flux-measuring aircraft). ARL focuses research attention on improving understanding of the processes that influence the geochemical cycles of ozone and its co-pollutants. ARL research concentrates on the physical (and frequently biological) mechanisms that influence ozone concentrations. Results obtained, together with the conclusions drawn from chemical process studies conducted mainly by other laboratories, are ingested into the comprehensive models such as are being developed in the Atmospheric Sciences Modeling Division, Research Triangle Park.

Several of the most relevant ARL activities are discussed below. These relate to surface deposition, tropospheric ozone transport, and chemistry (including tracer technologies).

Surface Ozone Research.

Work on ozone deposition is ongoing at the Atmospheric Turbulence and Diffusion Division, in Oak Ridge, Tennessee, and at the Atmospheric Sciences Modeling Division, Research Triangle Park, North Carolina. Much of what is known about the destruction of ozone upon contact with the surface ("air-surface exchange" of ozone) has been the result of intensive field studies made at locations that are carefully selected to permit scrutiny of particular processes without confusion from competing mechanisms.

It is studies of this kind that have generated the knowledge that is currently integrated into numerical models of the air-surface chemical exchange mechanism. These models emphasize that the controlling property is often biological, associated with the stomatal resistance of the vegetation at the surface and hence strongly a function of the biological species and the prevailing conditions. Recently, ARL has been moving more towards long-term measurement programs of similar kind, to capture a wide range of environmental conditions at a single location. This approach is useful, for example, to evaluate model performance during conditions of short-term water stress, dewfall, precipitation, etc.

Measurement capabilities include flux-measuring systems for use on towers as well as aircraft and boats. In general, measurements at fixed locations are used to investigate temporal variations in fluxes and in the process that control them. Aircraft and boat measurements have recently been made possible by the development of a Mobile Flux Platform capability, that can now be used to investigate the spatial distribution of fluxes. In association with the development of this multi-faceted flux measuring capability, new fast-response ozone sensors have been developed. Further improvements are being made at this time, to provide more stable and sensitive response from the instrumentation.

The models developed in this work are used routinely to assess ozone air-surface exchange at many sites distributed across the U.S., with most in the East. The monitoring of ozone concentrations remains central to this network operation. Data obtained are used not only to address research questions related to surface chemical and biological processes, but also to determine ozone exposure levels within ecosystems, ozone uptake rates by vegetation, and human health risk.

Current work is directed towards exploring the complex and rapid interactions among various nitrogen oxides, hydrocarbons, and ozone in the near vicinity of vegetated surfaces, where the reactions cause fluxes to change with height much more rapidly than for non-reactive species. Work of this kind requires the use of rapid-response sensors, presently still under development. Attention will first be paid to developing a fast-response NO detector, additional methodologies for fast-response measurements of O_3 (i.e., reverse NO chemiluminescence and/or ethylene chemiluminescence) and perhaps exploration of sensitive, fast-response measurements of biogenic hydrocarbon precursors (isoprene, etc.) to quantify emission/deposition fluxes of these compounds to/from the atmosphere. Much of this work is in collaboration with the Department of Meteorology, University of Maryland.

Tropospheric Ozone Research.

There has been a long history of boundary layer research within ARL, in which studies of ozone profiles have been common. For example, ARL scientists have routinely operated a tethersonde system to obtain information of this kind, often supported by profile data derived from use of aircraft.

Several extensive field studies have been conducted. These include the Lake Michigan Ozone Study, the San Joaquin Ozone Study, and the Arizona Ozone Study. In each case, the focus was on the causes of ozone anomalies of potential regulatory concern.

The performance of ozone monitors used in tropospheric boundary layer research was a major worry during the early 1990s. The results of this research are now widely known, and the studies themselves have been finalized.

A central interest at the time of this writing relates to how gas-phase photochemical reactions and processes interact with the meteorological processes that cause transport and dispersion. Critical measurements in this effort include O_3, $NO/NO_x/NO_y$, H_2O_2 and ROOH (organic hydroperoxides), CO, etc. An effort in re-establishing and enhancing ARL measurement capabilities involves the development of ultra-sensitive and fast response detectors for reactive nitrogen, including the building and testing of a super-sensitive and fast-response NO detector, and the appropriate converters for the detection of NO_x (photolysis cell) and NO_y (molybdenum and/or Au/CO oxidation). Several ARL divisions (notably at Silver Spring, Research Triangle Park, Oak Ridge, and Idaho Falls) are well equipped to measure ozone; effort is now being directed towards measurement of ozone precursors.

An understanding of the effects of meteorological variables on tropospheric ozone levels is essential to the detection of air quality changes resulting from emissions reductions. Only when these effects are known can air quality data be normalized for meteorology and changes detected. The effects of humidity, temperature, clouds, and solar radiation on ozone production must be measured. Determination of diurnal and seasonal variations in meteorological parameters and the changes in ozone production and transport they produce are necessary. The changes caused by climate patterns and resulting from solar radiation changes induced by stratospheric ozone depletion should be investigated. This meteorological data must have sufficient spatial and temporal resolution to enable boundary layer characterization including inversion height changes.

The fact that the transport of ozone and its precursors affects ozone levels in urban areas is well known. Violations of National Ambient Air Quality Standards (NAAQS) most often occur when new photochemical production is added to a high background ozone level. The origin of the high background ozone and the effect of transport on rural ozone, particularly the transport of reservoir species such as PAN, must be clarified. The entire range of spatial and temporal scales must be considered from flux measurements at the surface to regional concentration gradients in both the horizontal and vertical dimensions. In this context, ARL has long been a leader in studies of flow and dispersion over complex terrain, often with ozone measurements made at the same time as studies of meteorology. This long-standing work has recently been expanded by a new focus on effects due to vegetation differences. Together, topographic and vegetation differences are referred to in the general class of "land use."

ARL specializes in measurements of deposition from the atmosphere, using all of micrometeorological tower-based, aircraft, and inferential methodologies. ARL scientists (especially at Research Triangle Park) are active in studies of exchange between the boundary layer and the free troposphere, including the transport of ozone and precursors by convection in clouds and the interactions at the marine-continental boundary layer interface. ARL is the lead agency of the World Meteorological Organization's Quality Assurance Center for the Americas, a cornerstone activity of the WMO Global Atmosphere Watch with specific concern related to the measurement of tropospheric ozone.

AEROSOL STUDIES

Atmospheric Aerosols and Climate

Background.

It is widely acknowledged that atmospheric aerosols influence climate in a manner that tends to counter the more familiar greenhouse effect -- the increases in surface temperatures resulting from increases in atmospheric carbon dioxide will be reduced if atmospheric aerosols also increase in concentration. ARL workers are involved in several related activities.

Soil-derived Particles.

Investigations of the resuspension of surface particles are summarized elsewhere (see "Erosion, and Resuspension of Aerosol Particles"). Studies of the optical properties of soil derived aerosols show relatively unchanging size distributions and real and imaginary parts of the index of refraction for soil-derived aerosols ranging from the Sahara to Texas to Central Asia. Concentrations of soil-derived aerosols vary greatly in time and location, however. It is proposed that these rather uniform aerosol characteristics and the extremely variable concentration of soil-derived aerosols make the most cost-effective studies on the forcing of climate by soil aerosols to be quantification of the change of soil aerosols with time.

Present studies concentrate on revealing the aerodynamics of soil particle emissions. The two main study areas are Owens (dry) Lake in California and the Jornada del Muerto experimental range in New Mexico.

Anthropogenic Particles.

An attempt to use existing records to quantify the climate forcing of potential cloudiness generated by SO_2 emissions was undertaken, using hemispheric and global surface temperature (IPCC90) records. Linear regression of five year average temperatures (1960-1990) on CO_2 concentrations (from Mauna Loa) yielded temperature increases corresponding to a doubling of the current CO_2 level of $2.3° \pm 0.8°$ and $2.5° \pm 0.6°$ for the northern and southern hemispheres respectively. No significant correlation was found between the same temperature record and SO_2 data as published by the IPCC.

The radiation effect of aerosol water in the marine boundary layer (MBL) was investigated independently using the aerosol data measured during the 1992 ASTEX/MAGE intensive. Based on the shipboard measurement data of "ambient" and "dry" size distributions it was estimated that aerosol water would increase the aerosol optical depth of the marine boundary layer by 41% to 110%, which corresponded to 0.6% to 1.4% decrease in the total solar irradiance at the surface.

A further activity relates to the development and optimal use of various kinds of rotating shadow band radiometers. There are three variations now in use, each with a specific purpose but each also employing an identical measurement philosophy — as much as possible to depend on the use of a single sensor to measure different irradiance components, to minimize difficulties caused by sensor deterioration and to minimize the consequences of different sensor performance characteristics when operating in a spatial array.

Some practical applications of atmospheric extinction data do not require exceedingly high accuracy but rather continuing long-term precision. Relative measurements that encapsulate changes in scattering conditions can be made at small cost but with lasting benefit. Such measurements include monitoring the relative magnitude of the direct and diffuse irradiance components in an optically active portion of the solar spectrum. A single sensor that is periodically shaded by a rotating shadow band provides adequate data for many purposes of this kind. The simplest form of rotating shadow band radiometer is of this type. A single, silicon-cell, quantum sensor is mounted horizontally at the center of the sphere described by a rotating band, thick enough to provide a short period of shade but narrow enough to minimize errors in the measurement of total irradiance. Broad-band data are collected automatically, usually at intervals short enough to ensure that a representative fully-shaded value is reported for each brief pass of the shadow-band. Such sensors are being operated by ARL at numerous sites.

EROSION, AND RESUSPENSION OF SURFACE PARTICLES

Mechanistic Studies

Introduction.

The desertification and resuspension project is a field component of the Fluid Modeling Facility of the Atmospheric Sciences Modeling Division, at Research Triangle Park. The project concentrates on the mechanisms of resuspension and their description in numerical simulations. On a global scale the effect of these mechanisms furnishes signals of global change. For example, ice core researchers have found a strong correlation of dust concentration in the ice and Oxygen 18 to Oxygen 16 ratios (a proxy measure of air temperature). The correlations of dust concentration and air temperature have been interpreted as reflecting different source areas, wind stresses over these source areas, transport, and increased deposition rates due to climate change (and to global warming in particular).

On a regional scale, desertification (degradation of soil potential) of the land by wind erosion causes concentrations of small particles that exceed the PM-10 (particle mass smaller than 10 μm diameter) limits in downwind cities, such a Spokane, WA, for example. One of the most serious manmade disasters of the century, the nuclear contamination caused by the accident at Chernobyl, was largely a problem of resuspension of particles, once the initial contamination had settled.

The ARL desertification and resuspension project relies primarily on outdoor measurements and secondarily on laboratory studies. The outdoor experimental sites are Owens Lake, located near Lone Pine, CA and the Jornada del Muerto Experimental Range located near Las Cruces, NM. During 1994, the research focus was on experimentation at Owens Lake.

ARL Resuspension Research.

There is a well known "wind erosion fetch effect" that refers to the increase of erosion rate with distance downwind from a leading edge, after the threshold velocity for wind erosion is exceeded. Two new mechanisms for this fetch effect have been proposed. The first involves an aerodynamic feedback process that depends on the downwind distance (the fetch). That is, saltating sand grains could increase the apparent aerodynamic roughness height; this increase of roughness height could lead, in turn, to an internal boundary layer in which more momentum is transferred to the surface. The increase in momentum exchange could then cause even more surface particles to be suspended.

The second hypothesized cause for the fetch effect involves a change of the soil's resistance to erosion with distance. This hypothesis followed from observations which showed that as the fraction of the frontal area of nonerodible particles decreased, more of the wind momentum flux went to transporting soil through the air. Because soil aggregates (including soil crusts) would be expected to be increasingly destroyed with increased sandblasting, which itself increases as a function of distance from the leading edge, the same wind stress could transport more airborne soil mass as distance increased from the leading edge. This effect was detected as a decrease of threshold friction velocities with distance downwind.

A recent resuspension model starts with the premise that the emission of suspended particles from a surface is proportional to the surface vertical flux of kinetic energy by saltating grains and inversely proportional to the binding energy holding the particles to the surface. Binding energy of fine particles to larger aggregates varies with differences in soil texture (that is, the size distribution of soil particles), chemical composition of the soil, clay mineralogy, salt and organic content, and physical properties of the soil such as the (changing) size distribution of soil aggregates as affected by wetting, drying freezing, thawing and erosive processes such as sandblasting. The ARL measurements have added important field data for evaluating the assumptions of this recent model, and for refining the formulations on which the model is based.

Conclusions.

The data from the Owens Lake experiments confirmed the importance of each of the two hypothesized mechanisms, along with an older "soil avalanching" mechanism. Thus, the studies have revealed that there are three mechanisms that cause the wind-erosion fetch effect — avalanching, soil resistance, and aerodynamic feedback.

The distinctive consequences of aerodynamic feedback were observed for the first time during one of the ARL Owens Lake tests, in March 1993; progressive disintegration of soil crust by sandblasting caused a decrease of threshold friction velocity with distance from the unbroken crust. The gradient of threshold friction velocity contributed to an opposite gradient of soil flux. The avalanching effect is important for small-scale (of the order of a few meters) wind erosion fetch effects. At the leading edge separating nonerodible material from erodible material, it is a dominating effect. For scales of more than 50-100 m, however, avalanching is a residual effect, responsible for a small fraction of the total fetch effect. The dominating large-scale (greater than 100 m) fetch effect mechanism was found to be the variation of threshold velocity on the surface of the lake.

The vertical flux of particles smaller than 10 μm was estimated for a site at Owens (dry) Lake in California. The vertical flux was estimated using the profile method and provides a valuable data point for loam textured soils that was not available before. The Owens Lake data are consistent with those for other soil textures and suggests that the binding energy postulated in the recent model is of the same order as that for sandier soils.

Other important problems in resuspension are being studied at Owens Lake and the Jornada del Muerto Experimental Range. These problems include: the effect of limitation of particle supply on the flux of resuspension particles, the vertical flux of small (< 10 μm diameter) particles, and the breakup of natural crusts.

CLIMATE CHANGE AND THE IPCC

Contributions to the IPCC Second Scientific Assessment

Background.

The Intergovernmental Panel on Climate Change (IPCC) was jointly established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environmental Program. Its purpose is to provide the world's governments with authoritative summaries of the prospects for long-term climate changes resulting from human activities. Several ARL scientists of the Silver Spring Headquarters Division are Contributors to this effort. The ozone and temperature work is also included in summaries for the Stratospheric Processes And their Role in Climate (SPARC) Project of the WMO.

The ARL focus is on climate records from upper-air observations. Effects of such natural but irregularly occurring phenomena as volcanic explosions and El Niño events are studied, to help extract long-term climate change signals from records of temperature in the troposphere and lower stratosphere, water vapor in the troposphere, and total and stratospheric ozone. Other quantities examined are cloudiness and sunshine over the U.S. and high level tropical winds and temperatures as indicators of the Quasi-Biennial Oscillation (QBO). The data records begin at various times but each is now at least 22 years long. The bulk of the data originate from routine radiosonde observations, so there is particular sensitivity to questions of record homogeneity. Thus historical metadata are compiled, that is, information about the sensors used and the methods of data processing and any other information that would affect the interpretation of the data.

The IPCC is currently preparing a new report on climate change, scheduled to appear in early 1996. ARL has contributed material on metadata, tropospheric and stratospheric temperature, and water vapor to this effort, and has also served among the reviewers of the draft to be submitted to the Panel this year.

Metadata.

The collection and analysis of metadata about worldwide radiosonde observations is a critical step in the ARL effort to separate true changes in climate from data artifacts. The radiosonde metadata collection began several years ago when all the member nations of the WMO were formally requested to provide historical information about radiosonde stations in their networks. That survey yielded historical information from about 50 countries. Additional information is being collected from libraries and by interviewing experts in particular countries. The resulting historical information is currently being assembled in a consistent electronic format. A striking example of an apparent change in temperature is shown in Figure 1, where a change in radiosonde sensor at Tahiti coincided with the "drop" in temperature in 1976.

Temperature.

Virtual temperature for the troposphere, tropopause layer and lower stratosphere continue to be analyzed using data from a network of radiosonde stations, chosen to provide uniform geographic coverage. In the troposphere the 37-year record shows a warming of about 0.1°C per decade, despite a nearly constant temperature since 1979 (see Figure 2). This shorter period coincides with the satellite temperature estimates which also show virtually no warming. Because the end of this period is influenced by the eruption of Mt. Pinatubo, it would be premature to take this period as evidence that any long-term warming has ceased.

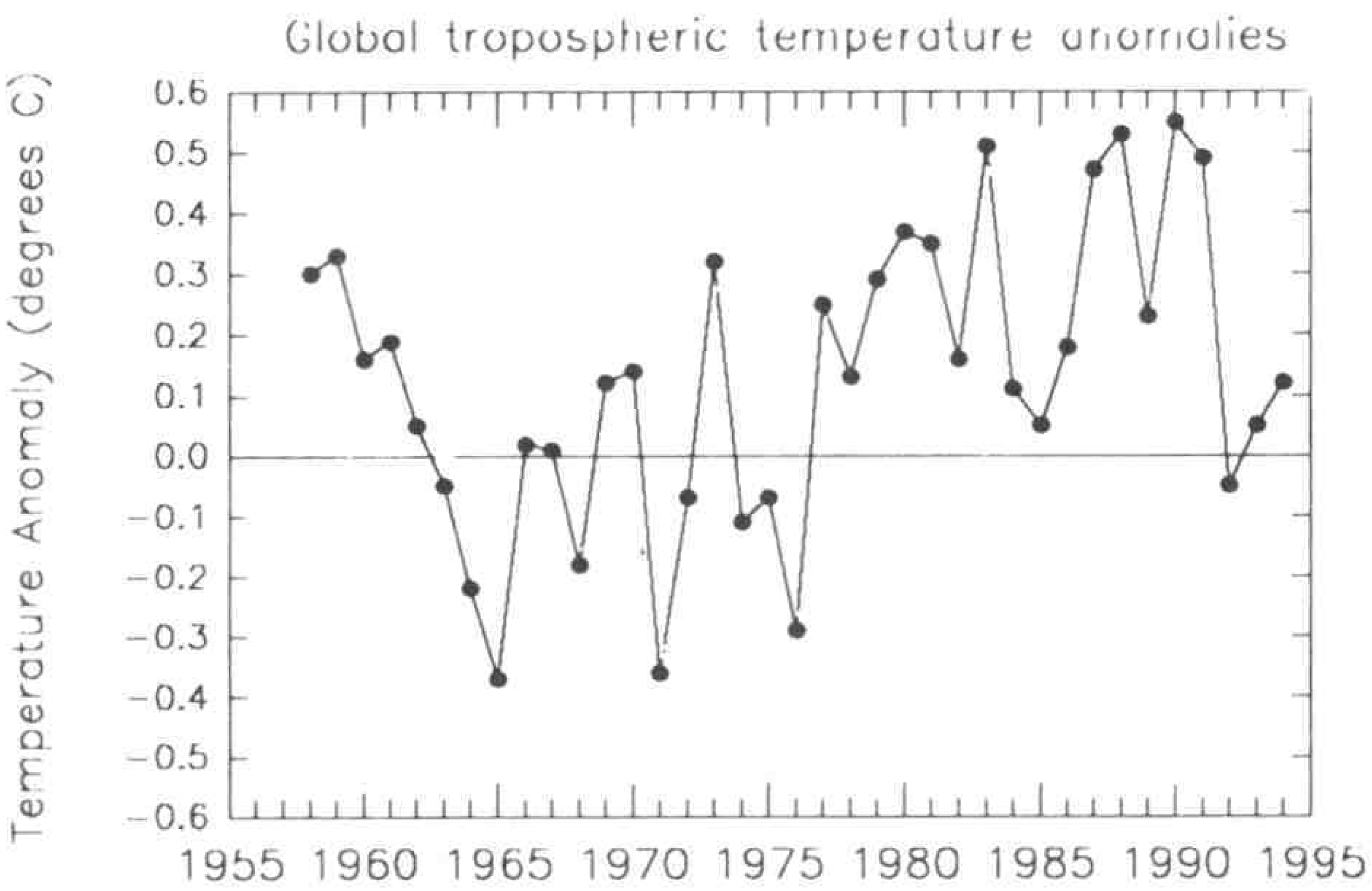


Figure 1. Monthly mean 100 mb temperatures from Tahiti. The break in 1976 coincides with a temperature sensor change from bi-metal to thermistor.

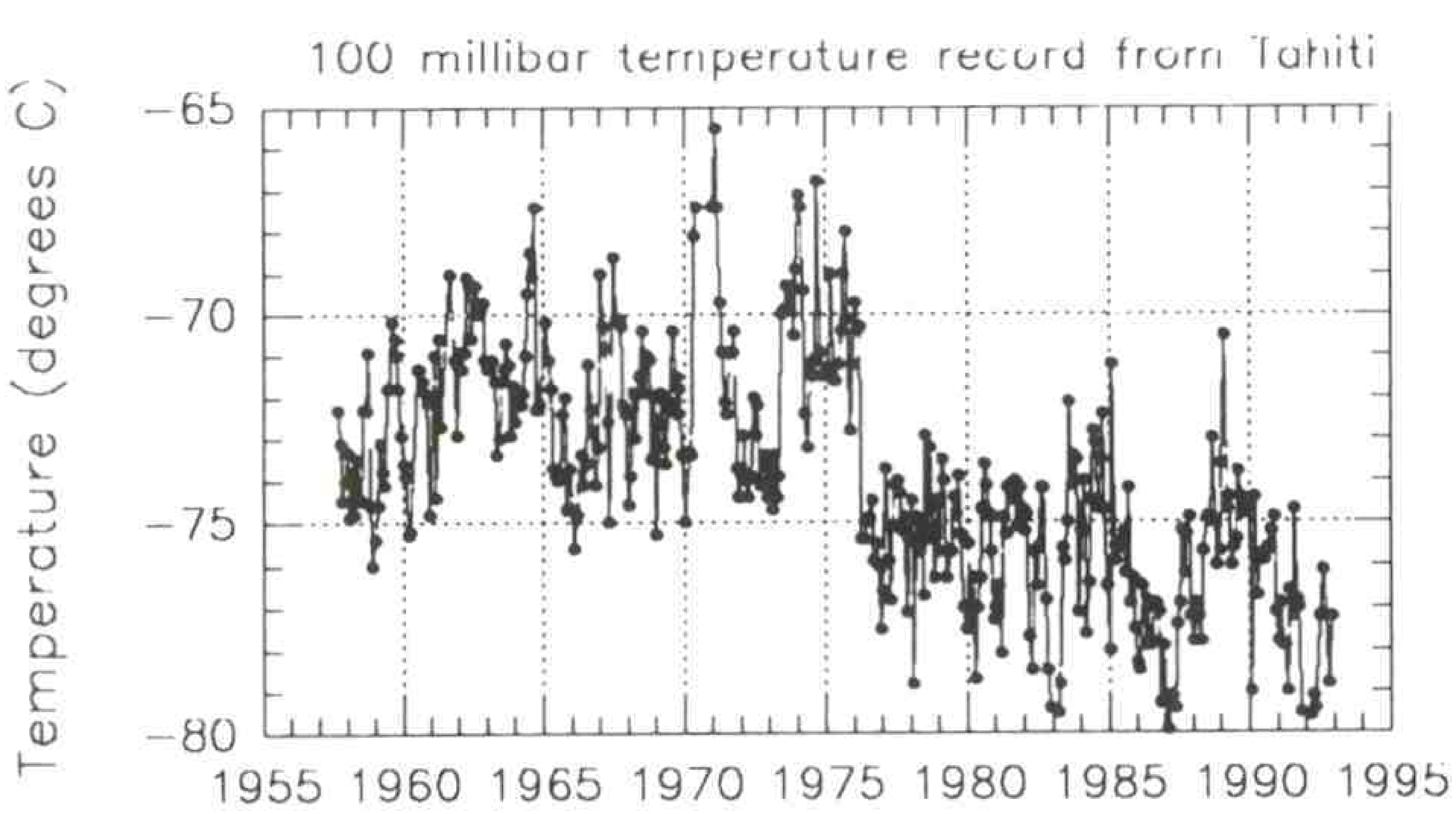


Figure 2. Mean annual virtual temperature anomalies for the 850-300 mb layer from the 63-station network.

In the stratosphere and in the 300-100 mb layer, there has been some cooling since 1958. Satellite observations agree on the stratospheric cooling since 1979, but show a smaller magnitude. Unfortunately, satellites do not give an estimate for the 300-100 mb layer, where the cooling was very pronounced in 1993 and 1994. Some of the apparent cooling may reflect inhomogeneities in radiosonde observations, like the one illustrated in Figure 1. This possibility is being examined. In addition, both the QBO and the irregular injection of particles into the stratosphere by volcanos affect stratospheric temperatures. All these factors must be considered in extracting any long-term signal from the data record.

Water Vapor.

For the humidity studies, nearly 1000 station records since 1973 have been examined and about 800 retained for analysis. A preliminary global climatology of water vapor in the air column below 300 mb has been constructed. (This represents well over 95% of the water in the total column.) It is preliminary because there are still station records to be examined for discontinuities. Some of the results obtained so far have been provided to scientists at Colorado State University, who have combined them with satellite data to obtain a more complete picture of the global atmospheric water vapor picture. Satellites can provide more detail on water vapor at high elevations and above regions lacking radiosonde observations, e.g. over remote ocean areas and some continental areas with few observing sites.

Based on stations selected for their relatively homogeneous data records, a separate climatology of water vapor above North America has been constructed. The data show a gradual increase in atmospheric water vapor content in the last 21 years over most of the region; at many stations the trend is statistically significant. The exceptions are northern and eastern Canada where slight decreases are found. In general the increases and decreases parallel changes in temperature, i.e. warming is associated with rising water vapor and cooling with decreasing water vapor, as illustrated in Figure 3. Relative humidity also tended to increase but the increases are less often significant.

In October, 1994, W. Elliott and D. Gaffen convened 125 scientists at Jekyll Island

GA for an AGU Chapman Conference on The Role of Water Vapor in the Climate System. The purpose was to bring together those modeling water vapor's distribution and its effect on radiative transfer with those using a variety of techniques to measure it.

Because water vapor is key to both radiative transfer and the global hydrological cycle, it is important to evaluate how well global climate models simulate water vapor. As part of the WMO-sponsored Atmospheric Model Intercomparison Project, ARL is involved in a diagnostics subproject comparing the simulations from about 30 general circulation models with radiosonde observations. Preliminary results indicate that most models seem to underestimate the amount of water vapor in the atmosphere, although the seasonal cycle is reasonably well simulated.

Cloudiness and Sunshine.

Because clouds reflect sunlight, a time series of one of these would be expected to be a mirror image of the other; for the most part this has been true over the U.S. since 1950 (Figure 4). The slight increase in cloudiness since 1958 mostly reflects the reduced cloudiness of the early 1950s (Little Dust Bowl). Since 1965 there has been little trend in clouds although there is a clear association of cloudiness and the occurrences of El Niño. During El Niño, cloudiness tends to be above average, particularly in the southern tier of states. The prolonged El Niño of 1991-94 has been associated with U.S. cloud cover 1-2% above average.

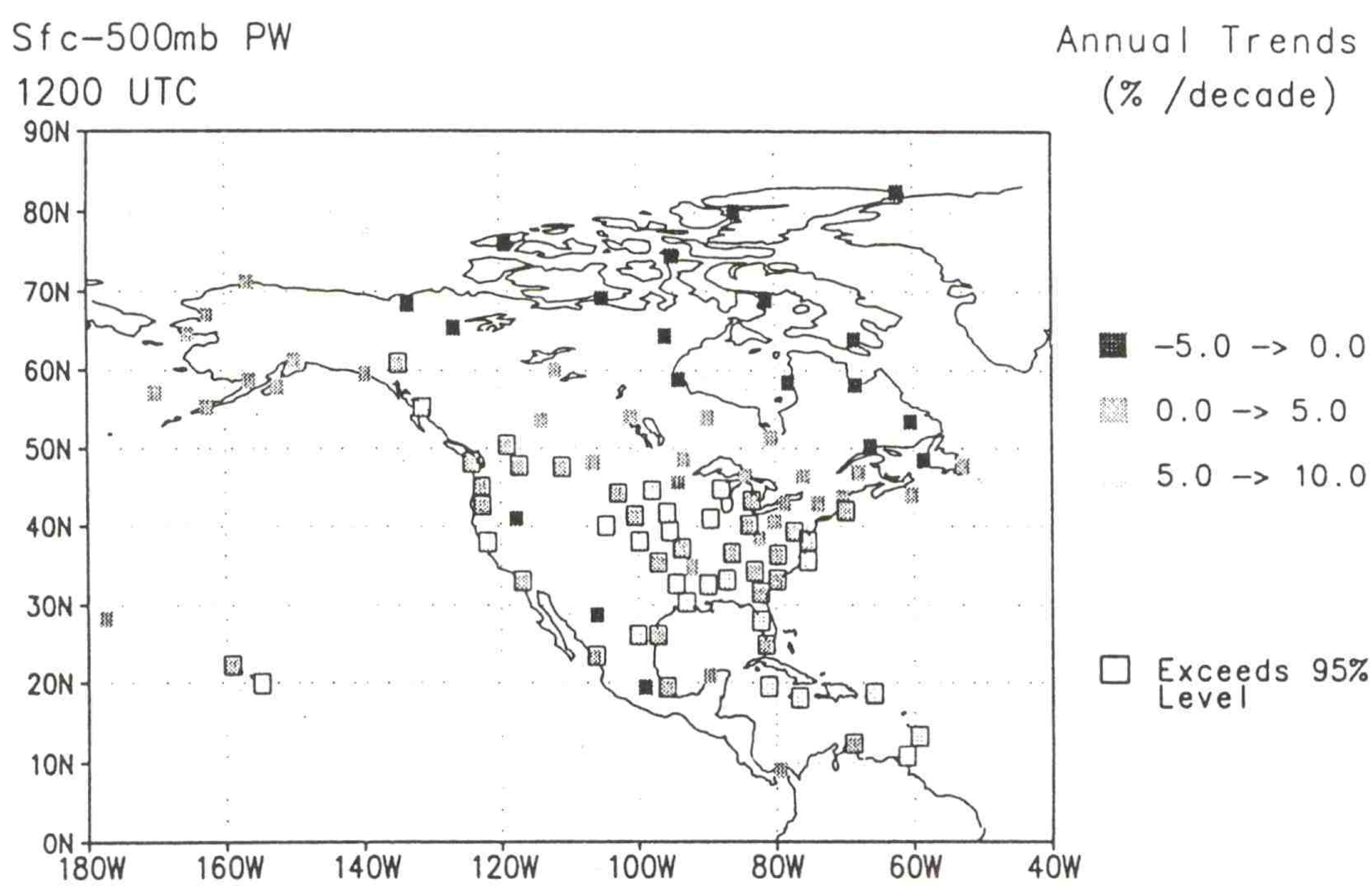


Figure 3. Trends in precipitable water over North America, based on radiosonde stations based on 1973 to 1993 records obtained at 1200 UTC. The units are % of annual mean per decade.

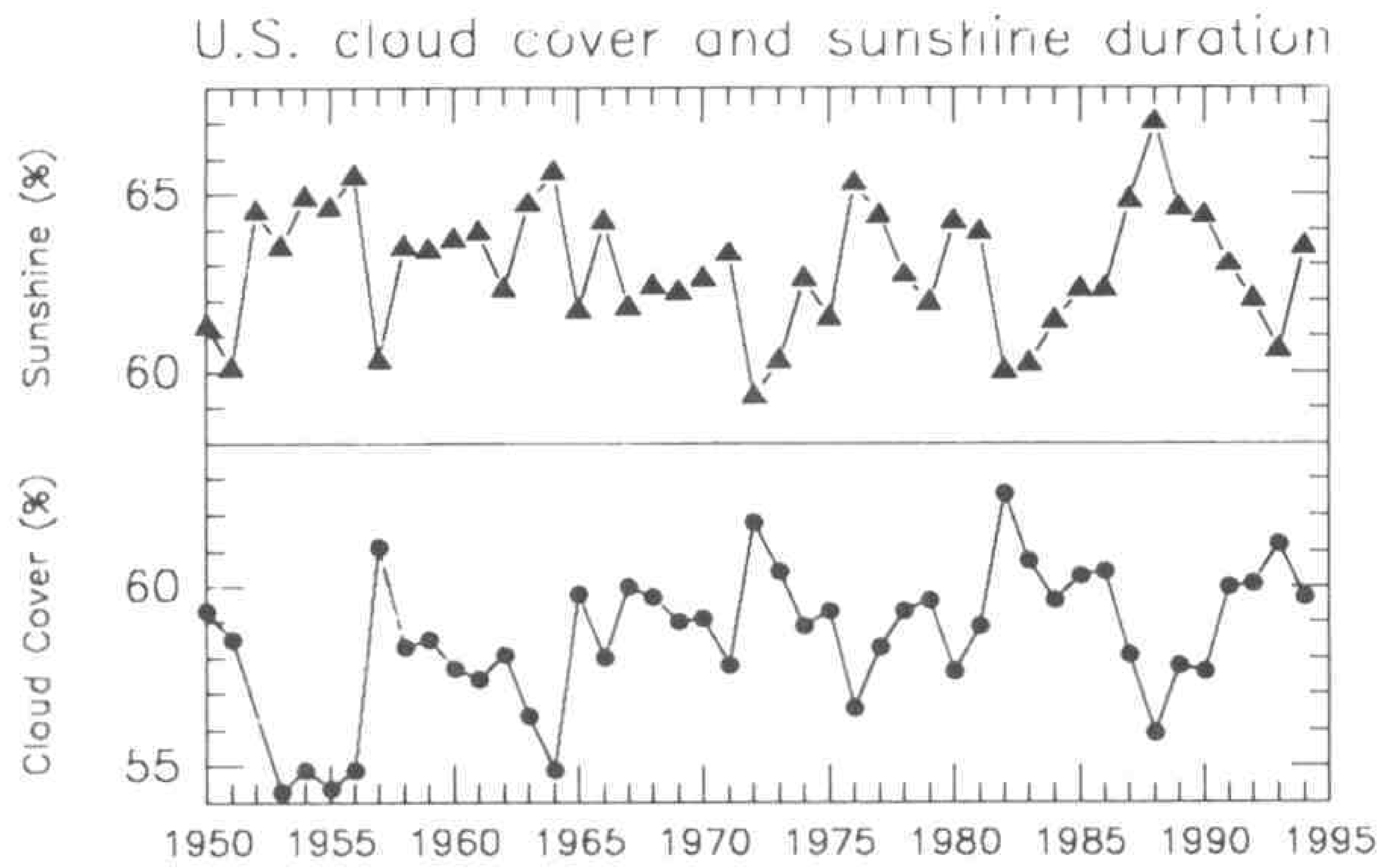


Figure 4. Mean Annual Sunshine (upper curve) and Cloudiness (lower curve) over the U.S. since 1954. Units of both curves are % possible sunshine and % (daytime) cloud cover.

Ozone.

The ground-based Dobson network shows a global decrease of stratospheric ozone of about 5% over the past 37 years of operation, with most of that occurring since 1980. Above the north temperate region the decrease has been nearly 10%. Most of the decrease is seen in the lower stratosphere rather than the high stratosphere as originally anticipated. The total column ozone reached a record low value in 1993 and recovered slightly in 1994. The low values can be attributed in part to the Pinatubo eruption which decreased ozone in the 16-24 km layer by almost 20%. By comparison, after El Chichon's 1982 eruption, low stratospheric ozone decreased by about 10% and after Fuego's 1974 eruption it decreased by about 5%.

Tropospheric ozone, as recorded by ozonesondes, showed increases in the north temperate region of about 20% from 1968 to 1980. However, since 1980 the record shows almost no increase in the troposphere and there is some indication of a slight decrease in the 1990s. This finding may be now slowly penetrating the ozone literature but it has not been widely realized.

ISIS

The Integrated Surface Irradiance Study

Background.

ISIS is a new network of radiation stations, distributed across the U.S.A., and made up of two tiers — Level 1 stations make relatively straightforward measurements of incoming radiation, primarily visible but also planned to have UV-B broadband sensors; Level 2 stations make additional measurements of outgoing and infrared components. The Level 2 sites include the sites sponsored by the NOAA Office of Global Programs under their SURFRAD program. All ISIS sites will eventually have rotating shadow band radiometers, designed to provide a widespread picture of atmospheric aerosol optical depth across the U.S.A.

Level 1 of ISIS is partly intended to constitute an up-dated continuation of monitoring previously conducted by the National Weather Service under its SOLRAD program. Because of the changes imposed by the modernization of the National Weather Service, many SOLRAD sites have been discontinued. Some of these discontinued SOLRAD sites are planned for replacement by new ISIS sites, at nearby locations.

The goal is to generate a single, coherent network, with common data recording, transfer, and archiving characteristics, and with as much continuity as possible, addressing needs of the surface irradiance community and with components addressing each of IR and UV radiation.

1994 Activity, Level 1.

Impacts of the NWS modernization were felt at many historic SOLRAD locations, and each was reviewed from the ISIS perspective. For example, the Albuquerque NWS station moved to new quarters in March 1994; ATDD installed a new data acquisition system in time for a replacement installation to be operational in time for a seamless transition. Five additional ISIS data retrieval systems were installed during 1994, and recalibrated sensors were also provided. Meetings with NCDC officials were held, to design the data ingestion process for archiving ISIS data.

Installation of the prototype ISIS site, in Albuquerque NM, was completed in May, 1994. Data are retrieved automatically, every day, via modem. This site has been viewed as a test case. It has operated continuously with 100% data retrieval since the installation of its full complement of instruments. Measurements include global shortwave, normally incident shortwave, UV-B (295-320μ), and photosynthetically active radiation (400-700 μ) under a rotating shadowband, with 15-minute statistics; these permit clear-sky turbidity estimation. Refurbished sensors for ISIS are calibrated by DOE's National Renewable Energy Laboratory (NREL).

The Nevada Integrated Surface Irradiance Study (ISIS) site, historically operated by the NWS at McCarren Airport in Las Vegas, is now scheduled to be moved to Desert Rock, Nevada (on the Nevada Test Site of the Department of Energy), where it will be operated by ARL personnel of the Special Operations and Research Division, Las Vegas.

1994 Activity, Level 2.

The first SURFRAD site (Bondville, IL) was successfully set up in April. Shakedown problems were solved within the first month, and since then data have been retrieved continuously.

The Fort Peck (Montana) SURFRAD site was installed in mid November. The site is located near a homesite on land owned jointly by the Assiniboine and Sioux Tribes. The homesite resident was trained to care for the instruments; a local Electronics Engineer from the Fort Peck Community College will handle technical problems. In early December, the SURFRAD facility at the Goodwin Creek Experimental Basin in northwestern Mississippi was installed. With the Bondville, Illinois SURFRAD station already operational, these recent installations complete the first sub-array of SURFRAD sites. An additional three sites are anticipated. Agreements between NOAA and the host organizations are based on an expectation that they will accommodate the SURFRAD sites for at least 25 years.

Following these installations, the search for the last three SURFRAD sites has commenced in earnest.

Work began on the Table Mountain "SURFRAD" site simulation, intended to provide a working model of a SURFRAD site within easy reach of Boulder, CO. The instrument set contains all instruments of a SURFRAD site and a shaded pyranometer and pyrgeometer have been added. As in the case of all SURFRAD (and ISIS) sites, telephone data transfer is planned.

Results.

The diagram below illustrates the kind of data obtained automatically from SURFRAD sites. The example shown is of data obtained at Bondville, Illinois, during a solar eclipse.

Arrangements are presently being made for ISIS data to be available via the World Wide Web. It is expected that today's data will be available tomorrow.

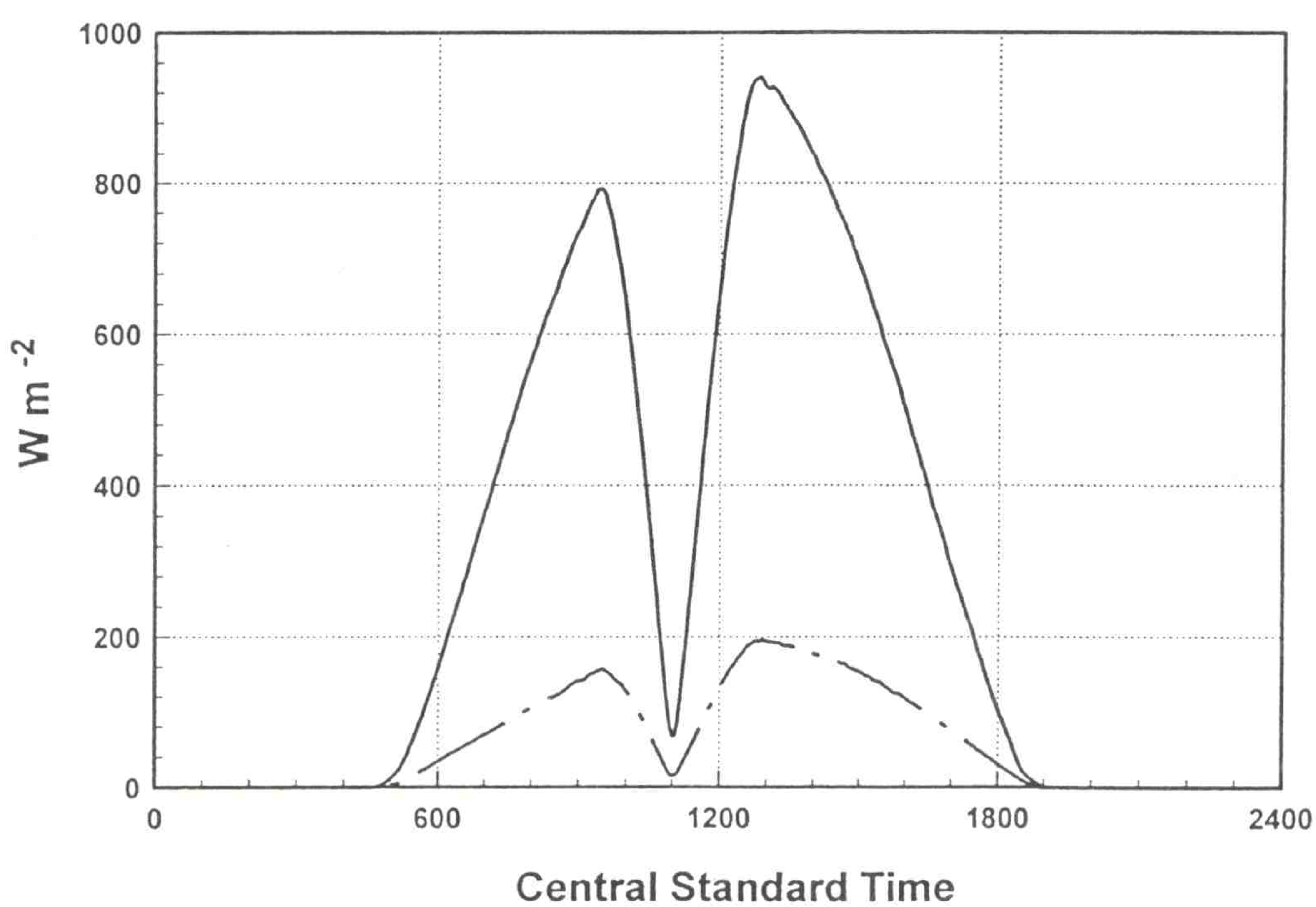


Figure 1. Radiation observations made at the Bondville, Illinois, SURFRAD/ISIS station on the day of a solar eclipse.

ATMOSPHERIC OPTICS

Visibility and Turbidity

Background.

ARL specializes in the geochemical cycling of atmospheric aerosols, particularly the particulate component. Research groups in ARL concentrate on the injection of dust and soil particles into the atmosphere (addressed elsewhere in this document), the transport of particles through the atmosphere, the production of aerosol particles in the air by chemical reactions, the scavenging of airborne particles by clouds and their subsequent deposition in precipitation, the dry deposition of particles as air moves across different landscapes, and the assembly of numerical models.

Through its long-standing involvement with WMO, ARL remains active in the study of turbidity (mainly involving the Silver Spring, Boulder, and Oak Ridge teams). Independently, ARL plays a strong role in the nation's research related to visibility (centered at Las Vegas). The two constitute a major program with a common theme of "atmospheric optics."

Visibility.

Since the transfer of SORD (Las Vegas) personnel from the National Weather Service to ARL early in 1994, a coherent program on atmospheric optics at the Nevada Test Site is slowly evolving.

The intent is to develop a research program at SORD that is consistent with the division's Department of Energy (DOE) support role at the Nevada Test Site (NTS) and with NOAA's research goals.

The organizational changes at Las Vegas served to consolidate a number of previously unconnected activities within the ARL/SORD program. As Chairman of the Grand Canyon Visibility Transport Commission Aerosol and Visibility Subcommittee, Marc Pitchford continued to participate in GCVTC activities, which have moved into an integrated assessment mode. An intensive meeting was held with the GCVTC Assessment Subcommittee in Denver, Colorado. The Assessment Subcommittee has selected contractors to design computer software that will combine all of the input data needed for an assessment (economic, social, emissions, atmospheric processes, optical effects, population growth projection, etc.) to allow policy makers to test the effects of various emission management options. The technical subcommittees are responsible for generating the required input data and evaluating the use of these data in the assessment. GCVTC recommendations on the protection of visibility at national parks and wilderness areas on the Colorado Plateau are required by law by fall of 1995.

Chairmanship of the Steering Committee for the Interagency Monitoring of PROtected Visual Environments (IMPROVE) Program also now resides within SORD. The IMPROVE organizational Memorandum of Understanding (MOU) was refined. This MOU is designed to formalize the cooperation and integration of visibility/aerosol monitoring sites, nationwide. Six federal agencies including NOAA, and three organizations representing state air quality control agencies cooperate in the management of IMPROVE. A final version of the MOU was ready for Agency review at the end of 1994.

Turbidity.

Two activities focus on atmospheric turbidity (or aerosol optical depth). The first activity is a consequence of earlier ARL participation in an extensive examination of turbidity data archived be NOAA on behalf of the WMO, and derived from sunphotometer observations at regional sites of the WMO Background Air Pollution Monitoring Network (BAPMoN).

With the redefinition of the WMO global monitoring activity, and the starting of a new Global Atmosphere Watch to subsume the highest quality components of BAPMoN, the question arose as to whether any elements of the BAPMoN turbidity program should be transferred to GAW. A four-member committee was set up by WMO to recommend actions. The report of this committee was prepared by ARL. In brief, the committee found few redeeming features in the current archive, and recommended that the long-standing sunphotometer observation program should be discontinued and replaced by a new program making full use of modern advances in the related science.

During 1994, the future of the GAW turbidity program was clarified. A formal report on a meeting of experts (hosted by ARL at the end of 1993) was prepared and is currently in press.

Rotating Shadow Bands.

The second activity relates to the development and optimal use of various kinds of rotating shadow band radiometers. There are three variations now in use, each with a specific purpose but each also employing an identical measurement philosophy — as much as possible to depend on the use of a single sensor to measure different irradiance components, to minimize difficulties caused by sensor deterioration and to minimize the consequences of different sensor performance characteristics when operating in a spatial array.

Some practical applications of atmospheric extinction data do not require exceedingly high accuracy but rather continuing long-term precision. Relative measurements that encapsulate changes in scattering conditions can be made at small cost but with lasting benefit. Such measurements include monitoring the relative magnitude of the direct and diffuse irradiance components in an optically active portion of the solar spectrum. A single sensor that is periodically shaded by a rotating shadow band provides adequate data for many purposes of this kind. The simplest form of rotating shadow band radiometer is of this type. A single silicon cell quantum sensor is mounted horizontally at the center of the sphere described by a rotating band, thick enough to provide a short period of shade but narrow enough to minimize errors in the measurement of total irradiance. Broad-band data are collected automatically, usually at intervals short enough to ensure that a representative fully-shaded value is reported for each brief pass of the shadow-band.

The data derived using this automatic device lend themselves to routine examination using a standard Langley plot approach. In addition, however, it is useful to quantify the variable $\mathscr{L} = (D/I).\cos(\zeta)$ from indicated values of the diffuse (D) and directly incident (I) radiation detected by the horizontal sensor, where ζ is the solar zenith angle.

Rotating shadow band sensors will be deployed at all radiation monitoring sites of ARL (ISIS Levels 1 and 2 - SURFRAD). The configuration addressed above is designed for ISIS Level 1 application. More advanced devices of the same general philosophy are used at all SURFRAD sites.

ATMOSPHERIC TRACER STUDIES

Studies of Air Mass Trajectories and Dispersion

Background.

The Field Research Division of ARL, in Idaho Falls, ID, has made a specialty of using atmospheric tracers to explore flow and dispersion in demanding circumstances and to test the predictions of models. A number of notable experiments have been conducted in past years, many involving other ARL divisions (particularly Silver Spring, Research Triangle Park, and Oak Ridge). The tracers of choice range from the fairly common sulfur hexafluoride to several far rarer perfluorocarbon compounds. Zero-lift tetroons are also used, sometimes fitted with transponders to relay their GPS position in response to radar interrogation.

Many model tests make use of the tower grid set up and maintained by FRD on the reservation of the Idaho National Engineering Laboratory. The FRD Grid III area is especially rich in meteorological and sampling sensor arrays. The winds at the INEL site are very predictable, leading to reduced experimental costs. FRD has received permission from the EPA and the State of Idaho to release several tracer gases over Grid III, in support of a number of effluent-detection test programs.

1994 Activity.

A March/April study was conducted at Fort Bliss in El Paso, Texas, to test the remote-sensing capabilities of a new Mobile Atmospheric Spectrometer (MAS) and to check chemical reconnaissance systems that are available for use in a battlefield environment. The MAS is a spectroscopic and radiometric measurement system designed to measure trace gas concentrations and profiles remotely. A 10 m tower with basic meteorological instrumentation was utilized, with five levels of vertical sampling supporting an array of ground samplers.

In July, FRD employed a new portable chemical dispensing system (necessitated for operator safety — some of the chemicals that were studied were hazardous) for a tracer study utilizing Grid III at the INEL.

"Smart" Tetroons.

During 1994, the FRD team worked on the design of adjustable lift tetroons for the ACE-1 study (of atmospheric chemistry over remote oceans), planned for late 1995 in the Southern Ocean. The tetroons will be used to help track the location of the air parcel being sampled.

The tetroons are designed to adjust their lift to compensate for any slow ascent or descent remaining after balancing for zero-lift at the time of launch. Previous experience indicated that it is exceedingly difficult to adjust the lift so that a standard tetroon will not "ditch in" to the ocean within 12 to 24 hours. The ACE-1 experiment is designed to track the changing atmospheric chemistry in a parcel of air that is identified by a marker tetroon, over a period of several days. The smart tetroon is intended to serve this purpose.

There is an additional important advantage of the advanced tetroon system to be used in ACE-1: the tetroons also carry a miniaturized Global Positioning System that automatically reports the balloon location to a receiving station some considerable distance away.

ETEX.

The Headquarters Division of ARL (Silver Spring) has been heavily involved with long-range tracer dispersion studies in North America. During 1994, the first European tracer release for evaluating dispersion model predictions was conducted. The ETEX sampler array is shown in Figure 1.

The European Tracer Experiment (ETEX) started with a series of tests of the models involved. Preliminary model results ("dry runs") showed large differences between some of the participants, especially in terms of maximum concentrations. It was suggested that a combination of large vertical shears in the horizontal wind and differences in vertical diffusion parameterizations lead to the large variations that were observed.

The first ETEX tracer release, from Brittany, occurred Sunday October 23, starting at 1600 UTC, after the passage of a trough. The expected transport pattern was right into the center of the ground-level sampling network. Aircraft sampling the next day, about 400 km downwind, measured tracer above the boundary layer. The NOAA plume forecasts agreed closely with those produced by the U.K. Meteteorological Office and the Canadian Meteorological Center.

A second tracer experiment was subsequently conducted, and results are currently being examined. About 20 dispersion modeling groups took part.

Figure 1. The network of surface samplers deployed for the European Tracer EXperiment (ETEX) of 1994 and 1995.

DISPERSION STUDIES

Basic Investigations of Plume Behavior

Background.

Classical studies of atmospheric diffusion have been conducted over simple surfaces -- flat, with homogeneous surface cover. The real world is substantially different. From the perspective of power plant siting, proper account needs to be taken of topographic influences, to ensure that topography does not direct emissions towards urban areas, sensitive ecosystems, etc. From the viewpoint of legal compliance, terrain effects can cause plumes aloft to contact the surface, resulting in exceedences that would not occur over flat land. These two views correspond, to a large extent, to the different focusses of complex terrain studies conducted at Oak Ridge and at Research Triangle Park, under DOE and EPA sponsorship, respectively.

Meanwhile, ARL workers at Idaho Falls and at Las Vegas are actively exploring new technologies for studying plume behavior, both in simple and in complex terrain.

ASCOT.

The ARL/ATDD group at Oak Ridge have been major participants in the DOE-sponsored Atmospheric Studies of COmplex Terrain (ASCOT) program for more than a decade. During 1994, work concentrated on dispersion regimes in the ridge/valley terrain of the Tennessee Valley. Data from an Oak Ridge meteorological site survey were used to study diurnal variations of wind speed and direction at various sites in the valley. Thermally driven circulations were found to be more important than anticipated. There is also evidence that flow through a gap in the western sidewall of the Tennessee Valley influences the observed winds at several sites west of Oak Ridge. Simulations generated by a hydrostatic mesoscale model are being used to support the data analysis. A number of modifications were made to improve the model's performance, simplify data input, and greatly increase execution speed.

Numerical simulations of the Tennessee Valley using a hydrostatic mesoscale model were conducted, starting with two sets of simulations representative of summer conditions, and a third set representing winter conditions. The simulations are being compared with tower observations collected in the Tennessee Valley (using the array illustrated in the accompanying summary of studies of nocturnal dispersion). Both the model simulations and the tower data show a distinct upvalley (southwest) flow during the day. At night, the tower data show some evidence of a general downvalley drainage flow, whereas the model simulations are more strongly influenced by drainage off the valley sidewalls. Attempts are now being made to quantify the relative importance of various flow mechanisms within the valley.

Preliminary calculations of gravity wave-induced drag on the planetary boundary layer using the ATDD hybrid PBL-gravity wave model were completed, with encouraging results. The one-dimensional time-dependent PBL model is initialized with an Ekman wind profile and a linearly increasing potential temperature gradient. The flow is simulated over a two-dimensional ridge. Wave stress is calculated every five minutes of the simulation, and the vertical divergence of the stress is added to the divergence of the turbulence stress. The wave-induced drag is found to strongly decelerate the PBL flow.

Plume Impaction.

Over the last decade, extensive studies of flow and dispersion over and around isolated hills culminated in the development of the EPA Complex Terrain Dispersion Model (CTDM). A family of specialized models has evolved from CTDM. During 1994, ASMD scientists completed a sensitivity test of the Industrial Source Complex - COMPlex terrain DEPosition (ISC-COMPDEP) model to various inputs including particle size distribution, particle density, scavenging coefficients, resolution of the particle size distribution, and terrain grid resolution. Maximum concentration and dry and wet deposition values were examined. The dry deposition values were found to be most sensitive to the specification of the particle size distribution. The wet deposition values seemed most sensitive to the specification of the scavenging coefficients.

The influence of terrain-generated downslope (or upslope) flows on pollution concentrations in plume impacts remains somewhat contentious. During 1994, the Journal of Applied Meteorology (JAM) received a comment on a 1992-published article on ASMD's Complex Terrain Dispersion Model (CTDMPLUS). It was asked if the estimates from CTDMPLUS were reasonable in the presence of downslope flow on the windward face of terrain. In response, it was stated that little is known about the influence of downslope flow on plume impacts. The published comparisons suggest that CTDMPLUS yields reasonable estimates even in the presence of downslope flows on windward terrain.

Plume Detection.

The "Crystal Mist" experiment was conducted on the Nevada Test Site in July, to test capabilities to track the dispersion of a silicon bead cloud (soda lime) released above the convective boundary layer. Remote measurements of the cloud were made using a Lidar.

The Crystal Mist study was jointly sponsored by the Department of Defense (DOD) and the Department of Energy (DOE).

ARL/SORD meteorologists wrote a program to calculate winds as frequently as the data would allow, for fine structure analysis of the atmosphere. Additionally, the standard SORD PIBAL software was modified to accommodate the many extra levels that were available from the body of meteorological data. The modifications allowed for up to 600 input levels and for a corresponding output capability.

At Idaho Falls, field support was given for another Department of Defense exercise, the Plume Dispersion Modeling Study. FRD developed portable chemical dispensing equipment for CONUS test/experiment sites. Grid III at the INEL is the standard field setting for such studies.

STUDIES OF NOCTURNAL DISPERSION

The Fallacy of Decoupling

Background.

It has long been assumed that atmospheric stability at night often becomes sufficient to prohibit turbulence and hence to permit pollutants aloft the be carried for long distances without ground contact. The various tracer studies conducted by ARL over the last twenty years (e.g. CAPTEX, ANATEX) have demonstrated that this argument is flawed. Vertical mixing can and does occur, even when stability regimes are conceptually prohibitive. The notion of intermittent bursts of turbulence arose, and has since developed into a central theme for many contemporary researchers.

Early studies of trace gas concentrations near the surface revealed the signature of a phenomenon that has since become more widely recognized: at night, periodic bursts of turbulence maintain "contact" among the various layers of the lower troposphere, and with the surface. The very intermittency of this phenomenon caused it to be overlooked in many early field investigations, since a micrometeorological "run" containing one of these bursts of turbulence would probably have been seen as "non-stationary" and would therefore have been excluded from the data sets selected for further scrutiny. Now, it is known that the "noise" of previous researchers has become the "signal" that it is now necessary to understand.

Nocturnal Turbulence and Gravity Waves.

Nocturnal mixing and the evolution of the nocturnal boundary layer are specialties of Oak Ridge ARL researchers. Turbulent breakdowns of the stable planetary boundary layer (PBL) receive special attention. Data from an intensive study of wind fields in the Oak Ridge area were reanalyzed. PBL breakdowns were detected using both conditional sampling of the wind speed-temperature covariance time series, and wavelet analysis of the wind speed and temperature time series. A specific goal was to relate the statistics of the PBL breakdown events (e.g., number of breakdowns per night, duration of the breakdowns, breakdown strength) to the PBL stability. These events are likely major contributors to nocturnal dispersion and air-surface exchange.

The study of interactions between turbulence and atmospheric gravity waves has historically been directed at the middle to upper atmosphere, where waves play an important dynamic role. It is now known that in the nighttime planetary boundary layer, say within the lowest 1 km of the atmosphere, gravity waves are also important, especially over hilly terrain. For example, hills and ridges with height and width scales of 100 m and 1000 m respectively can generate vertically-propagating gravity waves under typical nighttime conditions. These waves can grow in amplitude as they propagate upwards. If the amplitude grows too great, then the waves can break down, generating regions of turbulence and enhanced dispersion. "Clear air turbulence" is a related phenomenon. Such processes are not considered in conventional turbulence and dispersion expressions, and hence turbulence and diffusion in the nighttime lower atmosphere are often underestimated. The research under way at Oak Ridge focuses on how to account for wave-generated turbulence and dispersion in numerical models.

An experimental component to this investigation involves an array of surface towers set up in ridge/valley terrain of the Tennessee valley. Figure 1 shows the tower array constructed (the Regional Atmospheric Measurement and Analytical Network — RAMAN) by bringing together capabilities of several organizations and augmenting this array with towers operated by NOAA/ATDD.

Nocturnal Dispersion.

The Army Research Office/ARL Workshop on Turbulence and Diffusion in the Stable Planetary Boundary Layer was held at Arizona State University (Tempe). The meeting was hosted by the Department of Mechanical and Aerospace Engineering. The workshop was well attended, and considerable discussion followed each presentation. A detailed report is in preparation.

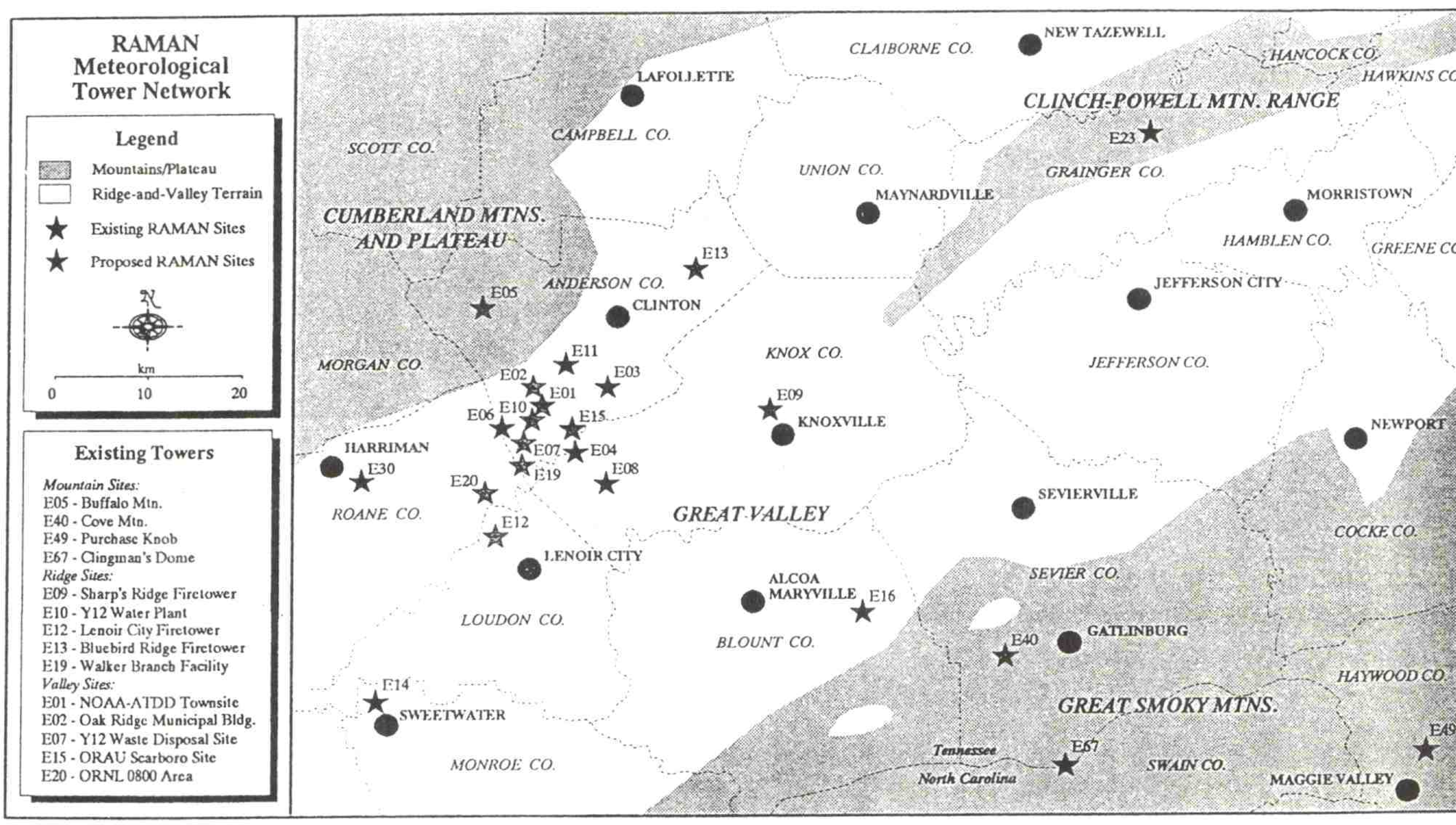


Figure 1. The RAMAN network in eastern Tennessee, set up to investigate the extent and causes of gravity waves and nocturnal turbulence bursts.

AIRCRAFT WAKE VORTICES

ARL Studies Related to Aircraft Safety

Background.

For many years, the ARL Field Research Division (Idaho Falls, ID) has conducted studies of the magnitude, persistence, and motion of the vortices left by commercial and some military aircraft. A test range on the Idaho National Engineering Laboratory reservation is instrumented with tall towers carrying meteorological instrumentation and photographic equipment to record the wake vortices left by an aircraft flying between them. Studies of this kind have provided critical information used by the Federal Aviation Administration to specify, for example, safe distances for small aircraft to land or takeoff after larger aircraft.

The unfortunate fatal crash of a Westwind corporate jet at John Wayne Airport in Orange County California in late 1993 generated widespread interest in the aircraft wake vortex problem. The Westwind was following a Boeing 757, an aircraft which was studied for its vortex characteristics by FRD in 1990. The FRD work received wide visibility because of this study and the recent crash. FRD personnel who took part in the B-757 wake vortex study were interviewed by newspaper and television reporters. In addition, a series of articles appeared in Airline Pilot, the official magazine of the Air Line Pilots Association, depending heavily on the FRD data. A subsequent article in *Aviation Week and Space Technology* also cited the FRD's research.

1994 Activities.

Flight safety, aircraft operations, and procedures for air terminals continued to be a news media and industry concern through 1994. Periodic media treatments kept the issues before the public and aviation industries. In July, Gene Start of FRD provided testimony to the House subcommittee on Technology, Environment, and Aviation. The hearing was on operational procedures for aircraft following the Boeing 757 aircraft within terminal area airspace. The 1990 NOAA tower flyby characterizations of the Boeing 757, which included the B-757 wake turbulence data sets and the report summarizing those findings, were an important part of that review. The hearing concentrated on whether or not there was a procedural flaw in the FAA operational planning and incorporation of research findings into their air traffic control protocols.

As a result of the continued attention, and in recognition of gaps in current understanding, the entire issue of aircraft wake turbulence was re-addressed during 1994.

A reanalysis of the B-757 data previously obtained by FRD was sponsored by FAA. The reanalysis focused on the relationship of vortex demise with ambient atmospheric turbulence. In parallel activity, new studies were sponsored by FAA in support of aircraft wake turbulence avoidance and enhanced airport traffic capacity. An initial meeting was conducted at NASA-Langley in late January, with representatives of DOT, FAA, NASA, and NOAA (ARL/FRD). It was concluded that DOT, FAA, NASA, and NOAA should form a technical advisory group to formulate plans and review proposed research aimed at resolving the knowledge gaps.

A reanalysis of 1990 data obtained by FRD on wake vortices from B-727 and B-767 aircraft was also initiated, with a focus on deriving a relevant turbulence statistic from the hot film anemometer data, to describe vortex demise. The goal is to determine a relationship of atmospheric turbulence with vortex decay.

The search for relevant turbulence quantities was extended to a field investigation using new remote-probing instrumentation. In October, 1994, a new lidar (developed by MIT Lincoln Laboratory) for measuring aircraft wake vortices was deployed at the Memphis, TN, airport. The lidar development had been funded by NASA. For this study, FRD characterized atmospheric variables, including various turbulence and flux quantities. FRD also installed a RASS radar profiler and sodar at the Memphis airport, to determine upper air turbulence characteristics. The field study ended in December.

The 1990 FRD data on B-757 and B-767 aircraft were the foci of a Wake Vortex Workshop held in Cambridge MA. This data set has become the new standard for testing vortex decay models. International participants included delegations from Canada, Germany, Great Britain, and France.

FRD was also invited by the Canadian government to review wake vortex work currently underway in Canada. The new effort uses the FRD 1990 wake vortex data in an international cooperative effort. The review will consider modeling work being done by Russian scientists under Canadian contract on Boeing 757 and 767 aircraft.

Several calculation algorithms were developed for modifying vortex velocities as used in circulation calculations. These were: 1) averaging the velocities on both sides of the vortex, 2) folding the data from one side of the vortex onto the other side using a least-squares fit, 3) using the data from the half of the vortex that was unaffected by the tower. Evaluations of these and other potential mechanisms for extracting additional information from the field data set continued into 1995.

FLUID MODELING

Background.

The Fluid Modeling Branch of the Atmospheric Sciences Modeling Division in Research Triangle Park conducts laboratory simulations of flow and dispersion in complex flow situations, including flow and dispersion in complex terrain, around obstacles such as buildings, and within dense gas plumes. The Fluid Modeling Facility employs large and small wind tunnels, a large water channel/towing tank, and a convection tank.

The large wind tunnel has a test section 18.3 m long, 3.7 m wide, and 2.1 m high. It has an airflow speed range of 0.5 to 10 m/s, and is generally used for simulating transport and dispersion in the neutral atmospheric boundary layer.

The towing tank has a test section 25 m long, 2.4 m wide, and 1.2 m deep. It has a speed range of 0.1 to 1 m/s, and the towing carriage has a range of 1 to 50 cm/s. Generally, the towing tank is used for simulation of strongly stable flow; salt water of variable concentration is used to establish density gradients in the tank, which simulate the nighttime temperature gradient in the atmosphere.

A convection tank measuring 1.2 m on each side and containing water to a depth of 0.5 m is used to study the convective boundary layer and flow and dispersion under convective conditions.

Terrain Downwash Study.

At the request of the EPA, a wind-tunnel study of terrain downwash at the Waste Technology Industries (WTI) hazardous waste incinerator located in East Liverpool, OH, was conducted. A peer-review panel that examined the draft risk-assessment plan expressed concern that terrain-induced downwash could be a problem in the deep Ohio River valley at this site and recommended a wind-tunnel.

A model of the terrain was constructed at a scale ratio of 1:480, representing a full-scale section approximately 0.5 km wide and 5 km long. The river valley itself is approximately 150 m deep. The wind direction chosen was that expected to produce the most severe terrain-downwash effects, *i.e.*, with the most prominent hill directly upwind of the stack. This model, centered on the incinerator stack, was placed in the meteorological wind tunnel, with a simulated atmospheric boundary layer approaching it. Figure 1 shows a view of the model installation.

Methane was metered from the model stack as a tracer to simulate the buoyant effluent, and flame ionization detectors were used to measure concentrations, primarily ground-level values, downwind. Three stack heights were examined, including the existing stack height of 45.7 m, the calculated good-engineering-practice stack height of 72.7 m, and an arbitrarily chosen "tall" stack height of 120 m (about 80% of the valley depth). For each case, concentration patterns were measured over a range of wind speeds to ascertain the maximum possible ground level concentrations. The model was then rotated 180° and a similar set of measurements was made. Finally, the terrain model was replaced by a flat-terrain model to quantify terrain effects relative to flat terrain.

Nearly 50 cases were studied, to take into account the two dominant wind directions in the complex terrain as well as in the flat terrain, the three stack heights, and several wind speeds for each combination of the above conditions. Most of the measurements were used to develop surface concentration maps. These maps reveal that there is some slight indication of the plume being directed around the south side of this first hill.

Whereas a large number of surface maps and vertical profiles of concentration as well as flow-structure and turbulence measurements were made, the results are difficult to interpret from a scientific viewpoint.

Many interacting factors contribute to the differences in the ground level concentration patterns observed as a result of emissions from the WTI site and those observed from the same source in flat terrain. The upwind hills tend to reduce the wind speeds at the stack top, which should increase the plume rise and reduce the maximum ground level concentrations. On the other hand, the upwind hills tend to produce downward wind velocities at stack top and to increase the intensity of ambient turbulence; both these effects tend to increase the concentrations. The downwind hills also tend to increase ground level concentrations, but the degree of increase depends upon the hill shape. Building influences were also observed, although the present study was not designed to investigate such. In spite of our inability to isolate and describe in detail the specific causes of the results, the broad picture is understood, and the concentration patterns and values should be eminently usable for the intended purpose.

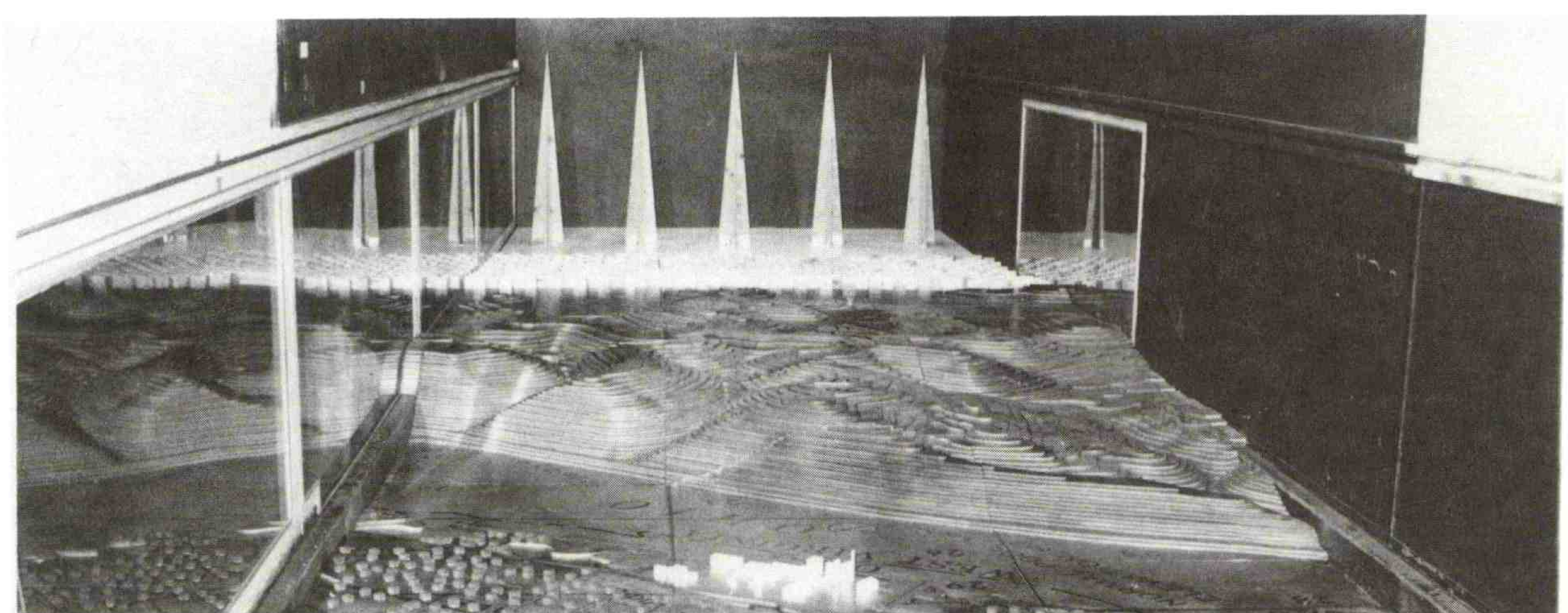


Figure 1. The physical model of the surroundings of the Waste Technology Industries hazardous waste incinerator, in East Liverpool, Ohio, as deployed in the wind tunnel.

HEAVY GAS DISPERSION

The Nevada Spills Test Facility

Background.

Critical health and safety issues arise when heavy gases are accidentally released into the atmosphere. Such gases are life threatening because of their behavior in the atmosphere. The dangers arise when volatile vapor clouds drift downwind. The concern is particularly intense in regions of chemical industry and in areas around facilities handling liquified natural (or petroleum) gas. There have been many spills that have underlined the hazards involved, culminating in the Bhopal (India) disaster of several years ago.

The physics involved is complicated, since gases spilled as liquids are subject to a surface phase change that complicates the thermodynamics of the dispersion process, and because the gases generated may well drift downhill, regardless of the direction of any prevailing wind. A key requirement is to provide some objective methodology to predict when the terrain slope effect will dominate the wind, and vice versa.

It was partially to answer questions such as this that a Liquefied Gaseous Fuels Spill Test Facility (LGFSTF) was constructed on a dry lake bed at Frenchman's Flat, on the Nevada Test Site and operated by the Department of Energy. The LGFSTF affords contracting agencies and companies the opportunity to conduct controlled spills of hazardous chemicals to assess mitigation techniques, protective measures and chemical behavior. Various ARL groups work in conjunction with the spills facility, to help study the behavior of large spills of volatile liquids.

The ARL Connection.

FOUR ARL groups are involved in studies at the Nevada spills facility.

- SORD (Las Vegas) provides climatological services for experimental planning, meteorological monitoring during the experiment phase, and weather forecasts in direct support of the experiments. SORD meteorologists also provide weather briefings and transport and dispersion estimates to the test management team. A SORD meteorologist serves on the LGFSTF DOE Safety Advisory Panel.

- ASMD (Research Triangle Park) has represented EPA interests in the operations at the spills facility. Bill Petersen has served as the convenor and chairman of an interagency committee coordinating scientific studies utilizing the spills facility.

- ATDD (Oak Ridge) has developed dense gas dispersion routines ready to be tested against data obtained at the facility, and participates in the related research planning.

- FRD (Idaho Falls) has conducted several studies at the facility, employing atmospheric tracers. These studies have been conducted for other agencies, addressing the need to detect trace quantities of airborne gases using remote probing techniques.

Wind Tunnel Tests.

A detailed experimental plan was developed for wind tunnel tests of candidate roughness arrays to be used in the field in conjunction with dense gas releases at the LGFSTF. The release site, a dry lake bed, is extremely smooth (roughness length = 0.2 mm), while the petroleum industry-sponsored Petroleum Industry Environmental Research Forum (PERF) experiment scheduled for August 1995 requires at least 100 times this roughness. Four different arrays of flat baffles facing the wind will be tested in an exploratory physical modeling program, with an option to test an altered version of the best array to achieve improved results.

1994 Field Studies.

The CO_2 and meteorological data from last summer's dense gas experiments at the DOE Liquified Gaseous Fuels Spill Test Facility, Nevada Test Site, were analyzed to provide guidance for design of the instrument array for the next tests to be performed in September 1994. It was found that last year's results agreed quite well with the predictions of simple algorithms resembling the Britter-McQuaid equations and nomograms. These plume depth, plume width, mean concentration, and maximum concentration algorithms were used to design sampler arcs for the 1994 experiments, in which dense gas releases were conducted at lower wind speeds and with stronger stability than ever before attempted.

A listing of specific experiments conducted at the Spills Facility is as follows.

1. Effluent Tracking Experiment #1 (ETE #1). The purpose of the ETE #1 was to characterize stack emission concentration profiles of simulated chemical manufacturing processes. The experimental series started in January, 1994, and lasted about three weeks.

2. Evaporation Rate Measurements from Chlorine and Ammonia Liquid Pools (ERMD). This program was designed to measure evaporation rates of chlorine and ammonia from spilled liquid pools. The program took place in August 1994.

3. Effluent Tracking Experiment #2 (ETE #2). This was a second experiment in the series initiated in January, this time taking place in August, 1994.

4. Dupont's Hands-On Training in the Mitigation and Cleanup of Sulfur Based Fuming Acids. The purpose of this experiment was to conduct mitigation and cleanup training on small spills of Sulfur Trioxide, 65% Oleum, and Chlorosulfonic Acid. The study took place in September.

5. Remote Sensor Test Range Program (RSTR). The RSTR program was designed to produce well-characterized, open-air plumes containing various concentrations of chemical vapors and aerosols, for testing remote sensing methods of detection. This test series was conducted in October 1994.

RSMC WASHINGTON

Regional Specialized Meteorological Center for Transport and Dispersion Model Products

Background.

As a result of the poor communications between countries following the Chernobyl accident in the Spring of 1986, the World Meteorological Organization (WMO) was asked by the International Atomic Energy Agency (IAEA) and other international organizations to arrange for early warning messages about nuclear accidents to be transmitted over the Global Telecommunications System (GTS). In addition some WMO member countries lacking extensive forecasting capability requested that specialized pollutant transport and dispersion forecasts be provided during these emergencies.

In 1989, Regional Specialized Meteorology Centers at Toulouse, Bracknell and Montréal were set up under interim arrangements between the WMO and the IAEA. Under these arrangements Meteo-France was to provide global coverage (with Bracknell as the backup center) until each WMO region had at least two RSMCs for transport model products.

The need for rationalization of transport and dispersion forecasts became even more apparent during the oil fire emergency after the Gulf War, when many organizations provided ground personnel with predictions of the smoke plume behavior. These predictions were often misleading; there was no existing and well-recognized system to sort out the predictions from less experienced sources.

In November 1992, a demonstration of NOAA's RSMC capabilities was made to the WMO's Commission for Basic Systems (CBS) during their Tenth Session. Following this demonstration, the NOAA RSMC was accepted by WMO and subsequently became effective 1 July 1993. The addition of RSMC Washington resulted in two RSMCs per WMO region - Washington and Montréal for RA IV and Toulouse and Bracknell for RA VI - and indicated the need to revise the interim arrangements. Under the new global arrangements, Region IV will be responsible for parts of Central and South America Region III), while Toulouse and Bracknell would cover the remaining Regions I and II (Africa and Asia). These new global arrangements were finalized at the WMO/CBS session in August 1994.

Recently, a fifth RSMC has been set up, in Melbourne, Australia, to provide products for Region V (western Pacific). The Melbourne RSMC has been initiated using some of the Washington (i.e. ARL) procedures and dispersion models. The RSMCs in Washington and Montréal will provide backup to Melbourne.

Structure.

The RSMC Washington is a joint venture between the NWS National Meteorological Center (NMC) and the Air Resources Laboratory, merging the forecast skills and operational capabilities at NMC with the pollutant dispersion modeling and analysis capabilities of ARL. In essence, NMC provides the 24 hour per day initial contact point for assistance requests. In the event of an accident, the NMC operational staff connect to ARL's computer system, which is continuously updated with NMC forecast model output fields. Customized transport and dispersion models would then be run. Model outputs would be distributed automatically to predesignated country representatives.

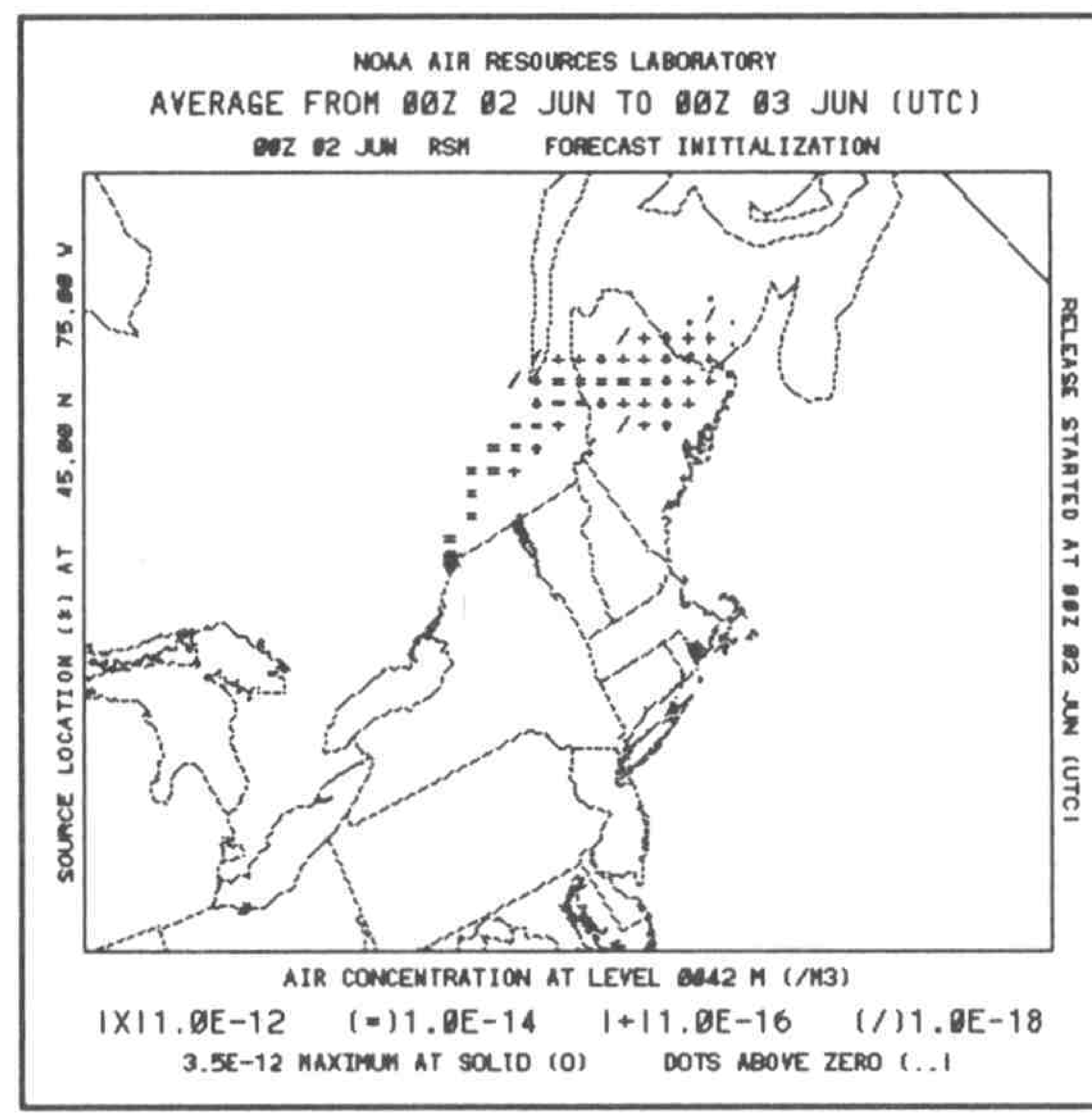
After the initial response by NMC the operational responsibility would be transferred to ARL, which at that point might modify the dispersion model products to more accurately reflect the conditions of the accident. The ARL response capability to assist in the RSMC's operation has been developed through various automated systems processes that link a telephone pager to a facsimile, E-mail, and GTS message center.

By agreement with the Canadian Meteorological Center (CMC), RSMCs Washington and Montréal will respond jointly to emergencies in their region of concern, each sending products to countries requesting assistance, as well as consulting with each other regarding model output differences, product interpretation, and uncertainty. Regular monthly tests are conducted with the CMC.

Recently, a joint project was initiated between ARL and NMC to develop a more operational coupled meteorological-dispersion model. Modifications are being made to NMC's Regional Spectral Model (RSM) to permit its application over any region of the globe. RSL model outputs will be linked directly with ARL dispersion models.

Example.

The standard model products to be distributed include forecasts of trajectories, air concentrations, and deposition. The following illustration shows the 24 h average air concentrations, forecast for a hypothetical release (presumed to be near Montréal) using the meteorological forecast data from the 40 km version of the RSM. There is a continuing program intended to identify occasions in which differences in RSMC predictions arise, and to find the causes for these differences. Dispersion model differences are partly due to differences in meteorological model's spatial resolution as well as the effects of the Lagrangian or Eulerian methods used to compute the pollutant dispersion. Prediction differences will have to be addressed by emergency planners when confronted by multiple model output products. Regional RSMCs (such as Washington and Montréal) plan to issue statements on differences between their products.



THE VAFTAD MODEL

Volcanic Ash Transport Forecasts To Protect Aviation Operations

Background.

Volcanic ash presents a danger to air traffic. Jet engines, in particular, are susceptible to malfunction if operated in a plume of volcanic ash. ARL is a partner in a multi-institutional collaborative activity designed to provide air traffic with warnings of the presence of volcanic ash along air routes. The other partners include the FAA, USGS, NWS, and NESDIS.

The VAFTAD Model.

As part of its emergency preparedness activities at Silver Spring, the Air Resources Laboratory has developed a Volcanic Ash Forecast Transport and Dispersion (VAFTAD) model for volcanic hazards alerts. The VAFTAD model:

- focuses on aviation operations by forecasting the visual ash cloud in both time and space,

- is user run, at any time, connected through INTERNET to an ARL workstation, using screen-prompted model input, and

- automatically telephones facsimile output charts of the forecast ash cloud to predesignated recipients; output is also made available over weather information distribution systems.

The model is coupled in realtime with National Meteorological Center (NMC) forecast meteorological fields and is designed to serve all of North America using a fine scale grid and the entire globe using a coarser scale grid. ARL updates and archives the NMC meteorological information twice daily. VAFTAD calculates the location of the volcanic ash cloud from a column extending from the volcano summit to the top of the plume. For aviation operations, calculated ash air concentrations have been correlated with ash clouds detected by satellite imagery for defining the visual plume.

Applications during 1994.

The accompanying figure is an example 8-panel chart of the forecast visual ash cloud, as routinely distributed over DIFAX. The four panels in any column are for a single valid time after eruption. Individual panels are for layers useful to aviation operations and are identified at the side of the panel with layer top and bottom heights. Following aviation practice, flight levels (FL) are reported in hundreds of feet. The bottom panel is a composite layer, from the surface to the top of the model. For each column, the valid time is given. Volcano emission information is given at the lower left, along with the run description. Three such charts are normally produced and distributed, representing different forecast periods. When viewed in sequence, the set gives an easily visualized time dependent view of the forecast ash cloud.

VAFTAD is continually available for emergency response operations. The initial run is typically completed within ten minutes; updated runs with the latest meteorological information can be continued for several days following an eruption. A continuing ARL verification program for VAFTAD has included three eruptions of Spurr in Alaska (June, August, and September, 1992), eruptions of Rinjani in Indonesia (June and July 1994), and a

24 hour eruption of Klyuchevskoi in Kamchatka, Russia (September 1994). Results comparing model ash forecasts with satellite imagery have been most encouraging.

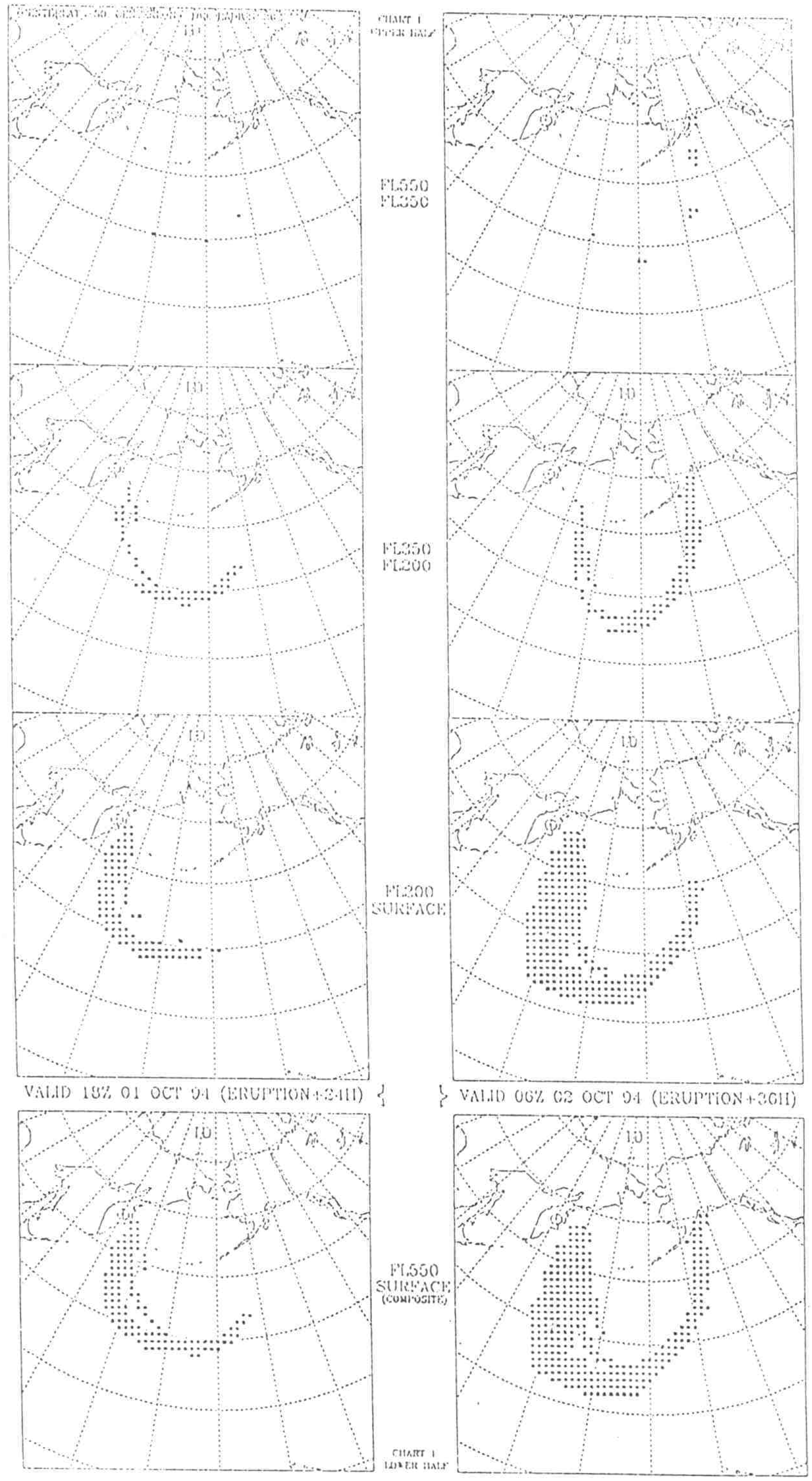


Figure 1. An example of the VAFTAD forecast output, as distributed in the even of a volcanic eruption.

A WMO/GAW SCIENCE ACTIVITY CENTER FOR THE AMERICAS

Background.

Recent WMO meetings (and a flurry of reports) have emphasized that the global monitoring of air and precipitation chemistry is in sad shape. In particular, there has been no process by which the quality of even the most basic environmental measurements can be assured. Major problems arose in the operations of so-called Regional Stations (measuring precipitation chemistry, atmospheric turbidity, and atmospheric particle loadings, for example); the data reported by research-grade global atmospheric observatories have not been so widely criticized. A fresh start is now being made, with a new Global Atmosphere Watch (GAW) forming the framework for a nested network of refined regional and global observing stations. This new network will subsume and replace the BAPMoN (Background Air Pollution Monitoring Network) activity of earlier decades. In essence, the Global Atmosphere Watch is a coordinated system of networks of observing stations, facilities, and arrangements, encompassing the many measurement programs devoted to the investigation of the changing global atmosphere.

A central goal of this activity is to permit data from individual national monitoring networks to be combined seamlessly, to provide the basis for sound regional environmental policy. To this end, a small number (three, or possibly four) of Quality Assurance Centers. One of these is to be sponsored by Germany (covering Europe and Africa), and another by Japan (covering Asia and Oceania). A provisional commitment has been made by NOAA to lead in the setting up of a center to cover the Americas. This is among the highest priority of all activities currently being promoted by the WMO. Because of its historic leadership in studies of precipitation chemistry and atmospheric radioactivity, and because of its recent role in atmospheric turbidity, NOAA/ARL is the lead organization for setting up the QA/SAC (Science Activity Center) for the Americas. The QA/SAC is operated by the State University of New York, at Albany.

The prospect is exciting, because for the first time there exists an opportunity to put in place rational and effective standard operating procedures world-wide, before a new generation of measurement programs commences. It is not intended to interfere with programs that are already working well, but to extend the experience of these programs to other topical areas that are currently seen as being vulnerable.

Initial Activities.

The WMO QA/SACs are established in accordance with general guidelines developed for WMO by a panel of experts (WMO GAW Report No. 80). A second meeting of experts developed a set of specific guidelines and recommendations for the functions and implementation of these QA/SACS.

It was initially estimated that a credible activity would require an annual budget of about $300k. At present, three U.S. agencies are directly involved: EPA, DOE, and NOAA. In the future, contributions from other sources will be sought.

Precipitation chemistry, atmospheric radioactivity, and surface ozone were identified as subjects for immediate attention by the new QA/SAC (Americas). In each case, the initial focus for the QA/SAC will be on designing quality control procedures for aligning relevant data collected at stations in the Americas, and on implementing quality assurance steps leading to an archiving function. It is intended that topics being addressed by the QA/SAC (Americas) will be expanded as the program continues.

Interactions with Data Centers.

The QA/SACs are an integral part of a tripartite structure — GAW sites, QA/SACS and Data Centers. The activities of the QA/SACs are loosely divided into "network-wide" and "center-specific" tasks. The "center-specific" tasks can again be subdivided into those associated primarily with data flow, those associated primarily with quality assurance support, and those designed to ensure affective communication and dissemination of information between the various partners.

a) Network-wide

Network-wide activities are related to the operations of the QA/SACs, which are conceived as forming a closely linked structure with minimum duplication and close coordination of activities. Many of the activities are much the same in all centers, but focused on a different group of sites. A system will be developed for close coordination and networking between centers. Thus responsibility should be allocated for the following activities:

- General networking and information exchange. All the information described under the center-specific functions must be passed on to the other QA/SACS to ensure maximum benefit to all network participants. In many cases joint activities (workshops, newsletter, etc.) will be more appropriate than single-center activities.

- Avoidance of duplication. Procedures should be developed to ensure mutual coordination of all development activities and to minimize duplication across the network.

- Assurance of parsimony. Care must be taken to guard against unwarranted or unnecessary attention to detail in any specific area of concern. A balanced measurement program is desired, without any part being of unacceptably low or unnecessarily high quality. Efforts to continually improve data quality should be moderated by consideration of why the data are being obtained.

b) Center-specific

From the communications point of view, the most important aspect of data flow is the development of methodologies to facilitate the uninterrupted and reliable recording and transfer of data from the site, through the QA/SAC, to the data center. This includes:

- Defining and reaching agreement on a standardized data format;

- Developing (identifying within the network) archiving software for recording of data, which can be made available to sites;

- Developing software for testing the acceptability of data sets and repackaging data into component parts for transfer to the data centers;

- Developing a schedule for transfer of data.

Quality assurance support activities include:

- Developing the schedule for quality control activities (site visits, performance and systems-audits, etc.).

- Designing and conducting of experiments, either to resolve discrepancies observed during review of data from individual sites, or in response to a request from a data center (to resolve discrepancies between data and different regions).

- Promoting close links between sites with more experience in the type of measurements required, and those where increased training is desirable. (Such twinning arrangements are likely to be the most effective means of ensuring rapid upgrading of all measurements in the network to the same high standard.)

- Reviewing site locations periodically, (a) to ensure that the locations are sufficient to meet the requirements for any new scientific objectives included in the program, and b) to identify possible gaps resulting from fundamental changes in site locations identified during routine quality assurance checks.

- Allotting station performance ratings according to well-defined definitions, and recommending removal of a station from the network if data are continually found to be of poor quality.

- Developing procedures for raising awareness of technological changes and ensuring efficient technology transfer within the network.

- Conducting instrument comparison workshops, and promoting improvements in instrumentation.

- Establishing research ties with those members of the scientific community who are potential users of the GAW data.

Program Oversight.

The QA/SACS are planned to receive direction and advice from the scientific community and interact with it through three formal mechanisms:

- The WMO Executive Council Panel/CASWG on Environmental Pollution and Atmospheric Chemistry (EC Panel). The specification and prioritization of science and science policy driven objectives will be developed under the guidance of the WMO EC panel and with the support of the QA/SACs.

- International Scientific Programs in Atmospheric Chemistry and Aerosols. At present primary examples of these programs include the International Global Atmospheric Chemistry (IGAC) Program and the International Geosphere Biosphere Program (IGBP).

- Science and Technology Advisory Panel. In addition, to enhance interactions between the QA/SACs and the scientific community, each QA/SAC has a Science and Technical Advisory Panel (STAP) to provide advice on matters concerned with site selection, instrumentation selection, instrument calibration, auditing procedures, etc.

INTERNATIONAL ACTIVITIES

Collaborations with Foreign Scientists

Background.

ARL participates in a number of international collaborations, as required to accomplish its mission and as appropriate to further related scientific research. ARL policy is governed by the recognition that the air quality of the United States is slowly improving, in response to regulatory actions and emission controls, while that of other parts of the world continues to deteriorate. The atmospheric environment of North America will doubtlessly become increasingly susceptible to emissions from locations over which the United States can exert no direct control. It is the goal of ARL international activities, therefore,

- to monitor such aspects of the global atmospheric environment so as to reveal the response of the atmosphere to changes in emissions in distant places,

- to construct integrated models capable of predicting future changes, and to quantify the effects of these changes on North America, and

- to encourage the development of local capabilities to provide relevant data.

The research component of these activities is viewed as an extension of the research programs now under way in the U.S. A controlling consideration is the need to detect the effects of changes in emissions, with demonstrable confidence, as soon as possible.

Egypt.

The Field Research Division, Idaho Falls, has been participating in a site-assessment model development program at El Dabba, Egypt, with the Egyptian Nuclear Power Plant Authority and the Atomic Energy Authority. Support from FRD continued through 1994.

Eastern Europe.

An extensive activity was begun, to improve eastern European programs now measuring wet deposition and to work towards a coordinated U.S.-style dry deposition program. In Poland, efforts are underway to establish two stations (near-urban and background) that will meet Western quality assurance objectives. In the Czech Republic, the wet and dry deposition monitoring station established in 1993 at Rudolicze is now fully operational. ARL has also participated in exploratory studies in Hungary.

Other eastern European countries are less advanced. To ensure that a common message was heard by all of the emerging countries in eastern Europe, a workshop was held in December, in Garmisch-Partenkirchen, Germany. The intent was to plan a long-term comprehensive deposition network for Central and Eastern Europe, in collaboration with the existing European EMEP program and with the WMO's Global Atmosphere Watch. Ten countries from Eastern and Central Europe participated.

Australia.

The ATDD-designed open-path infrared gas analyzer (IRGA) has proved to be widely popular among the flux-measuring CO_2 research community. Seven of the instruments are now in use in Australia and New Zealand. Personnel from ATDD fitted IRGAs to Flinders University's Cessna 340 and their Grob motor-glider. Tests of possible water valor contamination were conducted at CSIRO/DEM in Canberra, also during 1994. (The ATDD IRGA had negligible contamination.)

Italy.

ATDD has been working with the University of Tuscia (Italy), on the setting up of an international network to monitor CO_2 fluxes over terrestrial ecosystems. An inaugural workshop was held, in December. The goal was to establish an *ad hoc* global network to directly address the issue of the missing sink in the global carbon balance.

China.

Field tests of the rotating shadow band approach to atmospheric turbidity measurement are being conducted at sites in China, in cooperation with the WMO Global Atmosphere Watch.

New Zealand.

The New Zealand meteorological service is now an operational VAFTAD user.

Spain and South Africa.

The ARL Dry Deposition Inferential Method for evaluating dry deposition continues to receive favorable attention. The latest countries to settle on the DDIM approach have been South Africa and Spain.

Canada.

Lester Machta was the long-time Chairman of the Air Quality Advisory Board of the International Joint Commission. Lester stepped down in late 1993, and ARL is now represented on the Board by Rick Artz of Silver Spring.

Russia.

ARL provides the Chairmanship (Frank Schiermeier, ASMD) of the U.S./Russia Working Group 02.01 on Air Pollution Modeling, Instrumentation, and Measurement Methodology. During 1994, a working group meeting was held in St. Petersburg. Additional meetings explored the two operative bilateral agreements, the 1972 Nixon/Podgorny and the 1993 Gore/Chernomyrdin agreements. No decision was made on which of these might subsume the other, but the same scientists appear to be involved in both.

A cooperative project with the Moscow Physics Institute was commenced, to study Krypton-85 in the atmosphere. Kr-85 is a byproduct of nuclear fission that could possibly disrupt natural atmospheric electrical fields.

Mexico.

With the signing of the NAFTA treaty, a new emphasis is being placed on linkages with Mexican environmental scientists.

NAFTA.

ARL has participated in discussions on the environmental aspects of the North American Free Trade Agreement. Tom Watson (FRD, Idaho Falls) attended the NAFTA Quality Assurance organizational meeting, held in Queretaro, Mexico during November. The purpose of the meeting was to start forming an organization which will ensure that the environmental measurements made in the three NAFTA countries are comparable.

NATO.

The North Atlantic Treaty Organization Committee on Challenges on Modern Society (NATO/CCMS) was established in 1969 to improve communications among member countries on the task of providing a better environment. ARL provides the U.S. representation on the CCMS Pilot Study on Urban Pollutant Dispersion near Coastal Areas and the CCMS Scientific Committee for International Technical Meetings (Frank Schiermeier).

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