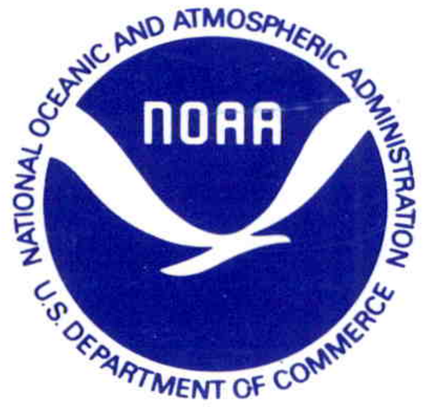
AIR RESOURCES LABORATORY
1992 REPORT



U. S. Department of Commerce

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

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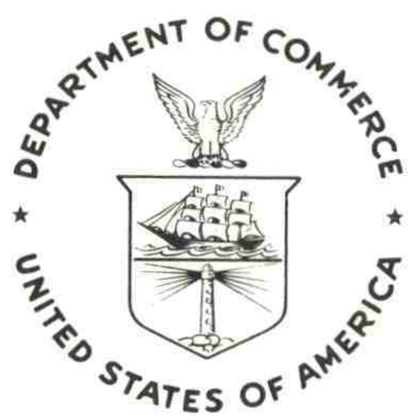

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Contents

1. Overview of ARL

1.1 Mission, Structure, and Themes

ARL conducts research for NOAA and for other agencies, on processes that relate to air quality and climate. These efforts concentrate 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 purpose is to improve the capability to make accurate forecasts and predictions related to the state of the atmospheric environment. 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. ARL research is oriented around three major themes, as follow.

1. Air Quality and Dispersion *(air-surface exchange/micrometeorology; acid deposition; ozone and oxidants; aerosols and visibility; toxics)*

2. Emergency Preparedness *(nuclear; volcanoes; large fires; dense gases)*

3. Climate Trends and Variability *(solar radiation, including IR, UV; meteorological trends; desertification)*

Work on all of these themes is multi-organizational within ARL, and requires extensive interaction with other agencies. The issues addressed by these programs relate to environmental effects, human exposure, and societal impact.

ARL operates four research divisions —

- Headquarters Division — Silver Spring, MD
  — FOCUS: TRANSPORT, WET DEPOSITION, AND CLIMATE CHANGE

- Atmospheric Sciences Modeling Division — Research Triangle Park, NC
  — FOCUS: INTEGRATED MODELING

- Atmospheric Turbulence and Diffusion Division — Oak Ridge, TN
  — FOCUS: TURBULENT DISPERSION AND EXCHANGE

- Field Research Division — Idaho Falls, ID
  — FOCUS: AIR QUALITY TRANSPORT AND MODEL EVALUATION

In addition, a Surface Radiation Research Group operates in Boulder, Colorado, as a field component of the Headquarters Division. Its focus is on solar radiation

1.1.1 Air Quality and Dispersion — Theme 1

ARL provides meteorological expertise to NOAA and to other agencies related to all air quality issues, including acid deposition, toxics, ozone and oxidants, sulfur oxides,

particulate matter, and radioactivity. In many instances, the products derived from physical and numerical studies take the form of improved models. A general goal is to develop new, or improved, numerical models to apply to the solution of air quality problems, both in uniform and in non-ideal, non-homogeneous, and non-stationary conditions.

Theme Element: Air-surface exchange (micrometeorology)

ARL conducts basic research on methods for predicting and measuring exchange of meteorological quantities (heat, moisture, and momentum) and trace gases and particles (e.g. ozone, carbon dioxide, sulfur and nitrogen oxides, base cations, nutrients, radioactives, and toxic chemicals) between the atmosphere and various surfaces. The historic emphasis has been on deposition, both wet and dry. Components of the ARL research program on air-surface exchange include

- direct measurement of eddy fluxes using tower, ship, and aircraft systems,
- indirect inference of local fluxes in situations where direct measurements are not feasible,
- theoretical analysis of the effects of surface complexity on the areal parameterization of air-surface exchange, and the development of specialized models to account for surface heterogeneity, and
- a special focus on the complexity introduced by the presence of water surfaces.

The experimental techniques developed by ARL are used in studies over surfaces of all kinds, including oceans and especially coastal areas. Recently, ARL researchers have demonstrated the feasibility of a breakthrough previously thought beyond technical reach — the use of eddy-flux methods on a floating platform at sea.

Theme element: Acid deposition

ARL is a world leader in the design and operation of wet deposition and dry deposition networks, and in the development of programs to investigate the processes that cause wet and dry deposition. ARL presently focuses its attention on

- the measurement of precipitation chemistry in remote environments,
- the development of systems for measuring deposition, both wet and dry,
- 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.

Theme element: Ozone and oxidants

ARL operates a network of sites at which ozone destruction rates at the surface are quantified. Local estimates of ozone deposition are verified using tower-mounted eddy correlation methods. Areal averages of surface destruction rates are derived from the use of aircraft eddy correlation systems. ARL also participates in and conducts field studies investigating the local and regional variability of ozone, through use of its aircraft sensing systems and its tethered balloon sounding capability. Information obtained from such studies is assembled into numerical models, the main variants being the Regional Acid Deposition Model and the Regional Oxidant Model, primarily produced for application by the Environmental Protection Agency.

Theme element: Aerosols and visibility

ARL specializes in the geochemical cycling of atmospheric aerosols, especially the particulate component. Research groups in ARL concentrate on the injection of dust and soil particles into the atmosphere, 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.

Aerosol research in ARL concentrates on

- the injection of dust and soil particles into the atmosphere,
- the long-range 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 development of appropriate numerical models.

Specific studies address aerosol transport from continents; the generation of dust from roads, arid land, etc.; particle chemistry and gas-to-particle conversion; trajectories of particles from volcanoes and large fires; aerosol deposition processes, both wet and dry; regional-scale transport and deposition of particulate air pollutants; modeling airborne particle concentrations; and the prediction of changes in optical opacity (with emphasis on visibility).

Through its long-standing involvement with WMO, ARL remains active in the study and interpretation of solar radiation (direct solar beam and diffuse radiation) and atmospheric optical properties. This subject is considered further under discussion of

1.1.2 Emergency Assistance — Theme 2

ARL provides meteorological support to several agencies, (a) to help predict the dispersion of material from accidental releases into the air, (b) to develop appropriate response strategies, and (c) to provide meteorological assistance in the event of accidents. Work concentrates on dispersion from releases of nuclear materials (e.g. Chernobyl), industrial accidents (e.g. Bhopal), and volcanic eruptions (Mt. St. Helens, Mt. Redoubt). In this context, NOAA-ARL is viewed by other agencies as a source of high-quality and independent technical expertise.

ARL is one of the world leaders in trajectory modeling, in all of its aspects:

- The prediction of the path to be followed by pollutants released from some source.
- The assessment of concentration fields that might influence population, ecosystems, and the environment in general.
- The identification of specific sources that contribute to air quality problems.

ARL has developed a unique capability to employ inert gases as tracers of air flow and pollutants. Recently, ARL studies have incorporated remote sensing wind and temperature profilers and Doppler lidars from other ERL laboratories. Data from studies such as these continue to form the foundation for understanding and modeling complex flows.

These special capabilities have caused ARL to become a recognized and sought-after authority in the event of accidents (or unusual natural phenomena) that inject potentially hazardous materials into the atmosphere. ARL capabilities contributed strongly to the national and international efforts following the volcanic eruptions of Mt. Agung, el Chichon, Mt. St. Helens, Mt. Redoubt, and Mt. Pinatubo, after the nuclear accidents at Three Mile Island and Chernobyl, after the chemical industrial accident at Bhopal, and during the oil fire emergency following the Gulf War. Routine, operational emergency response is not a major thrust of ARL. Our role is to improve the capability by which response can be provided by those agencies charged with this responsibility. Hence, ARL concentrates on guiding and advising other agencies who have appropriate responsibilities and jurisdictions. ARL becomes involved in actual response activities when our capabilities are required in order for NOAA to meet its mission or as required to assist other agencies to meet their own missions.

1.1.3 Climate Trends and Variability — Theme 3

ARL conducts research on trends and variability of temperatures in the troposphere and lower stratosphere and moisture in the troposphere. These studies have developed special global data sets which are continually updated from ongoing data collection. The efforts are directed at detecting trends, but also at defining the variability within which future trends will have to be detected. The data are analyzed for effects of El Ninos, quasi-biennial oscillations, volcanoes, and other regular and irregular global scale phenomena. Interannual changes in cloudiness and sunshine over the United States are also studied, as are variations in the North Polar Vortex.

Many of these analyses are used as "ground truth" by those developing satellite measurement techniques.

Theme element: Solar radiation

Through its long-standing involvement with the World Meteorological Organization, ARL remains active in the study and interpretation of solar radiation (direct solar beam and diffuse radiation) and atmospheric turbidity. The operation of the NOAA solar radiation network is a responsibility of ARL, and a new surface radiation network of highly sophisticated stations is presently being set up. ARL monitors surface UV-B radiation in an independent network, presently operated by the National Weather Service.

Theme element: Meteorological trends

ARL monitors and interprets atmospheric data including:

- temperatures in the troposphere and stratosphere,
- humidity in the troposphere,
- cloudiness and sunshine over the U.S.,
- upper atmosphere circulations, and
- ozone, with particular emphasis on the stratosphere.

Specific elements of ARL research concentrate on developing techniques to separate effects of changes in instruments and observing practices from changes in climate; comparing temperature and humidity records from radiosonde measurements with remotely sensed data; comparing model-based description of present climate with observations; and comparing temperature and ozone variations with those estimated from satellite observations.

ARL has been analyzing ozone data from around the world, at the Dobson stations and now using direct ozonesonde observations. These data are assembled into zonal averages to describe trends and interannual changes and to relate them to such irregular phenomena as volcanic eruptions, El Nino Southern Oscillation events, and the solar cycle.

Theme element: Desertification

Soil erosion and the resuspension of surface dust has been a long-term component of ARL research, previously as related to acid deposition and now directed at desertification. The research conducted on this topic by ARL scientists is now reaching a new community of concerned environmentalists. The importance of the work is illustrated by the fact that desertification is proposed to be the topic for the next round of international debates on environmental issues of critical importance to the habitability of the planet.

1.2 Organization of the Air Resources Laboratory

Staff Distributions

	Total Technical Staff Ph.D.	MS	BS/BA	NOAA employees
Silver Spring, MD (HQ)	6	8	4	22
Boulder, CO (ARS)	3	-	4	8
Oak Ridge, TN (ATDD)	13	4	9	15
Research Triangle Park, NC (ASMD)	25	32	10	57
Idaho Falls, ID (FRD)	2	7	4	14

During 1992, a total of 27 formal, peer-reviewed papers were published by ARL authors. In addition, 14 peer-reviewed articles were published as Technical Memoranda or as formal agency reports. A complete list of 1992 formal publications concludes the present report. Not included in this list are preprints of presentations at meetings, or their abstracts, even though some of these were published in journals.

In common with most other NOAA research laboratories, the Air Resources Laboratory is in a period of continuing financial stress. At the same time, existing programs at ARL Divisions at Oak Ridge, Research Triangle Park, and Idaho Falls need strengthening. In response, the Aerosol Research Section in Boulder, Colorado, is being disbanded and its personnel relocated to bolster other ARL scientific programs.

Research Triangle Park. Here, there is a growing effort to model particle transport and deposition. This group also operates perhaps the leading wind tunnel research capability in the U.S. All of this is under sponsorship of the EPA; the need to provide a NOAA-sponsored component has been long recognized, but such desires have not been realized due to budget constraints. A NOAA research element at RTP, focusing on particle physics and resuspension, is required.

Oak Ridge. Here, the expanding studies of air-surface exchange continue to require instrumentation and especially aircraft electronics and computing skills, not presently available. To satisfy the needs of NOAA research programs, the existing NOAA-funded capability must be expanded. The changes proposed are designed to strengthen an existing aircraft program, which is expected to employ a NOAA Twin Otter.

Idaho Falls. Recent growth has been in areas related to atmospheric chemistry. Work on aerosol physics (especially particle composition and morphology) has been centered within the Department of Energy's research operation at Idaho Falls. There is need for additional

coordination and cooperation between DOE and NOAA at Idaho Falls, as well as with other NOAA elements. Additional effort is needed in the study of meteorological processes.

Boulder. ARL is initiating a new focus on solar radiation and the surface energy budget. Network operational responsibilities will reside at Oak Ridge, but with scientific leadership in Boulder, under Dr. John DeLuisi. Although the overall program is still under discussion, it is clear that there will continue to be a need for ARL scientists in the Boulder area. It is expected that the new Surface Radiation Research Section will be operated in close collaboration with the DOE National Renewable Energy Laboratory, in Golden Colorado. Negotiations with the Department of Energy are under way.

Awards and recognitions

- Bronze medal winners

Joan Novak, Ken Schere, Tom Pierce, and Jim Godowitch, all of ASMD, Research Triangle Park, received Bronze Medal Awards from the EPA for their participation on the EPA Regional Oxidant Modeling - NorthEast Transport modeling team. ROMNET drew on the combined skills of the EPA regulatory and NOAA research staffs to assist the northeastern States in evaluating effective ozone control strategies. The ASMD-developed Regional Oxidant Model (ROM) was used to generate urban boundary conditions to be "handed off" to the States for use in urban dispersion models to demonstrate ozone attainment.

Two ARL employees received DOE Gold Medals for their participation in the Kuwait Oil Fire emergency: Will Pendergrass (Oak Ridge) and Bruce Hicks (Silver Spring. Two ARL employees from Idaho Falls received NOAA Bronze Medals for their contribution: Gene Start and Jerry Sagendorf. David Auble and Rick Eckman (Oak Ridge), and Jeff McQueen (Silver Spring), received commendations from NOAA. In addition, Randy White of the ATDD/ORAU staff (Oak Ridge Associated Universities) received a special ORAU commendation for his role.

1.3. International Programs

The Air Resources Laboratory participates in international activities as required and appropriate to accomplish its mission.

ARL's involvement in international activities is governed by the recognition that the air quality of the United States is slowly improving, in response to regulatory actions and the imposition of emission controls, while that of many other parts of the world continues to deteriorate. The atmospheric environment of North America is feared to become increasingly susceptible to effects of 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 atmospheric monitoring component of these activities is viewed as an extension of the AIRMoN program being promoted for North America. The guiding philosophy of this program is to make not only accurate measurements of changes in air quality, but also sufficient ancillary measurements to demonstrate the reasons for these changes and to permit extrapolation into the future. The design of all measurement protocols is such that effects of changes in emissions are detected, with demonstrable confidence, as soon as possible.

2. ARL Themes: Summary of Activities

2.1 Air Quality and Dispersion

In general, work on Air Quality and Dispersion is directed towards improving techniques for forecasting near-term air quality and for predicting the consequences of changes in emissions or other controlling influences. This is the largest of the three ARL thematic research areas.

2.1.1 Air-Surface Exchange and Micrometeorology

Studies of air-surface exchange

An analysis of forest floor dry deposition fluxes of H_2O, CO_2, O_3, and SO_2 at Huntington Forest, NY (where ATDD operates a dry deposition monitoring site) indicated that more than 50% of the total flux is due to turbulent events that occur only 10% of the time. This is consistent with results for momentum flux obtained at Walker Branch Watershed four years ago.

Eddy fluxes of methane from a landfill in eastern Tennessee were measured using a new fast-response sensor (Southwest Sciences, Inc.). The measured fluxes were large, on the order of 16 mmol m^{-2} h^{-1}. This figure exceeds maximum reported fluxes over rice paddies and swamps by a factor of 20. Power spectra determined from the raw time series show excellent sensor frequency response and sensitivity.

Beginning in late July, 1992, an experiment was conducted at the Walker Branch Watershed to study processes affecting the emission of isoprene from leaves, canopies, and forested regions. The study was a multi-group and multi-disciplinary effort, with participants from NCAR, Washington State University (WSU), NOAA/ATDD, and EPA. Parallel studies were conducted by Oak Ridge National Laboratory, ATDD, WSU, and New Mexico School of Mines to measure the exchange rates of ozone, mercury, radon, and peroxides.

Collaborative measurements of mercury gradients at the Walker Branch Watershed near Oak Ridge also began in mid-July, in conjunction with the isoprene flux emission study described above. Daytime one- to two-hour integrated mercury vapor samples were made above the forest canopy by Oak Ridge National Laboratory. Corresponding measurements of water vapor and CO_2 gradients and fluxes were made by ATDD in an attempt to use the

modified Bowen-ratio method to interpret the gradients of mercury. Gradient measurements were also made near the bottom of the canopy to determine whether or not the forest floor acts as a source and/or sink of mercury vapor.

Aircraft eddy fluxes

The ATDD flux analysis program, with much-improved position determination, was modified to treat the July 1991 Lake Michigan Urban Air Toxics Study (LMUATS) data. The spatial inhomogeneities found in the data illustrate the complexity of studying toxic plumes over Lake Michigan. Lake breeze effects cannot be ignored. Indications of a lake breeze circulation can be seen in transects of water vapor, latent heat fluxes, and ozone concentration and flux data. Significant trends in the measured water vapor, O_3, and CO_2 data can also be seen in the transects over open water, probably because the airplane passed through the Chicago urban plume, blown out over the lake by a southwesterly synoptic scale flow.

Dry Deposition Inferential Method

The Air Resources Laboratory generated the methodology by which most dry deposition data are now gathered, the so-called Inferential Method. In this, air concentration data are collected at sites that are simple enough to apply knowledge gained elsewhere to infer dry deposition rates. This cannot be done except in highly constrained circumstances, and only for a few chemical species. In essence, ATDD operates a small network of sites at which the dry deposition inferential method (DDIM) is being tested, and a subset of sites at which its results are being compared against other, more complicated methods. As a component of its work for the EPA, ASMD assists in the operation of a larger inferential monitoring network, recognized as the National Dry Deposition Network.

Site visit/refurbishment of the NOAA dry deposition monitoring stations occurs annually. During 1992, the program included installation of a new site in Wye, MD, in collaboration with the ANICA program (see below). A new site east of Burlington, VT, has also been set up, as part of the project investigating deposition to the Lake Champlain area.

An analysis of the correlation of the dry deposition inferential method (DDIM) estimates for deposition velocity with corresponding measured hourly SO_2 concentrations was begun for the dry deposition CORE sites located at Argonne National Laboratory and Pennsylvania State University. The summer 1989 data showed that a day-night sampling protocol would reduce the bias error to 7% at the PSU site, but no improvement would result for the ANL site. Day-night sampling protocols are recommended by several research groups; in essence, these call for the use of separate chemical samplers to characterize daytime and nocturnal air chemistry regimes. ARL research shows that the additional complexity may not lead to a significant improvement in the data quality.

A simplification was found to be warranted, however, in the use of meteorological data — hourly-averaged meteorological data used in place of the 15-minute data previously used produced nearly the same results. This significantly reduces analysis time.

Emissions Inventories

During April, 1992, 30 international experts gathered in Boulder, Colorado for an International Global Atmospheric Chemistry (IGAC) Global Emission Inventory Activity (GEIA) workshop on biogenic nonmethane hydrocarbon (NMHC) emissions. The objectives of the IGAC-GEIA workshop were to summarize the state-of-science on biogenic emissions, to recommend how an initial global inventory should be assembled, and to recommend areas of future research. A representative from ASMD headed the group discussion on the construction of the initial global biogenic NMHC emissions inventory. This inventory is to consist of speciated, monthly average emissions for 1° x 1° grid cells around the world.

The AIRMoN Program

The Atmospheric Integrated Monitoring Network (AIRMoN) program presently being initiated by ARL is designed specifically to couple monitoring and modeling activities to reveal the effects of emissions changes as rapidly as possible. The program relies on sampling over time intervals compatible with the time increments of contemporary forecast models. AIRMoN responds to the call by the Clean Air Act Amendments of 1990 for a rapid detection of improvements generated by the newly mandated emission controls.

AIRMoN is to have three distinct but often collocated components: air quality, wet deposition, and dry deposition, all reporting specifically as needed to rapidly detect changes attributable to emissions reductions. Although the AIRMoN operation is not intended to start up in earnest until FY 1994, an early start is being made.

Following a July meeting involving ARL, the National Atmospheric Deposition Program (NADP), and several site operators, sampling protocols have been established for the new AIRMoN precipitation chemistry network. Current plans call for sample collection on a daily basis at an initial set of operational stations at Lewes, Delaware; Oxford, Ohio; State College, Pennsylvania; Ithaca, New York; Champaign, Illinois; Oak Ridge, Tennessee; and Underhill, Vermont. Additional stations will be added to the network as funding becomes available. AIRMoN data will be benchmarked against existing NADP stations during the first year of the project; chemical analyses for major ions will be provided by the Illinois State Water Survey. Additional chemicals will be analyzed by other laboratories as required.

Marine Aerosol and Gas Exchange (MAGE)

The First International Radiation Experiment's Atlantic Stratocumulus Transition Experiment (ASTEX) was conducted in June, 1992. A multi-laboratory study of Marine Aerosol and Gas Exchange (MAGE) was conducted as a component of ASTEX; MAGE is a field experiment under the auspices of the International Global Atmospheric Chemistry Program. Three ARL groups participated.

A team from Idaho Falls conducted tetroon experiments, to help guide sampling aircraft into specific air masses. This work made use of a new Global Positioning System (GPS) transponder system, modified by ARL specifically to satisfy the needs of the overall ASTEX/MAGE study. The modifications were designed to extend the battery life of

tetroon-borne systems beyond the four-day requirement for the experiment. Opportunities arose to launch only a few of the modified systems; however, they worked well. The project involved a tracer release program as well as constant-level tetroons. Several automatic atmospheric tracer samplers were used.

Two ARL scientists from Boulder studied optical scattering by particles in the marine environment. The experimental program involved (a) characterizing near-surface size distributions as a function of aerosol chemistry and meteorological conditions, and (b) measuring the water associated with aerosol particles in the accumulation and sea-salt modes. Preliminary data assessment shows that in the near-surface accumulation mode over the ocean, there appears to be a strong dependence of aerosol water amount on particle size. Such information on aerosol water is considered to be of substantial importance, since only two or three data sets have been previously obtained. None of these earlier studies characterized the dependence of aerosol water on particle size, and only poorly its dependence on aerosol chemistry.

In addition, the Silver Spring group helped organize and conduct profiling studies aboard the ship. The meteorological data became part of a larger database which now includes measurements of CO, radon, aerosol physical properties, and black carbon.

Atmospheric Nutrient Input to Coastal Areas (ANICA)

ANICA is a slowly-evolving program intended to develop methods for quantifying the contribution of atmospheric deposition in the context of total pollution inputs to large water bodies. The program is primarily focussed on the deposition of nutrients, but the methods apply to other chemicals as well. The deposition of relevance occurs in both dry and wet forms; each must be addressed separately. Moreover, it is not only the flux to the water surface itself that is important — there is also some transfer of deposited material through the entire catchment area. ANICA is designed to assess the actual deposition to the water surface itself, and to provide an independent assessment of deposition to the catchment area. By analyzing these data in conjunction with stream-flow and other water body data, an estimate of the amount of deposited chemicals that is retained as water passes through the watershed is to be derived.

The initial focus of ANICA is on the Chesapeake Bay, for which previous assessments have indicate that about 35% of nitrogen input is derived from atmospheric sources. The study has obvious relevance to the implementation of cost-effective control strategies; ANICA results will permit consideration of the benefits already to be realized through the limitations imposed by the Clean Air Act Amendments of 1990, for example.

A research site has been set up at Wye River, at a facility operated by the University of Maryland on the Eastern Shore of the Chesapeake Bay. A tower has been erected near the center of an experimental watershed planted with maize; this is being used to make micrometeorological and chemical measurements as part of a Dry Deposition Inferential Method (DDIM) system that has been operational since mid-1992. Wet deposition is also obtained at the Wye River facility.

Deposition to the surface of the Bay is being assessed using equipment on board a buoy operated by the University of Maryland. Using bulk transfer models originally developed

for the open ocean, an iterative model for heat and water exchange has been extended to yield deposition velocities appropriate for deposition of nitric acid vapor; this is the dominant chemical species contributing. The analytical technique calculates the stability regime using ten minute averages, and has been tested using data collected in Looe Key by the ATDD research team, from Oak Ridge. Preliminary results (using two months of data collected on the Bay) show that between 30-40% of conditions on the Bay are too extreme for traditional models to treat adequately. Also, it appears that deposition mainly occurs at high winds, and is a function of stability only at low wind speeds. It is anticipated that further tests of the model will be possible after the ATDD TOGA/COARE experiment is completed in 1993.

Using buoy data collected since March, using the bulk exchange model, and accepting certain assumptions, the meteorological measurements made from the buoy allow dry deposition to the Bay surface to be estimated. Estimates of total deposition ranged from 0.75 to 2.24 million kg of nitrogen as HNO_3 to the Bay proper per year. Due to assumptions made in this estimation, these values are probably biased on the low side. This makes these results even more significant; estimates of the wet deposition of all nitrogen species to the Bay proper are on the order of 2.0 million kg/yr.

It is planned to use eddy correlation to test the results of the deposition velocity methodologies that have been developed; this will be a joint activity of ARL scientists from Oak Ridge and Silver Spring. In addition, field programs are planned to study nitrogen speciation on and around the Chesapeake Bay.

<u>The Great Lakes</u>

Annual atmospheric concentrations and total deposition amounts of trace metals to Lake Michigan were calculated by the REgional Lagrangian Model of Air Pollution (RELMAP, developed at Research Triangle Park). These metals included arsenic, cadmium, chromium, lead, nickel, and selenium. Annual emissions were calculated by ASMD using the 1985 National Acid Precipitation Assessment Program emissions database (for both U.S. and Canadian sources) and available emission factors for the individual metals. EPA Region V: Air and Radiation Division will use these calculations in preparing the Lake Michigan Lake-Area Management Plan. Annual mean concentrations of lead were the greatest, ranging from 32 ng/m^3 to 244 ng/m^3 depending on the geographical location and size of particle. Similarly, the annual deposition of lead was greatest, 106 kg/year or approximately 1 kton/year.

<u>Lake Champlain Study</u>

ARL is participating in a Congressionally-mandated study of deposition to Lake Champlain; this subject is among many to be addressed in a report now being prepared by EPA — the Great Waters report to Congress. The ARL contribution centers around quantification of input rates from the atmosphere, with emphasis on nutrients but also on toxic chemicals such as mercury.

Three ARL groups are involved in this effort. Workers at Oak Ridge are operating a dry deposition system at Underhill, Vermont, near Lake Champlain, at a site where wet deposition is already being measured. Modeling activities are under way at both Research

Triangle Park and Silver Spring. Measurement programs to assess mercury deposition rates are being coordinated from Silver Spring, through a joint effort with the University of Michigan and the University of Vermont.

Modeling studies are concentrating on exploring specific cases of high pollution exposure of mercury, arsenic, and other atmospheric trace chemicals. A nested grid model is being used, centered over the lake valley. Outputs from this model are also being used as input to larger-scale transport and dispersion models, to quantify likely impacts of emissions from several specific pollution sources.

The DOE Atmospheric Radiation Measurements program (ARM)

ATDD collaborated with several DOE laboratories and universities, including Battelle Pacific Northwest Laboratory, Argonne and Los Alamos National Laboratories, and Texas A & M University, in a second intensive field experiment at Boardman, Oregon, during the first two weeks of June. The data and subsequent analyses are intended to support significant improvements in the methods of determining a bulk value for air-surface exchange of heat and moisture over inhomogeneous surfaces, an important parameterization in calculations of cloud distribution in global climate models. ATDD collected mean and eddy correlation flux measurements from an airplane-mounted Mobile Flux Platform. Heat, moisture, and CO_2 fluxes were measured using eddy correlation over a potato field using a stationary and a ground-based mobile flux station. Goals for the ground-based systems were to examine factors controlling trace gas exchange of the field, and to examine intra-field variability using the mobile flux station.

A detailed comparison of eddy correlation aircraft and tower flux data from the June 1990 Boardman OR study for the DOE's ARM program was completed. The differences between the airplane-measured heat flux and the fluxes from ATDD's towers in irrigated fields of corn and wheat are quite small, considering that the crops are discrete fields only 0.8 km across. However, a comparison of airborne heat flux data with another laboratory's tower data over an adjacent desert area indicates a substantial bias between systems; this difference is still being investigated.

The RAMS Model.

The Colorado State University's Regional Atmospheric Modeling System (RAMS) was selected as a testbed for the development at Silver Spring of improved air-surface exchange formulations, and for coupling with larger-scale numerical products of the National Meteorology Center to yield finer spatial resolution. When operating, the 90 km initial fields of the NMC Nested Grid Model are used to drive RAMS on a 40 km coarse and a 10 km fine grid. Tests have been conducted with the grids centered on Cape Kennedy, Florida; Oak Ridge, Tennessee; the Chesapeake Bay; and Lake Champlain.

In one operational configuration, RAMS model wind field outputs can be linked with the HY-SPLIT trajectory model, to give a finer resolution and more terrain-sensitive prediction of pollution plume dispersion. The intent is to provide an improved capability for use in emergency situations.

2.1.2 Studies of Dispersion

Dispersion at Night

A lesson learned in the 1987 Across North America Tracer Experiment conducted by ARL during the first phase of the National Acid Precipitation Assessment Program essentially destroyed the earlier assumption that nocturnal flow continued relatively unimpeded by dispersive contact with the ground. Subsequently, work conducted at Oak Ridge has focussed on explaining the physics associated with the turbulent bursting phenomenon that is now known to maintain a significant level of contact between flow aloft and the surface.

Data from an extensive regional study of the Oak Ridge area, conducted by ATDD in 1990, have been examined in detail to show the coupling of nocturnal winds within the Tennessee River valley to those above the valley. For low wind speeds, valley winds are often decoupled from those aloft, and there is evidence of thermally-driven circulations in the valley. For moderate wind speeds, valley winds are usually parallel to the valley axis, with a transition from up- to down-valley flow occurring when the winds aloft were roughly perpendicular to the valley axis. In strong winds, transition from up-to down-valley flow often occurs when winds aloft are parallel to the valley axis. This mean behavior is modulated by an intermittency that now appears to be associated with passing pressure disturbances. Theory developed to address the generation and propagation of wavelets has been used to investigate the turbulence variations associated with several large-amplitude pressure disturbances observed with the ATDD microbarograph array operated during the Oak Ridge regional intensive study. The analysis indicates that the pressure disturbances are frequently associated with bursts of turbulence activity at the surface.

Carbon Monoxide Studies

A series of field studies has been conducted by FRD, to assist the understanding of conditions that lead to high concentrations of carbon monoxide in complex terrain. Much of the work was conducted in Utah County, Utah. Laboratory analysis of tracer samples was performed at the ARL Idaho Falls office; all data are being archived at Idaho Falls, where they will be used for model development and study. Some of the air samples contained unidentified compounds that hindered rapid analysis of BCF (Bromochlorodifluoromethane), one of the tracers. The conditions studied were selected to be conducive to extremely high concentration CO measurements.

A radar profiler with RASS was operated during the field program in Utah County. Meteorological data (wind speeds and directions along with some temperature information) were collected from a network of ten 10 m towers spaced throughout the area. The meteorological complexities of the wintertime setting appear similar to the 1991 Medford, Oregon, STAGMAP program. Complex local airflows (see below) and atmospheric processes appeared to be the dominant factors in CO accumulations and non-attainment concerns (along with sources). The project data set is extensive and may be useful for follow-on modeling diagnostics.

2.1.3 Studies of Complex Terrain

Several ARL groups are actively involved in studies related to transport and dispersion in complex terrain. At Research Triangle Park, the focus is on high altitudes and plume impaction, at Oak Ridge it is on valleys and stagnation, and at Silver Spring on incorporating terrain complexity in large grid cells of numerical models.

During 1992, ATDD's VALPUFF complex terrain puff-trajectory model was used to simulate hourly surface SF_6 tracer concentrations as observed during a field program conducted in 1991 near the DOE Rocky Flats Facility north of Denver. Hourly concentration plots for the inner and outer sampler arcs show that the magnitude and variations about the peak concentration were predicted well, though the modeled concentration peaks were slightly shifted to the north; wind data inaccuracies are a possible cause.

Another simulation of measured hourly surface tracer concentrations for one night at the DOE Rocky Flats Facility was carried out using ASCOT on-site meteorological data and digital terrain information. The original puff- trajectory TRIAD model (TRIAD-89) model was modified to include subsidence velocity, and to account for elevation differences between the source and receptors. TRIAD-92 was then used to simulate concentrations for the actual 10 m release, and for a hypothetical 200 m release. Following a sensitivity analysis, an average subsidence velocity of 3 cm/s was used in the simulations. Agreement with the tracer data was surprisingly good, especially considering the known complexity of the local flow fields.

A new complex terrain algorithm for the INPUFF model was developed at Research Triangle Park. Tests revealed an error that intermittently produced negative concentrations. The intent is to install the new flow algorithm in the Complex Terrain Dispersion Model (CTDMPLUS) to correct some inconsistent behavior previously noticed.

2.1.4 Acid Deposition

Modeling

The Regional Acid Deposition Model (RADM) is a widely-recognized product of the National Acid Precipitation Assessment program (NAPAP) that was developed largely by ARL scientists working at Research Triangle Park under EPA sponsorship. RADM was used extensively in the preparation of the NAPAP State of Science and Technology review papers, and also was relied on heavily in the development of the US/Canada accords on acid deposition. At the end of the first phase of the NAPAP program, RADM still contained several imperfections. The focus in the second phase of NAPAP will be to remedy these imperfections.

The field test of RADM revealed that the model underpredicted sulfate concentrations near the surface. Two alternative hypotheses explaining this underprediction were examined — insufficient sulfate production by nonprecipitating convective clouds and insufficient primary sulfate emissions. Three contrasting pairs of tests against field data were applied to these hypotheses: source *vs.* downwind regions; mid summer *vs.* late summer seasons, and sunny-dry *vs.* cloudy-wet synoptic types. The sulfate emissions hypothesis,

tested by artificially boosting sulfate emissions, fared better than expected but was rejected because of its poor performance on the regional and seasonal contrast tests. The RADM nonprecipitating cumulus modification successfully captured the seasonal and the late summer synoptic contrasts but improvement is still needed for the regional and mid summer synoptic contrasts. Encouraged by this result, modifications of the RADM cloud and scavenging module were completed, to better simulate nonprecipitating cumulus clouds.

RADM is not the only acid deposition model running in ARL. Calculations of sulfate wet deposition and air concentrations for the entire year of 1989 were also completed using a Lagrangian transport and dispersion model (HY-SPLIT, developed at Silver Spring). Calculations were made using two hourly meteorological data fields generated by NMC's Nested Grid Model (NGM). Two sets of calculations were performed. One used the NGM predicted precipitation fields, and the other used measured precipitation values generated from gridding the observed precipitation to the NGM meteorological data grid. Seasonal model calculations were compared with available measurements. In terms of SO_2 air concentrations, both computations showed comparable results with the seasonal correlation coefficients between 0.70 and 0.75, and little bias. The SO_4 air concentration calculations showed greater variability. Calculations using NGM precipitation resulted in lower air concentrations than those calculations made with measured precipitation data by a few percent in winter, to as much as a factor of two in summer. However, the correlation coefficients varied from a low of 0.36 in autumn to a high of 0.94 in summer. In general the NGM underpredicts precipitation amounts in the initial forecast hours of the model run from which the meteorological data archive was constructed. The high correlation coefficients suggest that the bias can be corrected and the NGM data used in lieu of obtaining additional measured precipitation data.

2.1.5 Ozone and Oxidants

Extensive ozone profile data were gathered near Oak Ridge. Time-height (0 to 550 m AGL) cross-sections for 0700-2300 EST were created for O_3 concentration and potential temperature. $[O_3]$ and potential temperature at the same height tend to track each other during the morning and evening hours, suggesting the dominance at these times of diurnal PBL dynamics in determining the vertical $[O_3]$ distribution.

The Boulder ARL group conducted a series of four research flights over the Denver metropolitan area, to compare the ozone concentrations measured by four real-time ozone monitors. An extensive set of laboratory tests prior to the flights led to the suspicion that some of the devices might be sensitive to rapid changes in environmental humidity. The flights confirmed this. Under constant humidity conditions all the sensors agreed to within a few ppb. But, under rapidly changing humidity conditions, one device reported ozone concentrations that were 10% to 20% too high or too low and in direct correlation with changing humidity. The cause of this error appears to be in the zeroing technology. It was recommended that simple humidification and dehumidification tests be conducted prior to field studies, to reveal whether any given instrument has this problem.

Ozone in the Southeast

There are two programs that involve ARL scientists in ozone-related research in the Southeast: the Southern Oxidants Study (SOS) and the Regional Oxidants in the Southern Environment (ROSE) program of NOAA.

The ASMD team in Research Triangle Park is heavily involved in the planning and modeling associated with the SOS. Workshops were held in January and February 1992 to discuss final plans for the regional monitoring network to be used in the 1992 field intensive for the Southern Oxidants Study (SOS). 1992 was the second summer of SOS monitoring, and the first year of intensive field operations both on the urban (Atlanta) and southeast regional scales. Eleven sites within the southeast U.S. measured continuous ozone, NO/NO_y, SO_2, CO, and meteorological parameters, as well as VOC samples every six days during the ozone season. The monitoring network operation is referred to as the SOS SouthEast Regional Oxidant Network (SOS/SERON).

The ATDD group in Oak Ridge is heavily involved in ROSE. During 1992, ATDD participated in the ROSE experiment in Meridian, MS, and rural western Alabama. ATDD used a tower-mounted above-canopy eddy correlation flux system to measure surface-atmosphere exchange of sensible heat, latent heat, ozone, NO_2, and CO_2. As a quality control check, the total energy budget was measured, including radiant fluxes and energy storage terms throughout the forest. These included biomass storage, ground storage, and forest space subcanopy storage. In addition, NO_y and NO fluxes were attempted with the help of Aeronomy Laboratory scientists. Besides the tower-based measurements, airborne flux and concentration measurements were performed. Eddy flux measurements of ozone are now somewhat simplified, with the recent development of a new fast-response ozone sensor with improved reliability.

An animated visualization was generated of the evolution of potential temperature, water vapor mixing ratio, and ozone vertical concentration profiles spanning a diurnal cycle observed during the ROSE study. Correlations between measured quantities and growth of the daytime mixed layer and nocturnal boundary layer become readily apparent in such a presentation.

Modeling of Ozone

The Regional Oxidant Model (ROM) developed jointly by EPA and NOAA scientists at Research Triangle Park has been used extensively to study different emissions scenarios for the Ozone Transport Commission (OTC). In brief, the findings from these simulations are: 1) the 1990 Clean Air Act Amendments (CAAA) mandated control programs projected to the year 2005 should result in widespread reductions (up to 0.03 to 0.05 ppm) in peak ozone across the Northeast with reductions of 70 to 90 percent in population exposure to ozone above 0.12 ppm; 2) further controls beyond those in the CAAA may well be needed for attainment under meteorological conditions like those experienced in the summer of 1988; 3) even adopting more extensive mobile source controls, including a California-type program, may not provide sufficient emissions reductions, in part because mobile emissions are estimated to be a much smaller fraction of total emissions in future years; and 4) stringent NO_x controls should provide a relatively small benefit to ozone levels along the Northeast Corridor.

The $NO-NO_2-O_3$ photostationary state was studied using a PC-based symbolic/analytical mathematical software package. The software allows sensitivity analyses in equation form, eliminating the time-consuming need to convert the equations into numerical code. Mathematical worksheets were developed to calculate nighttime O_3 losses due to reaction with available NO; instantaneous O_3 production/loss rates and equilibrium O_3 mixing ratios for given initial concentrations of O_3, NO, and NO_2; sunrise/sunset times and solar zenith angles for a given date and location; and theoretical photolysis rates for NO_2.

Global ozone.

At Silver Spring, comparisons were made between the total-ozone changes obtained from the Total Ozone Mapping Spectrometer (TOMS) on NASA's Nimbus 7 satellite, the TIROS Operational Vertical Sounder (TOVS) on NOAA satellites, the ground-based Dobson network, and integration of Umkehr and ozonesonde layer-ozone values. In the north temperate zone during 1979-90, the corresponding total-ozone changes were -3.9%, -2.7%, -3.6%, and -3.4% per decade, with decreases largest in winter-spring (about -4½% per decade). Because of unrepresentative station locations, the Dobson network has underestimated ozone depletion in the south temperate zone, and as a consequence for the world as a whole, the Dobson-derived total-ozone change is
-2.7% per decade compared to -3.4% per decade for TOMS. These disparate data sets show that there has been a global total-ozone decrease of close to 3% between the sunspot maximum in 1979 and the sunspot maximum in 1990. However, the Dobson network shows little change in global total ozone between the sunspot maxima in 1958 and 1979. The reason for the transition from essentially no ozone change in the two decades prior to 1980 to a large and significant ozone decrease after 1980 remains to be determined.

The possibility of forecasting the depth of the Antarctic Ozone Hole based on equatorial quasi-biennial oscillation (QBO) and sea surface temperature (SST) data was re-examined. From 1962 through 1991, the correlation between October-November averages of total ozone at Amundsen Scott (South Pole) and October-November averages of 100 mb temperature above Antarctica is 0.96 (0.95 if the trend is removed), so that a forecast of total ozone includes a forecast of low-stratospheric temperature in this region. With regard to a QBO influence, Singapore 50 mb zonal winds in the winter and spring have proved a useful indicator of the strength of the Antarctic ozone hole. In addition, an above-average SST in summer and autumn (El Nino) makes a deep ozone hole more likely.

Based on data from the Dobson network, in the winter of 1991-92 north temperate total ozone was 7% below the 1958-1990 average, the largest seasonal deviation so far observed in this zone. The deviation was especially large in Europe, -13%. In the global average, the deviation for this season was -4%, the largest seasonal global deviation yet observed despite the impact of the Antarctic ozone hole on global deviations in austral spring. It is uncertain how much of this record diminution is due to the Mt. Pinatubo eruption.

The San Joaquin Valley Air Quality Study (SJVAQS)

The Boulder group made an extensive investigation of a curious phenomenon observed off the west coast of California during the San Joaquin Valley Air Quality Study (SJVAQS) of

1990. Regions with no ozone at the boundary between the planetary boundary layer (marine layer or mixing layer) and the free troposphere were frequently observed. These ozone-free regions were encountered during flights in July and August, 1990. The depleted regions were associated with extreme dryness (-20°C dew point), low particle content (backscatter < 10^{-7} m^{-1}), low NO_y concentrations (< 100 pptv), and low H_2O_2 concentrations (< 50 pptv).

Very low ozone concentrations have occasionally been reported in the remote tropical marine boundary layer. However, no corresponding reports have materialized at mid-latitude sites. Also, no currently accepted chemical process explains these measurements. Thus, either the observations showed real environmental significance, or the instrumentation was flawed. Extensive tests have finally revealed that some ozone instruments respond dramatically to rapidly changing relative humidity conditions. When the relative humidity is quickly reduced, an apparent decrease in ozone can be indicated, and vice versa. Clearly, experimenters should be especially aware that ozone concentrations reported by well-accepted instruments may be misleading, especially in coastal conditions.

Regulatory guidance.

ASMD was a leading contributor to discussions with the California Air Resources Board Model Advisory Committee (MAC) on the use of a new reactivity scale in proposing new and alternate vehicle fuels within California. The state recently adopted such guidelines, and the MAC discussed the technical merits and deficiencies of the reactivity issue as a means of reducing the high ozone concentrations within California.

ASMD scientists recently briefed the EPA on the sensitivity of biogenic emissions due to uncertainties associated with corn production. The research was prompted by recent Regional Oxidant Model (ROM) simulations for the Lake Michigan Ozone Study. The uncertainty in corn's emission factors and the corresponding effect on the biogenic component of the emissions inventory was investigated. In the midwestern U.S., contributions of biogenic emissions ranged from 54% to 65% of the total VOC inventory and from 4% to 15% of the total NO_x inventory. This suggests that improvements in determining emission factors for corn are needed. It also suggests that additional ROM simulations may be warranted to study the impact of biogenic emission uncertainties on regional ozone near Lake Michigan.

A Committee on Atmospheric Chemistry and Modeling was set up to prepare a general research plan to support Section 185B of the 1990 Clean Air Act Amendments (CAAA). The committee's mission was to formulate a research plan to address science issues on the chemistry and modeling of ozone, in support of ozone control strategies. This plan will be used to construct a national research agenda. ASMD played a leading role in the generations of the plan; other ARL groups also participated.

The Regional Oxidant Model (ROM) was used to simulate the photochemistry of the eastern United States for the episode July 2-10, 1988. The simulations suggest that: (1) NO_x controls may be more effective than VOC controls in reducing peak ozone over most of the eastern United States; (2) VOC controls are most effective in urban areas; (3) NO_x controls may increase ozone near large NO_x sources, whereas VOC controls rarely increase

ozone levels; and (4) the benefit gained from increasing the amount of VOC controls lessens as the amount of NO_x control is increased.

The American Meteorological Society (AMS) and the Environmental Protection Agency established the AMS/EPA Regulatory Model Improvement Committee (AERMIC) during 1992, to assist EPA in the introduction of state-of-the-art modeling concepts into regulatory dispersion models.

2.1.6 Toxics

The role of the atmosphere as a vector for transferring toxic chemicals from distant sources to sensitive aquatic ecosystems is becoming increasingly acknowledged. Several ARL groups are involved in related work. At Research Triangle Park, numerical models of the emission-transport-deposition system of processes are being developed. At Oak Ridge, detailed studies of deposition processes are being conducted, with emphasis on Lake Michigan and the need to improve understanding of the dry deposition of mercury, in particular.

Forty toxic chemicals are being evaluated for addition to the interim toxic emission modeling inventory developed by ASMD. The inventory, which is undergoing revision to reflect new information, already contains 26 toxic chemicals for the 48 contiguous states based on EPA Region V Great Lakes program needs. The additional chemicals will reflect the overall priorities of the Great Waters and Urban Area Programs under Title III of the Clean Air Act Amendments of 1990.

Annual atmospheric concentrations and total deposition amounts of trace metals to Lake Michigan are calculated by ASMD, using the REgional Lagrangian Model of Air Pollution (RELMAP). These metals included arsenic, cadmium, chromium, lead, mercury, nickel, and selenium. Results indicate that annual mean concentrations of lead are the greatest, ranging from 32 ng/m^3 to 244 ng/m^3. Similarly, the annual deposition of lead was predicted to be the greatest, 106 kg/year to Lake Michigan.

In April, an Air Toxics Risk Assessment Workshop was conducted by ASMD in Durham, NC. The primary objective was to discuss research issues, current efforts, and plans for air toxics risk assessments. The workshop covered the range of activities planned by all involved agencies, including EPRI, and was conducted as a first step towards generating a report on related human health risk scheduled to be delivered to Congress in May 1994. A second workshop was organized and conducted by ASMD to recommend a preliminary plan for monitoring toxic chemicals in the Lake Michigan airshed. Although a preliminary sampling protocol and network design were recommended, a consensus on the list of pollutants to be sampled was not reached.

Further in this series of meetings related to the Great Lake pollution problem, ASMD convened a workshop at Research Triangle Park in September to discuss the objectives and approaches of the Lake Michigan/Lake Superior Toxics Loading Study. The workshop focused primarily on research needs and monitoring requirements to estimate relative loadings of specific toxic pollutants to the Lakes. Discussions also included determination of relative contributions from source categories, development of recommendations for pollution control strategies, establishment of a baseline for toxic pollutant loadings,

development of a mass balance model, and data provisions for atmospheric model calibrations.

Silica is emerging as an atmospheric contaminant with potential health risk. Silica has its most common mineralogical form as quartz, which is a major component of soil- derived dust. In California, silica is now labeled as a carcinogen under Proposition 65, and a cancer risk assessment is required. ARL activities concerning silica in air are extensions of earlier work conducted as part of the National Acid Precipitation Assessment Program (NAPAP) on dust emissions and soil erosion, also addressed later in the discussion of desertification.

The Boulder ARL group invested considerable energy on the development of new chemical sampling systems, for use in detecting trace quantities of toxic chemicals from aircraft platforms. A field study was conducted in Florida, the Airborne Collection Equipment (ACE) program, involving scientists from the ARL Headquarters Division, Field Research Division, and the Aerosol Research Section. The goal was to find and track a plume of SF_6, released from a surface site near Orlando, FL. Observations of the plume were compared against predictions made by the ARL "HY-SPLIT" trajectory model. In a subsequent study, releases were made of SF_6 (among other tracers) from a site in Central Florida. A primary purpose of this series of tests was to demonstrate that an instrumented research aircraft could locate and orbit within a plume of tracer material for periods approaching 1 hr. This goal was accomplished. In addition, the results support both the theoretical and numerical model predictions of tracer concentrations downwind of the release point.

These studies made use of a new light-weight Global Positioning System (GPS) transponder designed at Idaho Falls, and based on a light-weight, 5-channel Rockwell receiver and a newly designed single board controller/transmitter. This allowed transponder weight to be kept at about 12 ounces with batteries. Keeping the transponder at this weight allowed the devices to be carried by a standard FRD 1 cubic meter tetroon. Some difficulty was encountered with transmitter electronic drift launch of the transponder. This problem was resolved and some of the transponders were tracked out over the Gulf of Mexico.

2.1.7 Aerosols and Visibility

Representatives from all ARL field groups participated in a Boulder meeting during March to discuss the future of ARL's aerosol research program. Three major research areas involving regional scale modeling were identified and included: air-water exchange processes (specifically as related to airborne toxic compounds), cloud-aerosol interactions, and organic aerosols. Specific studies on resuspension of aerosols and the study of toxic (arsenic) aerosols from dry lakes, such as Owens Lake in California, will be included in the research program. The workshop was organized and led by Joe Boatman, of the ARL Aerosol Research Section in Boulder.

A four-week field study was performed to investigate the role of cumulus and stratiform clouds on pollutant formation and transport and, conversely, the effects of anthropogenic aerosols on cloud microphysics. This is the second field study conducted as part of a cooperative agreement with the University of North Dakota (UND). From its temporary

base of operations in Milwaukee, the UND Cessna Citation II research jet sampled gaseous and particulate air pollutants in and around cumulus and stratiform clouds in the vicinity of Lake Michigan. Data obtained will be used to improve models of gaseous and particulate chemical species and their interactions with clouds.

A second focus of ARL work on atmospheric opacity and visibility has been on the EPA-sponsored (with Southern California Edison) Measurement Of Haze and Visual Effects (MOHAVE) field study. Two ARL groups have been involved: Research Triangle Park has been leading the planning and modeling efforts, and Idaho Falls has been conducting tracer studies to support visibility measurements. MOHAVE is designed to provide an experimental basis for determining and assessing the relative contributions of the Mohave Power Plant and other pollution sources to visibility impairment at the Grand Canyon National Park.

A wintertime intensive field campaign was conducted from mid-January to mid-February. FRD provided chemical tracers to characterize air flow and dispersion of power plant pollutants into the Grand Canyon, Bryce and Zion National Parks. To differentiate possible effects associated with emissions from different sources, two different tracers were used. One tracer was released from a remote National Park Service site about 65 km north of the Navajo Generating Station, near Page, Arizona. A second tracer was injected into a stack of the Southern California Edison plant in Laughlin, Nevada.

A summer intensive field campaign began on 12 July and continued until 31 August 1992. Three tracer release sites were used: in the LA basin, along the Mexican border, and from the MOHAVE Power Plant. In addition, tetroons carrying Global Positioning System (GPS) transponders were released from Tehachapi; these were tracked by vehicle and aircraft.

Soil Erosion and Desertification

Recently, a field expedition took place to measure threshold friction velocities for dust production in the Mojave and Sonoran deserts. The sites for testing were selected by collaborators from the U.S. Geological Survey. NOAA AVHRR and GOES imagery were scanned for dust storms and source areas of dust were noted. These measurements of threshold friction velocities using a portable wind tunnel were part of a program to model the dust production of the Southwestern United States.

During 1992, a radio-linked meteorological tower was erected at Owens Lake, California. The tower became fully operational in May, and thereafter monitored the meteorological conditions at the lake and the fluxes of sand and the presence of dust. Three additional towers were erected at the southern part of Owens Lake for a separate experiment which is scheduled to have preliminary tests in the fall of 1992, These towers are set up to investigate the extent of the area relevant to measurements made by a single observing tower — the so-called fetch effect. These towers measure wind stress, sand flux and other meteorological parameters. Preliminary data revealed that soil physics is responsible for the observed increase of dust flux as a function of distance from the leading edge of erodible material at Owens Lake.

2.2 Emergency Preparedness

2.2.1 Nuclear

Three ARL components provide plume prediction and forecasting assistance in the event of a nuclear accident. At Oak Ridge, activities are concentrated on the special needs of the contractors overseen by the DOE Oak Ridge Operations office. At Idaho Falls, the focus is on the plants operated by DOE contractors at the Idaho National Engineering Laboratory. Both activities are site-specific, tailored to the well-instrumented areas where nuclear inventories are maintained. At Silver Spring, attention is concentrated on the provision of guidance to the Nuclear Regulatory Commission, and to other government agencies in the event of releases into the atmosphere of nuclear materials that then cross state (or national) boundaries.
In the context of international incidents, the General Accounting Office requested updated information on transport and dispersion that might follow an accident at the nuclear reactor at Cienfuego, Cuba. Testimony was previously given on this subject by Dr. Lester Machta in 1986. Using the latest archived meteorological data at ARL and the HY-SPLIT model, with a newly written statistical program, a revised analysis was completed. The new assessment made up part of a package sent to "the Hill" and now included in the Congressional Record.

A subroutine is being developed that will allow calculation of doses from nuclear materials emitted into the atmosphere using the HY-SPLIT trajectory and dispersion model. Doses are calculated from the estimated concentration field after completion of the model run. Only one species is considered at this time.

2.2.2 Volcanoes

A new Volcanic Ash Forecast Transport And Dispersion (VAFTAD) model was developed by ARL at Silver Spring, and completed for emergency response use. A revision of the MOU for Volcanic Hazard Alerts is being considered and will be pushed for adoption by ARL when automatic facsimile transmission of VAFTAD output is completed and thoroughly tested. The National Meteorology Center has agreed to run VAFTAD operationally for emergency response, and the National Weather Service will base volcanic warnings issued to pilots (through FAA) on VAFTAD ash cloud predictions. The VAFTAD model is also fully operational on the ARL RISC/6000 computing system, the primary computer used for volcanic hazards alert emergency response operations.

During 1992, ARL ran the VAFTAD model for three separate eruptions, Mt. Pinatubo (Philippines), Mt. Bogoslof (Alaska), and Mt. Spurr (Alaska). Considerable satellite imagery was used to test model predictions. The model did a good job of forecasting initial 12-h ash positions, but at times the predicted speed of transport was too slow.

2.2.3 Large Fires

A meeting was held during May, in Geneva, Switzerland, to examine the activities that took place during the Kuwait oil fire plume emergency. ARL contributions were presented by Will Pendergrass (ATDD), Farn Parungo (ARS), Jeff McQueen and Bruce Hicks (H/Q).

Hicks also chaired the meeting. A draft report on the meeting has been prepared and distributed (by ARL) for initial comment.

A one-day workshop was hosted by ARL to resolve remaining questions about the rates of chemical conversion within the Kuwaiti oil fire smoke plumes. The workshop was well attended by representatives from NOAA/ARL, EPA, NCAR, DOE, Drexel University, and the University of Washington. A key result of the meeting was the emergence of surprisingly consistent conversion rate estimates for SO_2. The range of rates narrowed considerably after the anomalously high values (up to 50% per hour) reported by one research group were revised significantly downward. The bulk of the estimates now range from approximately 1-10% per hour, with a probable value of 4 ± 4% per hour. The sulfur was most likely adsorbed onto particles within the smoke plume; high concentrations of background sulfur within the region tended to complicate the interpretation of the data.

2.2.4 Dense Gases

In the context of atmospheric emergencies, dense gases offer a special challenge — of all of the potentially dangerous materials that can be injected into the air, dense gases impose the greatest need to use advanced models with detailed consideration of local terrain. Because of their density, such gases can remain undiluted in the atmosphere for considerable periods, especially at night, and in their undiluted form can flow under the influence of gravity rather than as dictated by low-level wind fields alone. The need to consider both the wind and the local terrain and to apportion the roles of these factors by some objective means underlies much of the dense gas dispersion modeling research that is being conducted at this time.

The HARM-II model developed at Oak Ridge considers a large number of chemicals that when spilled can generate a dense gas cloud. HARM is designed to assimilate data from an array of meteorological towers located so as to guide the dispersion computations. An alternative is to guide the computations using computer-generated wind fields. In complex terrain, it remains better to use carefully-selected observations than to rely on the predictions of even the most advanced dynamic model. Nevertheless, the complex terrain research programs also underway in ARL focus directly on the methodologies by which such computer wind field data can be generated (see separate complex terrain discussion). At the same time, ASMD researchers are embarking on a new experimental activity to study the behavior of dense gas clouds when released into the atmosphere, using the DOE spills facility operated at the Nevada Test Site.

Version 2.3 of the HARM-II code was completed during 1992. Revisions include new heavy gas parameterizations, multiple graphic windows, and some user-requested interface changes.

2.2.5 Site-Specific Studies

The Field Research Division has been involved in an upgrade to the Telemetering and Emergency Response Capabilities at the Idaho National Engineering Laboratory (INEL). The improvements focused on modernization of the meteorological network and the corresponding data acquisition systems, to support both normal daily routine operations and to assist INEL emergency response operations.

At Oak Ridge, ATDD's HARM-II atmospheric dispersion model was officially transferred to DOE/ORO. HARM forms the basis for the atmospheric emergency component of the DOE Oak Ridge Operations' Emergency Operations Center, major responsibility for which now resides with the individual site contractors. Direct involvement of ARL has been greatly reduced, following delivery of the HARM model and transfer of operational authority to the individual DOE/ORO operating contractors.

At Silver Spring, a subroutine has been developed that will allow multiple surface (and tower) meteorological data to be assimilated into the HY-SPLIT trajectory and dispersion model. NMC model meteorological data are replaced by gridded observed surface data at those grid points containing observed surface data. This enhancement may improve the initial transport and dispersion near the release point since local meteorology will be used instead of the coarser meteorological model data. In essence, this advance permits HY-SPLIT to be employed as a site-specific model, tailored to local conditions by ingesting data from strategically located towers.

2.3 Climate Trends and Variability

2.3.1 Surface Radiation (including IR, UV)

Steps have been initiated to impose some badly needed improvements on solar radiation monitoring in the United States. At this time, there is a network of slightly more than 30 stations, producing data from poorly-maintained instruments operating at sites of uncertain suitability. It is now proposed to close sites that are greatly deficient, to refurbish equipment at those that are deemed most valuable, and to set up a new network of more sophisticated stations to satisfy the needs of climate researchers.

Arrangements were completed for the transition from a national routine solar radiation monitoring network run by the NWS to a more intensive monitoring activity with fewer sites, run as a research monitoring operation by ARL under a new Surface Radiation Research group to be set up by ARL, in Boulder, Colorado. Network operations will be centered at Oak Ridge. Arrangements are being made for DOE to handle calibrations, at the National Renewable Energy Laboratory in Golden, CO.

International solar radiation data are archived by the World Radiation Data Centre, in St. Petersburg, Russia. ARL forestalled an imminent closure of the St. Petersburg operation by the last-minute transfer of sufficient funds to ensure the continued operation of the centre, through the end of 1993. Preliminary arrangements have been made for WMO to step in if future problems of this kind arise.

2.3.2 Meteorological trends

<u>Global air temperature trends</u>

During the winter of 1991-92, the global tropospheric temperature was below the 33-year average for the first time since 1978; perhaps indicating the cooling influence of the Mt. Pinatubo volcanic eruption. There was a near balance between very warm north temperate and south polar zones, cool north subtropic and equatorial zones, and a cold south temperate zone.

Global tropospheric temperatures in the summer of 1992 were the coldest for that season since 1976, nearly 0.8°C cooler than in 1991. For the year as a whole, global tropospheric temperatures in 1992 were the coldest since 1976, 0.2°C below the 1958 to 1991 average and 0.5°C colder than 1991. After adjustment for the El Nino influence, global tropospheric temperatures in 1992 were the same as the record low values (0.4°C below the 1958 to 1991 average) observed in 1964 following the Mt. Agung eruption. The global low stratosphere was about 1°C warmer in 1992 than in 1991. This tropospheric cooling and stratospheric warming is probably mostly due to the Mt. Pinatubo eruption in June of 1991.

These conclusions are based on analysis of data from a 63 station radiosonde network, a continuing program operated at Silver Spring. Based on an analysis of 9-season-average values to minimize the quasi-biennial oscillation (QBO) influence on temperature, global warming in the 16 to 20 km layer was greatest following the eruption of Mt. Pinatubo and least following that of Mt. Agung. Such warming at higher altitudes was a maximum in the tropics and a minimum in the polar zones. The warming following all recent major eruptions (Mt. Agung, Mt. Pinatubo, and Mt. Hudson, Chile) was greater in the Southern Hemisphere than in the Northern Hemisphere. Above 20 km in the tropics the warming was greatest after El Chichon (Mexico), with clear evidence of warming at 31 km from both radiosonde and rocketsonde data.

Cloudiness

United States daytime cloudiness in the summer of 1992 was 10% above average, the second cloudiest summer since the beginning of the record in 1950, exceeded only by the "El Nino summer" of 1982 (11% above average). The cloudiness was well-above average in all 6 regions of the U.S., ranging from 6% above in the south central region to 15% above in the Northwest. United States sunshine was 4% below average during the summer, the third lowest value in the 43 years of record.

3. International Activities

3.1 The World Meteorological Organization

3.1.1 The Global Atmospheric Watch

A survey was completed, in collaboration with a Russian colleague, of the precipitation chemistry field and laboratory programs of the former USSR World Meteorological Organization Background Air Pollution Monitoring Program (WMO BAPMoN). Field and laboratory procedures were discussed, siting criteria were examined, station histories were documented, and four Soviet quality assurance techniques were reviewed. Comparison of data from three Soviet BAPMoN stations with data from three US BAPMoN stations indicated that sulfate concentrations were comparable, but that US samples were typically much more acidic. As a general rule, Soviet samples have higher concentrations of cations of soil origin and higher concentrations of ammonium.

ARL is heavily involved in the organization of the new Global Atmospheric Watch of WMO, which is replacing BAPMoN as the WMO pollution monitoring activity. A considerable effort is being made to ensure that GAW does not suffer the same flaws as BAPMoN.

3.1.2 Regional Specialized Meteorological Center

On November 6, a presentation was made to the WMO Commission on Basic Systems (CBS) in Geneva, Switzerland, to designate ARL as a Regional Specialized Meteorological Center (RSMC) to provide transport model products for environmental emergency response. Similar presentations were made by the Canadian, French, and British meteorological services. The four proposals were accepted and final approval is expected at the executive council meeting in June of 1993. The designation of ARL as an RSMC will not initially alter day-to-day life at ARL Silver Spring, but it at least provides some recognition of functions that have been performed for quite some time. This will also provide a mechanism for the centers to coordinate research, output products, and backup plans for each facility.

3.2 Other International Activities

3.2.1 International Air Sampling under the Open Skies Treaty

ARL assembled a working group of experts to recommend environmental measurements to be made aboard flights conducted under the Open Skies Treaty. The treaty is now signed by 25 countries (including Russia and other parts of the former Soviet Union), with more signatories expected. Under the terms of the treaty, inspection aircraft of any signatory nation may overfly any other signatory's territory, within understandably strict limitations. Use of these flights for making environmental measurements is now being discussed. It was the purpose of the ARL activity to advise on what air quality measurement possibilities should (and should not) be negotiated, and at the same time to provide guidance to the teams soon to commence work on preparing aircraft, which were initially planned to be USAF WC-135's. Two working groups were assembled, one addressing the use of multispectral scanners and the other the requirements for air chemistry studies. If implemented, the Open Skies flights will offer an unprecedented opportunity to make air quality/trace gas measurements for the first time over large areas of the troposphere previously off limits to U.S. researchers.

3.2.2 Programs with International Scientific Collaborators

<u>Russia</u>

In January 1992, two Soviet scientists, Drs. I. Granberg and R. Razakov, visited the U.S., at the invitation of ARL/ARS, to meet with their American counterparts, to make a site visit of the Owens Lake, and to discuss plans for joint research on the Aral Sea and Owens Lake.

Dr. Larissa Koval from the Institute for Hydrology, St. Petersburg, spent most of 1992 working with the Silver Spring group on the development of computer routines to describe air-surface exchange in the presence of mixed vegetation.

Dr. Nina Zaitseva of the Central Aerological Institute in Moscow, an expert in Soviet upper-air systems, visited ARL for the week of 29 June to 3 July to exchange information about past, present and future radiosonde systems and methods.

Dr. Eugene L. Genikhovich, from the Main Geophysical Observatory in St. Petersburg, Russia, joined the ASMD Fluid Modeling Facility as a Senior Research Associate under the NOAA/NRC Resident Research Associateships Program for an initial term of one year. His research interest is in the area of downwash of pollutants from sources located in the vicinity of buildings.

Belarus

At the invitation of the Belarus State Committee of Ecology, an air quality management expert team was organized by the World Bank to review existing laws and practices relating to air quality management in Belarus and former Soviet Union (FSU). John Irwin of NOAA/ARL took part. The team met in Minsk, Belarus from June 28 through July 11. A report was drafted summarizing the existing system of air quality management in the FSU, including recommendations for strengthening and improving the existing system to make it more suitable and effective in regulating air quality and adapting to a free market economic system.

Egypt

The Field Research Division, Idaho Falls, has been collaborating with the Atomic Energy Authority of Egypt, specifically with regard to the performance of tracer experiments to test the site selection for proposed nuclear power installations. As part of this collaboration, four Egyptian scientists undertook a 6-week training course in general meteorology, air pollution meteorology, and tracer technology at Idaho Falls. Training included such topics as general circulation, solar radiation, atmospheric stability and vertical motion, plume rise, basic diffusion concepts, Gaussian diffusion models, and gas chromatography analysis techniques. The last item received special attention: part of the overall activity involved the provision of a newly designed sampling and analysis system to the Egyptian government.

A complete gas chromatograph for the Egyptian government was completed and shipped on schedule. The system is intended to support tracer release experiments to be conducted in Egypt. It includes a chromatograph, a custom autosampler designed specifically for handling air samples, complete operating software, some support equipment, and an operating manual that includes a discussion of the theory of operation as well as installation, operation, and trouble-shooting instructions.

China

Scientists of the Aerosol Research Section in Boulder are working with Chinese colleagues to study the long-range transport of Gobi Desert dust during springtime. Field experiments were conducted along the dust plume at various stations and on a research ship in the East China Sea. Measurements were of aerosol particle concentration, size distribution, and chemical composition. The information obtained is of special interest in the context of

global climate change, since China is a major source region for tropospheric sulfate particles that are known to influence atmospheric radiative properties.

India

There has been a long-term interaction between ATDD scientists and staff of the Center for Atmospheric Sciences of the Indian Institute of Technology (IIT) at New Delhi. In early 1992, ATDD participated in some SF_6 tracer experiments conducted by IIT in an urban area in New Delhi. Old associations with the Center for Environmental Science and Engineering of IIT, Bombay, were also renewed during 1992.

Italy

ATDD collaborated with the University of Tuscia in Viterbo, Italy, on leaf and canopy stomatal conductance models based on state-of-the-art physiology, under the RAISA research fellowship program sponsored by the National Research Council of Italy. Among the products of this work were improved algorithms for isoprene emission and O_3 and SO_2 uptake.

Japan

ASMD joined with the National Institute for Environmental Studies in Tsukuba, Japan, in a six-week study to improve the Urban Airshed Model (UAM) for use in Japanese conditions. This interaction was arranged through the Japan Society for the Promotion of Science. The project involved a numerical meteorological model equipped with four-dimensional data assimilation to simulate the transport and formation of oxidants in the greater Tokyo area during a high ozone episode. Since the meteorological model encompassed a larger domain and a greater grid cell size than the UAM, an interface (nesting) processor was successfully utilized to prepare input data files of winds, temperatures, and mixing heights for UAM simulations. The model simulations and graphical analyses were performed on workstations at the Institute.

In a separate study, a visitor to Research Triangle Park from the Tokyo Institute of Polytechnics in Japan, studied the flow field and dispersion of pollutants released near the base of twin high-rise buildings, systematically varying such parameters as the height of the towers, the spacing between them, and the location of the source. The study made use of the meteorological wind tunnel of the ASMD Fluid Modeling Facility. The results of the study will help engineers to locate building air intakes and to predict impacts on ambient air concentrations.

Mexico

ATDD participated in field studies of ozone and air pollution in Mexico City, led by Los Alamos National Laboratory. The ATDD contribution focused on such aspects as the time variation of surface ozone concentrations as affected by insolation; the effects of the nocturnal stable boundary layer on the profiles of O_3, water vapor and wind speed; and the effect of local storm passage on the O_3 concentration profiles.

Poland

ATDD took a leading part in a U.S. collaboration with Polish scientists aimed at determining the cause of increasing damage to historic carvings in the Wieliczka Salt Mine art repository. Monitoring equipment included a meteorological station on the surface above the mine, six stations monitoring air flow, air temperature, and humidity within the mine, and five chemical sampler systems (operated by California Institute of Technology) to evaluate gaseous and particulate concentrations in the mine. Portable equipment was used to conduct exploratory studies within the mine passages, and to help in selecting appropriate locations for the fixed sampling sites. The goal was to determine the source of moisture that is damaging salt carvings in the mine, and to recommend remedial actions to the mine authorities. The studies revealed that the cause of the damage was moisture entering through the ventilation system used to help encourage tourism.

In an independent venture, the American Express Foundation provided a grant to ATDD to procure equipment needed by the Conservation Department of the Academy of Fine Arts in Krakow, Poland, for measurements related to the formation of condensation on the stained glass windows of an ancient church. The high concentrations of air pollutants in Krakow react with the constituents of the wetted glass, producing an opaque film.

Canada

At the request (and expense) of the Canadian Ministry of the Environment, a training workshop was designed and conducted in Victoria, British Columbia, to introduce the ASMD-developed CTDMPLUS and CTSCREEN complex terrain dispersion models to government scientists and modelers in western Canada. The workshop included a technical discussion of the modeling methodologies, hands-on experience applying the models to British Columbian situations, and a general exchange of complex terrain modeling experiences in both the United States and Canada.

ARL is an active participant in the activities of the International Joint Commission between Canada and the U.S. Lester Machta, as the U.S. Chairman of the International Joint Commission's Air Quality Advisory Board (Rick Artz is the executive secretary) testified before the Commission in April in Washington, D.C. Among the Commission's more immediate interests in air matters are their forthcoming summary of public comments on the first report of the Committee established under the Canada-U.S. Air Quality Agreement of 1991 and the air deposition of toxic substances to Lake Superior. The first Air Quality Agreement report deals exclusively with acid deposition, summarizing both the governments' plans for future emissions controls and the science of the acid deposition issue. Lake Superior has been selected by the Commission as the first of the Great Lakes to be studied under the Virtual Elimination program. There is speculation that the atmospheric pathway for pollution delivery is very important.

4. 1992 Publications and Reports

(ARL authors are shown in capital letters)

4.1 Formal Publications, 1992

ANGELL, J.K. Evidence of a relation between El Nino and QBO, and for an El Nino in 1991-92. *Geophysical Research Letters 19(3)*:285-288.

The possibility of a relation between El Nino and the quasi-biennial oscillation (QBO) in equatorial low stratosphere is investigated. Based on the 9 El Ninos and 16 quasi-biennial variations in 50 mb zonal wind at Singapore between 1954 and 1991, the sea-surface temperature (SST) in eastern equatorial Pacific has averaged nearly 0.5°C warmer one season after QBO east-wind maximum than 4-5 seasons before and after this maximum, but this difference in temperature is not statistically significant. Because of the difference in period of these oscillations (2 1/4 years on average in the case of the QBO, about 4 1/2 years on average in the case of El Nino), there can not be an El Nino associated with every QBO east-wind maximum, i.e., any relation between El Nino and QBO east-wind maximum has to "skip a beat" on occasion. This paper presents evidence for a pattern in this "skip", such that an El Nino is associated with a QBO east-wind maximum except when the El Nino associated with the previous east-wind maximum was a major one and/or the SST maximum followed the previous east-wind maximum by a few seasons. On the basis of this pattern an El Nino would not have been expected in 1989 or 1990 (because the El Nino of 1987 was a major one) but would be expected in 1991 or 1992 in association with the QBO east-wind maximum projected to occur in the northern summer of 1992. Comparison with earlier "skips" shows that an El Nino would be most likely before the next east-wind maximum, or at the end of 1991. Because it would follow the aborted warm event of 1990, it probably would not be a major El Nino.

ANGELL, J.K. Relation between 300-mb North Polar Vortex and Equatorial SST, QBO and Sunspot Number and the Record Contraction of the Vortex in 1988-89. *Journal of Climate 5(1)*:24-29.

The size of the 300-mb north circumpolar vortex and quadrants has been estimated between 1963 and 1989 by planimetering the area poleward of contours in the main belt of westerlies on the 300-mb mean-monthly polar-stereographic maps analyzed by the Meteorological Institute, Free University of Berlin. The annual-mean vortex was most contracted in 1989, 6.4% less than average size, and next most contracted in 1988, 4.6% less than average size. There have been three extensive vortex displacements during this period, the last toward the North Pacific and associated with the strong El Nino of 1982-83. Based on 108 seasonal deviations, there has been a significant correlation of -0.39 between sea surface temperature (SST) in the eastern equatorial Pacific and vortex size three seasons later, that is, the vortex has tended to be contracted following El Nino. There has been a highly significant correlation of 0.45 between this SST and the size of quadrant 90°W-180° in the same season, that is, this "El Nino" quadrant has tended to be expanded at the time of El Nino. The correlation of -0.29 between the 50-mb zonal wind at Singapore and vortex size one season later (contracted vortex

in the west-wind phase of the stratospheric equatorial QBO) is not significant. There is better evidence for contraction of the vortex in the west-wind phase of the QBO when the sunspot number is relatively high.

AUBLE, D.L., and T.P. MEYERS. An open path, fast response infrared absorption gas analyzer for H_2O and CO_2. *Boundary-Layer Meteorology 59*:243-256.

An open path infrared absorption based instrument for fast response measurements of H_2O and CO_2 fluctuations is described. This instrument performed reliably in several field experiments in both terrestrial and marine environments, on both fixed (tower) and mobile (boat, plane) flux platforms. Noise levels for H_2O and CO_2 concentrations were less than 10 mg/m^3 and 300 μg/m^3, respectively for frequencies between 0.005 and 10 Hz. Drifts in instrument output, associated with changes in instrument temperature, are compensated for electronically.

CRAWFORD, T.L., and R.J. DOBOSY. A sensitive fast-response probe to measure turbulence and heat flux from any airplane. *Boundary Layer Meteorology 59*:257-278.

The theory, configuration, and accuracy of an inexpensive probe to measure turbulence from a small airplane are presented. The probe employs a nine-hole pressure-sphere design along with in-probe high-frequency pressure, temperature, and acceleration sensors. This sensor suite is specifically designed to extend mass, momentum and energy eddy-flux measurement to the higher frequencies characteristic of marine and nocturnal boundary layers. The probe is part of a mobile flux system independent of the conveyance, which does not require a separate Inertial Navigation System. The new nine-port pressure sphere turbulence probe allows accurate turbulent velocity measurement with proper probe installation and appropriate computation technique for dynamic pressure. A thermistor in the central pressure port provides simultaneous temperature measurement, at a location symmetrical with respect to the flow, for accurate determination of true airspeed and heat flux. The probe-mounted temperature sensor gives heat fluxes with variance 5% of the mean in a weakly-turbulent marine boundary layer.

DRAXLER, R.R. The accuracy of trajectories during ANATEX calculated using dynamic model analyses versus rawinsonde observations. *Journal of Applied Meteorology 30*:1446-1467.

Aircraft tracer measurements all made within 300 km of the release sites during the Across North America Tracer Experiment (ANATEX) provided 30 separate trials to evaluate the error of back-trajectory calculations. The trajectory calculations used dynamic-model-output meteorological data from the NOAA prognostic Nested Grid Model (NGM) and from comparable gridded meteorological fields from 4-day rawinsonde or 2-day rawinsonde observations. Over all trials, no significant difference was discernable in trajectory accuracy using the different meteorological input data; absolute trajectory error ranged from 20% to 30% of the travel distance. When the trajectories were grouped into similar categories, the NGM data provided the best results when smaller-scale flow features were present; ones that could not be resolved in the rawinsonde network. Four-day rawinsonde data provided the best results when fronts or low pressure systems were present in the

vicinity of the tracer release. Slower transport in more homogeneous zonal flow regimes resulted in some of the smallest errors of around 15% of the travel distance for all the methods. In 70% of the events, the 4-day and 2-day rawinsonde calculations were comparable, suggesting that linear temporal interpolation of the flow field is reasonable for most situations. The primary conclusion is that the NGM-generated meteorological data can be an adequate substitute for rawinsonde data in trajectory calculations.

Duce, R.A., P.S. Liss, J.T. Merrill, E.L. Atlas, P. Buat-Menard, B.B. HICKS, J.M. MILLER, J.M. Prospero, R. Arimoto, T.M. Church, W. Ellis, J.N. GALLOWAY, L.Hansen, T.D. Jickells, A.H. Knap, K.H. Reinhardt, B. Schneider, A. Soudine, J.J. Tokos, S. Tsunogai, R. Wollast, and M. Zhou. The atmospheric input of trace species to the world. *Global Biochemical Cycles 5(3)*:193-259.

Over the past decade it has become apparent that the atmosphere is a significant pathway for the transport of many natural and pollutant materials from the continents to the ocean. The atmospheric input of many of these species can have an impact (either positive or negative) on biological processes in the sea and on marine chemical cycling. For example, there is now evidence that the atmosphere may be an important transport path for such essential nutrients as iron and nitrogen in some regions. In this report we assess current data in this area, develop global scale estimates of the atmospheric fluxes of trace elements, mineral aerosol, nitrogen species, and synthetic organic compounds to the ocean; and compared the atmospheric input rates of these substances to their input via rivers. Trace elements considered were Pb, Cd, Zn, Cu, Ni, As, Hg, Sn, Al, Fe, Si, and P. Oxidized and reduced forms of nitrogen were considered, including nitrate and ammonium ions and the gaseous species NO, NO_2, HNO_3, and NH_3. Synthetic organic compounds considered included polychlorinated biphenyls (PCBs), hexachlorocyclohexanes, (HCHs), DDTs, chlordane, dieldrin, and hexachlorobenzenes (HCBs). Making this assessment was difficult because there are very few actual measurements of deposition rates of these substances to the ocean. However, there are considerably more data on the atmospheric concentration of these species in aerosol and gaseous form. Mean concentration data for 10° x 10° ocean areas were determined from the available concentration data or from extrapolation of these data into other regions. These concentration distributions were then combined with appropriate exchange coefficients and precipitation fields to obtain the global wet and dry deposition fluxes. Careful consideration was given to atmospheric transport processes as well as to removal mechanisms and the physical and physicochemical properties of aerosols and gases. Only annual values were calculated. On a global scale atmospheric inputs are generally equal to or greater than riverine inputs, and for most species atmospheric input to the ocean is significantly greater in the northern hemisphere than in the southern hemisphere. For dissolved trace metals in seawater, global atmospheric input dominates riverine input for Pb, Cd, and Zn, and the two transport paths are roughly equal for Cu, Ni, As, and Fe. Fluxes and basin-wide deposition of trace metals are generally a factor of 5-10 higher in the North Atlantic and North Pacific regions than in the South Atlantic and South Pacific. Global input of oxidized and reduced nitrogen species are roughly equal to each other, although the major fraction of oxidized nitrogen enters the ocean in the northern hemisphere,

primarily as a result of pollution sources. Reduced nitrogen species are much more uniformly distributed, suggesting that the ocean itself may be a significant source. The global atmospheric input of such synthetic organic species as HCH, PCBs, DDT, and HCB completely dominates their input via rivers.

Fowler, D., J.H. Duyzer, and D.D. BALDOCCHI. Inputs of trace gases, particles and cloud droplets to terrestrial surfaces. ACIDIC DEPOSITION, Its nature and its impacts. *Proceedings of the Royal Society of Edinburgh, 97(B)*:35-59.

The deposition of reactive gases on terrestrial surfaces is one of the primary mechanisms by which pollutant gases are removed from the atmosphere. The chemical properties of the gases (SO_2, NO_2, HNO_3, HCl) and of the absorbing surfaces lead to differing rates of exchange and controlling processes. The most reactive gases HNO_3, HCl (and for many surfaces NH_3) exhibit negligible surface resistances: deposition velocities (V_g) appropriate for short vegetation ranging from 2 to 5 cm s^{-1}, for forests V_g may approach 10 cm s^{-1}. The large rates of deposition for NH_3 on moorland and forests lead to annual inputs in areas with large atmospheric concentrations of NH_3 ($\geq$ 5 μg NH_3 m^{-3}) ranging from 20 to 60 kg N ha^{-1}. The net exchange of NH_3 over cropland attributable to deposition during vegetative growth and emission of NH_3 during senescence is less well known but believed to be small. The co-deposition of NH_3 and SO_2 on external surfaces of plant canopies is believed to enhance SO_2 deposition with reported deposition velocities over short vegetation of 2.0 cm s^{-1}. Rates of cloud droplet deposition to vegetation have been shown to be very similar to rates of momentum deposition (i.e. $V_1 \approx r_{am}^{-1}$). These findings provide the basis for estimates of cloud deposition inputs of major ions to upland Britain where they may contribute up to 30% of the wet deposited sulphur and nitrogen.

GAFFEN, D.J., and T.P. Barnett. A comparison of observations and model simulations of tropospheric water vapor. *Journal of Geophysical Research 97(D3)*:2775-2780.

Observations of tropospheric specific humidity from radiosondes for the period 1973-1986 are compared with simulated specific humidity fields from a University of Hamburg version of the European Center for Medium-Range Weather Forecasting General Circulation Model (GCM), forced by observed sea surface temperatures. The mean January and July fields are shown to be in good agreement, despite the much poorer resolution of the radiosonde network used. Temporal and spatial variations of specific humidity are examined through empirical orthogonal functions analysis of troical data. The first mode of variability of the data was similar to that of the model simulations and shows evidence of a coherent, decadal-scale variation in tropospheric moisture content. The overall agreement between the model and the data, while not complete, suggests that long-term mean patterns and decadal variations in moisture, as delineated by a sparse data network, are reasonably well simulated. More comprehensive comparisons of tropospheric moisture data with GCM simulations from different models are suggested.

GAFFEN, D.J., W.P. ELLIOTT, and A. Robock. Relationships between tropospheric water vapor and surface temperature as observed by radiosondes. *Geophysical Research Letters 19(18)*:1839-1842.

Using radiosonde data from 50 stations for 1973-1990, we quantify relationships between surface air temperature (T_s) and precipitable water vapor (W) for different time scales. Monthly mean observations are fairly well described by an equation of the form $\ln W = A + BT_s$, but the coefficients A and B depend on the T range considered. At high T_s, the relationship is poor. This relationship and relationships between sea surface temperature (SST) and W based on satellite microwave observations over oceans are in remarkably good agreement over restricted SST ranges. Monthly and annual anomalies of W and T_s are well correlated only outside the tropics, but on longer time scales, there is some evidence of positive trends in both W and T_s at most of the stations studied. Thus the relationship between W and T_s depends on the time scales and geographic region considered.

GALLOWAY, J.N., J.E. Penner, C.S. Atherton, J.M. Prospero, H.Rodhe, R.S. ARTZ, Y.J. Balkanski, H.G. Bingemer, R.A. Brost, S. Burgermeister, G.R. Carmichael, J.S. Chang, R.J.Charlson, S. Cober, W.G. Ellis, C.J. Fischer, J.M. Hales, D.R. Hastie, T. Iverson, D.J. Jacob, K. John, J.E. Johnson, P.S. Kasibhatla, J. Langner, J. Lelieveld, J. Levy,II, F. Lipschultz, J.T. Merrill, A.F. Michaels, J.M. MILLER, J.L. Moody, J. Pinto, A.A.P. Pszenny, P.A. Spiro, L. Tarrason, S.M. Turner, and D.M. Whelpdale. Sulfur and nitrogen levels in the North Atlantic Ocean's atmosphere: A synthesis of field and modeling results. *Global Biogeochemical Cycles 6(2)*:77-100.

In April 1990, forty-two scientists from eight countries attended a workshop at the Bermuda Biological Station for Research to compare field measurements with model estimates of the distribution and cycling of sulfur and nitrogen species in the North Atlantic Ocean's atmosphere. Data sets on horizontal and vertical distributions of sulfur and nitrogen species and their rates of deposition were available from ships' tracks and island stations. These data were compared with estimates produced by several climatological and event models for two case studies: (1) sulfate surface distributions and deposition and (2) nitrate surface distributions and deposition. Highlights of the conclusions of the case studies were that the measured concentrations and model results of nitrate and non-sea-salt sulfate depositions appeared to be in good agreement at some locations but in poor agreement for some months at other locations. The case studies illustrated the need for the measurement and modeling communities to interact not only to compare results but also to cooperate in improving the designs of the models and the field experiments.

Grant, R.F., and D.D. BALDOCCHI. Energy transfer over crop canopies: Simulation and experimental verification. *Agricultural and Forest Meteorology 61*:129-149.

The exchange of energy between the atmosphere and the surfaces of crops and soils stabilizes the thermal regimes at these surfaces, allowing sustained biological activity to occur. In this study, a simple Eulerian submodel of energy exchange was constructed from published algorithms in order to reproduce the dynamics of water and energy exchange between the soil-crop surface and the atmosphere as part of a larger agroecosystem model. Hourly output from the submodel was compared with data recorded over a soybean (Glycine max. L. Merr) canopy at Mead, Nebraska on two dates during which soil water status differed. Recorded diurnal trends of leaf water potential and leaf stomatal resistance were reproduced in simulated diurnal trends of canopy water potential and canopy stomatal

resistance on both dates. Under water stress, simulated canopy water potential was 0.1-0.2 MPa higher, and simulated canopy stomatal resistance approximately 25% lower, than recorded leaf values. Simulated fluxes of net radiative energy, and of latent, sensible, and soil heat were within 50Wm^{-2} of recorded values. Differences between simulated canopy and recorded air temperatures were consistent with those calculated at other sites under comparable atmospheric conditions. Inclusion of these algorithms in the agroecosystem model allowed a more comprehensive validation of the simulated transport of water and energy through the agroecosystem than would otherwise be possible.

HICKS, B.B., and R.S. ARTZ. Estimating background precipitation quality from network data. *Environmental Pollution 75*:137-143.

Assessments of the relative merits of alternative acid-rain control strategies revolve around considerations of potential benefit per unit effort and/or cost. A question that often arises concerns the changes in deposition that would follow if all industrial (or societal) emissions were eliminated, in which case precipitation chemistry would be dominated by emissions from natural sources. Estimates of the "natural background" of precipitation chemistry can be based on (a) measurements made at distant locations, (b) reducing emissions to zero in numerical simulations, or (c) examinations of existing data. Each alternative is flawed because (a) of the assumption that natural emissions in one location are like those in another, (b) no existing model contains descriptions of chemical processes involving all of the chemical species of importance, and (c) all contemporary data records of relevance are affected by precisely the emissions we wish to reduce. Here, the third alternative is explored in detail, using event precipitation chemistry data from North America. The analysis reveals a background pH level that varies from site to site, but always lies in the range 5.0 - 5.3.

Johnson, T.C., D.A. GILLETTE, and R.L. Schwiesow. Fate of dust particles from unpaved roads under various atmospheric conditions. In Precipitation Scavenging and Atmosphere-Surface Exchange, Vol. 2, The Semonin Volume: Atmosphere-Surface Exchange Processes, S.E. Schwartz & W.G.N. Slinn, Coordinators, Hemisphere Publishing Company, Washington, DC, 933-945.

A lidar/micrometeorological study on the deposition of road dust showed the time to reduce initial plume mass to e^{-1} to be about 10 - 40 s. On the basis of published particle size distributions in the initial plume, this would imply a time of about 1-4 min for the reduction of initial particle mass by e^{-1}, for particle size between 1 and 10 μm.

Lindberg, S.E., T.P. MEYERS, G.E. Taylor, Jr., and W.H. Schroeder. Atmosphere-surface exchange of mercury in a forest: Results of modeling and gradient approaches. *Journal of Geophysical Research 97(D2)*:2519-2528.

We have modified recently published dry deposition models to estimate deposition velocities (V_d) for Hg in both fine aerosol and vapor form to forest canopy surfaces. Aerosol and total vapor phase Hg concentrations in air previously measured at Walker Branch Watershed in Tennessee have been used with model results to

estimate dry deposition to a deciduous forest. The concentration data confirm that airborne Hg is dominated by vapor forms at this site and exhibits concentrations moderately above continental background levels. The modeled V_d values reflect published data which suggest that dry deposition of Hg vapor is strongly controlled by surface transport processes notably stomatal and mesophyll resistances, the latter dominating. Weekly mean V_d values ranged from 0.006 (winter) to 0.12 (summer) cm s^{-1}. We have also measured concentration gradients of Hg vapor in air above this forest to estimate air-surface exchange during short-term experiments. While the model results indicate that the canopy is a sink for Hg vapor, the concentration profiles suggest that the forest soils are a source during some periods, the combined effect of which is net Hg fluxes in the upward direction. Application of a detailed canopy turbulence model yielded soil emission rates of the order of 50 ng Hg m^{-2} h^{-1}, ≈10% of which is deposited in the canopy. Our modeled dry deposition estimates plus limited measurements of wet deposition in this area suggest that dry and wet deposition may be comparable in magnitude.

LURIA, M., J.F. BOATMAN, J. HARRIS, J. RAY, T. STRAUBE, J. CHIN, R.L. GUNTER, G. HERBERT, T.M. Gerlach, and C.C. VAN VALIN. Atmospheric sulfur dioxide at Mauna Loa, Hawaii. *Journal of Geophysical Research 97(D5)*:6011-6022.

Measurements of sulfur dioxide (SO_2) were made at the National Oceanic and Atmospheric Administration's Mauna Loa Observatory in Hawaii, during a 12-month period beginning in December 1988. SO_2 concentrations varied from background levels of less than 0.05 ppbv to a maximum of 50 ppbv, during episodes that lasted from 2 to 24 hours. Emissions from the Kilauea crater, approximately 35 km southeast of the observatory at an elevation of about 1000 m above sea level (asl), and the current eruption of Puu O'o 50 km east-southeast, are the most likely sources for the higher concentrations. These episodes occurred 10-25 times each month, mostly during the day; peak concentrations were usually recorded at mid-day. The SO_2 concentrations can be grouped into three periods; low (June-September), high (October-January), and intermediate (February-May). A clear diurnal cycle of SO_2 concentration exists throughout the year, although day-night changes were greatest during October-January and were barely detectable during the June-September period. The highest SO_2 concentrations were recorded when the predominant wind direction was northerly to northwesterly, even though the apparent sources are in the southeastern sector. Nighttime concentrations were usually at background levels; however, many exceptions were observed. A few cases of higher than background SO_2 were observed when free tropospheric (FT) conditions were identified. The possibility that long-range transport was the cause for elevated SO_2 concentrations under FT conditions was examined using air mass back trajectories analyses. The highest nighttime SO_2 concentrations, under FT conditions, were observed during periods with slow easterly trajectories, and the lowest concentrations were found during westerly flows. Twenty-four nighttime free tropospheric events were recorded when the SO_2 concentration exceeded 0.2 ppbv. During 18 of these episodes, unusually high CO_2 concentrations were observed.

MEYERS, T.P. On the use of models to identify critical atmosphere-canopy exchange processes. Proceedings of the Fifth International Conference on Precipitation Scavenging

and Atmosphere-Surface Exchange Processes, July 15-19, 1991; Precipitation Scavenging and Atmosphere-Surface Exchange, Vol. 2, The Semonin Volume: Atmospheric-Surface Exchange Processes, S.E. Schwartz & W.G.N. Slinn, Coordinators, Hemisphere Publishing Company, Washington, DC, 1035-1051.

Models are useful for not only providing a means of routinely estimating dry deposition, but can be used to address some of the uncertainties associated with estimates of deposition rates. In this report, a combination of data and models are used to assess several aspects associated with estimating dry deposition. The use of scaling physiological leaf level processes by the canopy leaf area index (LAI) to determine the stand level uptake tends to overestimate the deposition rate of SO_2. Another major processes that receives relatively little attention compared to physiological responses is mass transfer through leaf boundary layers. For gases in which the diffusion through stomata is the primary transport pathway to the leaf (e.g. SO_2 and O_3) large uncertainties can be tolerated for estimating the deposition rate. However, the modeled uptake of HNO_3 (which has little surface uptake resistance) is very sensitive to the parameterization of the leaf boundary layer resistance. An upper estimate of deposition to sites or locations that far exceed the basic assumptions of the model (flat and horizontally homogeneous) can be made by assuming the aerodynamic resistance is zero. When compared to the "flat terrain" estimate, a 25% difference is observed for SO_2. For HNO_3, a factor two difference is seen.

NAPPO, C.J., and G. Chimonas. Wave exchange between the ground surface and a boundary-layer critical level. *Journal of Atmospheric Sciences 49(13)*:1075-1091.

Gravity waves induced by two- and three-dimensional terrain features are examined theoretically in the planetary boundary layer (PBL) using a linear wave model that includes reabsorption at a critical level. The PBL structure is characterized by a constant Brunt-Väisälä frequency and a hyperbolic tangent wind speed profile, which can be adjusted to produce critical levels. It is found that for typical values of wind speed and thermal stratification in the stable PBL and for even mild terrain disturbances, the Reynolds stress and surface drag caused by surface-generated waves can be at least as large as those conventionally associated with surface friction. The wave drag will act on the PBL flow where wave dissipation occurs, for example, at a critical level or in regions of wave breaking. The drag over a given crosswind section of a two-dimensional ridge is about twice as great as that over a three-dimensional hill of approximately the same horizontal area. An entirely new result is the prediction that over a three-dimensional hill the wave stresses may generate a horizontal layer of counterrotating vortices immediately below a critical level.

PARUNGO, F.P., C.T. NAGAMOTO, M.Y. ZHOU, and N. ZHANG. Wet and dry deposition of atmospheric aerosols to the Pacific Ocean. Proceedings of the Fifth International Conference on Precipitation Scavenging and Atmosphere-Surface Exchange Processes, July 15-19, 1991; Precipitation Scavenging and Atmosphere-Surface Exchange, Vol. 2, The Semonin Volume: Atmosphere-Surface Exchange Processes, S.E. Schwartz & W.G.N. Slinn, Coordinators, Hemisphere Publishing Company, Washington, DC, 867-881.

During eight research cruises in the Pacific Ocean from 1984 to 1990, we collected rain and aerosol samples for chemical analyses. The surveyed areas were classified into eight regions. The regional variations of rain and aerosol chemistry were studied in relation to natural and anthropogenic sources and long-range transport. Values of enrichment factors (EFs) that is ratios of $SO_4^=$ NO_3^-, Ca^{++}, and K^+ to Na^+ in rain or in aerosol particles divided by ratios of the same ions to Na^+ in sea water were greater than unity for both rain and aerosols throughout the ocean, but decreased with increasing distance from land. The Efs of Mg^{++} were close to 1 and the Efs of Cl^- were less than 1. Scavenging ratios varied with regional cloud characteristics. The available records of regional rainfall and dry deposition velocities of various particles were used to calculate regional wet and dry deposition fluxes for various ions. The relative importance between wet deposition and dry deposition varied geographically.

Paumier, J.O., S.G. PERRY, and D.J. Burns. CTDMPLUS: A dispersion model for sources near complex topography. Part II: Performance characteristics. *Journal of Applied Meteorology 31*:646-660.

The Complex Terrain Dispersion Model (CTDMPLUS), described in Part I of this paper, was evaluated using the SO_2 field study data from the Lovett generating station in southeastern New York state. For perspective, CTDMPLUS estimates were also compared with these from the regulatory version of the Rough Terrain Diffusion Model (RTDM). For comparisons unpaired in space or time, the highest 25 CTDMPLUS model predictions tended to overpredict the highest 25 hourly observations by, on average, about a factor of 2. Similar results were found for 3-h and 24-h average predictions. Overpredictions occurred mainly for stable atmospheric conditions. In contrast, the hourly and 3-h average model concentrations paired in time with observations underpredicted the observations by as much as a factor of 4. CTDMPLUS displayed no strong bias in estimating the 24-h average concentrations. To understand the performance of CTDMPLUS, the meteorological conditions associated with the highest 25 observed concentrations were examined. This analysis suggests that the most significant factors affecting CTDMPLUS predictions for stable conditions are the height of the plume and its relation to the diving streamline; in convective conditions, significant factors are the fraction of plume material penetrating the stable layer aloft, lateral plume spread, and wind direction.

PERRY, S.G. CTDMPLUS: A dispersion model for sources near complex topography. Part I: Technical formulations. *Journal of Applied Meteorology 31*:633-645.

The Complex Terrain Dispersion Model (CTDMPLUS), a point-source, steady-state model for complex-terrain applications, is described. The model simulates the flow and plume distortion near user-selected, three-dimensional terrain features, yet retains simplicity by applying flow-distortion corrections to flat terrain, Gaussian, and bi-Gaussian pollutant distributions. The algorithms for stable and near-neutral conditions are based on the demonstrated concept of a dividing streamline. These algorithms were developed using data from three major plume-impaction field studies and a number of fluid-modeling studies. The algorithms for plumes released into convective layers are based on recent understanding of the convective

boundary layer through fluid modeling, numerical modeling, and field studies. The non-Gaussian nature of vertical dispersion is accounted for; lateral dispersion is modeled with the aid of convective scaling concepts. A terrain preprocessor and a meteorological preprocessor, which provide input specifically for the CTDMPLUS model, are described. The model requires a fully three-dimensional description of individual terrain features in order to estimate flow (and plume) distortions. Estimates of surface-layer parameters (friction velocity and Monin-Obukhov length) and depth of the mixed layer are required to define the state of the boundary layer.

PLEIM, J.E., and J.S. Chang. A non-local closure model for vertical mixing in the convective boundary layer. *Atmospheric Environment 26A*:965-981 (1992).

A simple non-local closure model for vertical mixing in Convective Boundary Layers (CBL) has been developed specifically for application in regional or mesoscale atmospheric chemistry models. The model, named the Asymmetrical Convective Model (ACM), is based on the concept ttha vertical transport within the CBL is inherently asymmetrical. Upward transport by buoyant plumes originating in the surface layer is simulated by mixing from the lowest model layer directly to all other layers in hte CBL. Downward transport, however, proceeds only to the next lower layer in order to emulate gradual compensatory subsidence. The ACM is similar to the model developed by Blackadar (1978, 4th Symp. on Atmospheric Turbulence, Diffusion and Air Quality, pp. 443-447, Reno, Am. Meteorolo. Soc.) but differs in its treatment of downward transport. The realism of the ACM is tested through comparisons to large-eddy simulations of several idealized test cases. These tests show that while the ACM shares the Blackadar model's ability to simulate rapid transport upward from the surface layer to all levels in the CBL, it is clearly superior in its treatment of material emitted from elevated sources either within or above the CBL. The ACM is alos tested in the context of the Regional Acid Deposition Model (RADM) both to determine sensitivity to different CBL mixing schemes and to compare to vertically resolved aircraft measurements. These tests demonstrate quicker upward transport of ground-level emissions by the ACM as compared to the eddy diffusion scheme currently used in RADM. The ACM also affects ozone photochemistry in the boundary layer resulting in lower ozone concentrations in areas of high NO_x emissions.

Ray, J.D., C.C. VAN VALIN, and J.F. BOATMAN. The vertical distribution of atmospheric H_2O_2: A case study. *Journal of Geophysical Research 97(D3)*:2507-2517.

Vertical profiles of H_2O_2 mixing ratios were obtained for each season from a site in central Arkansas during 1988. Aircraft-based measurements indicated that H_2O_2 mixing ratios followed an annual cycle, peaking during the summer at >6 parts per billion by volume (ppbv). The minimum occurred in winter when mixing ratios for H_2O_2 averaged about 0.2 ppbv. The H_2O_2 mixing ratio generally peaked at an altitude of about 800 mbar (2 km), although there may have been some seasonal dependence. The annual cycle followed variations in solar intensity, water mixing ratio, and temperature. Within a season, strong variations could be related to meteorological events. A daily cycle was inferred in which the H_2O_2 mixing ratio varied by a factor of two to three; the peak observed values were at night. H_2O_2

mixing ratios at altitudes higher than 0.7 km were generally greater than local SO_2 values above 0.7 km during all but the winter season.

ROLPH, G.D., R.R. DRAXLER, and R.G. De PENA. Modeling sulfur concentrations and depositions in the United States during ANATEX. *Atmospheric Environment 26A*:73-93.

The Hybrid Single-Particle Lagrangian Integrated Trajectory (HY-SPLIT) long-range transport, personal-computer-based model was incorporated with a non-linear chemistry module that includes gas and aqueous-phase oxidation of sulfur dioxide (SO_2) and dry and wet removal of SO_2 and sulfate (SO_4^{2-}) particles. The model considers multiple area and point sources (~500) and calculates simultaneously 24-h averages of several species: air concentrations of SO_2 and SO_4^{2-} particles and SO_4^{2-} wet deposition on each grid cell of the meteorological domain. Three-month averages of modeled air concentrations of SO_2 and SO_4^{2-} were compared with measurements from five National Oceanic and Atmospheric Administration/Air Resources Laboratory dry deposition sites. The model tended to underpredict air concentrations of SO_2 (ratios of model-predicted to measured concentrations between 0.6 and 1.2) and overpredict air concentrations of SO_4^{2-} (ratios between 1.0 and 1.6). Modeled SO_4^{2-} wet deposition values were calculated, averaged for the 3 months, and compared with the measured values at 137 combined UAPSP, MAP3S, and NADP precipitation chemistry sites. For the majority of these sites, the agreement was good; the ratios between modeled and measured deposition were between 0.5 and 1.6. However, a consistent underprediction was observed across the southern and extreme eastern U.S. This underprediction was primarily attributed to the proximity of the edge of the model domain to the eastern and southern U.S. which caused trajectories from the continent that would have curved back into the south-eastern U.S. to terminate prematurely. When SO_2 emissions were reduced by 50% over the entire model domain, approximately 50-55% reductions were observed in SO_2 air concentrations over the entire model domain and at all levels. However, sulfate air concentrations and depositions were only reduced 35-50% due to non-linear reactions involving SO_2. When emissions of SO_2 were reduced by 50% only in the Ohio Valley, reductions in SO_2 and SO_4^{2-} air concentrations to the north and south of the Ohio Valley were generally less than 15%. These small reductions are attributed to local emissions of SO_2 and long-range transport of SO_4^{2-} from other regions not affected by the reduction in emissions. SO_4^{2-} wet deposition, however, was reduced by 15-23% to the north of the Ohio Valley, indicating some long-range transport from the Ohio Valley. In the Ohio Valley, reductions of SO_2 air concentrations were between 10 and 42%, depending on the proximity to major sources, and reductions of SO_4^{2-} air concentrations were between 10 and 30%. However, SO_4^{2-} wet deposition was reduced less than 10, consistent with the assumption that its primary contribution is from long-range transport.

TANGIRALA, R.S., K.S. RAO, and R.P. HOSKER, Jr. A puff model simulation of tracer concentrations in the nocturnal drainage flow in a deep valley. *Atmospheric Environment 26(A)*:299-309.

During the 1984 ASCOT field study in Brush Creek, CO, two gaseous tracers were released into valley drainage flow at different heights at the same site on 5 nights.

This paper describes simulations of surface concentration data from two tracer experiments, one elevated release and one surface release, which complement those reported by Rao et al. (1989, J. appl. Met. 28, 609-616). The integrated Gaussian puff model adapted by them has been improved and used for these new simulations. The improved model, VALPUFF, affords a physically realistic simulation of the mean transport for elevated plumes under highly variable emission conditions. The model simulations are evaluated by comparing predicted hourly concentrations with the corresponding observed values at 51 surface samplers. For the elevated release case, the observed mean concentration is 28 plℓ^{-1}, and the predicted mean is 31 plℓ^{-1}. Almost 85% of predictions are within a factor of 5 of observations, and 50% within a factor of two. For the ground release case, the observed and predicted means are 128 and 183 plℓ^{-1}, respectively. About 53% of predictions are within a factor of five of observations, and 23% within a factor of 2. The effects of varying wind field inputs and turbulence parameterizations on model performance are tested using several variations of the VALPUFF model. Cumulative frequency distributions of the ratio of modeled and observed hourly concentrations, and other evaluation statistics, are presented for each model. Applying resampling methods, 95% confidence intervals for fractional mean bias and normalized mean square error are calculated for the predictions of each model and for differences between the predictions of various models. It is shown that the VALPUFF model that uses vertically-averaged winds (for elevated releases) and dispersion parameters based on on-site turbulence data gives the best overall performance.

TOUMA, J.S., and K.T. Stroupe. Further development of an interactive air transport model for superfund site applications. International Symposium, Measurement of Toxic and Related Air Pollutants, Co-Sponsored by the Atmospheric Research & Exposure Assessment Lab and the AWMA, May 1992, Durham, NC.

TSCREEN is an IBM PC computer program that provides, by use of interactive menus and data entry screens, simplified screening methods for determining maximum short-term ambient air quality impact from various well-defined releases of toxic air pollutants from Superfund sites and other sources. Recently, TSCREEN was revised to include an additional scenario, estimation of ambient air quality impact on elevated receptors and complex terrain, more extensive on-line help, and new interactive menus and data screens. TSCREEN implements the methods outlined in an EPA workbook of screening techniques for toxic air releases using a logical problem solving approach. An extensive help system, text editing, and graphical display capabilities are also provided to guide the user throughout the program. The purpose of this paper is to describe the changes and to present an example in which TSCREEN would be used.

Zhang, Y.Q., A.H. HUBER, S.P.S. Arya, and W.H. SNYDER. Numerical simulation to determine the effects of incident wind shear and turbulence level on the flow around a building. *Journal of Wind Engineering 52*:261-266.

The effects of incident shear and turbulence on flow around a cubical building are being investigated by a turbulent kinetic energy/dissipation (κ-ϵ) model (TEMPEST). The simulations demonstrate significant effects due to the differences in the

incident flow. The addition of upstream turbulence and shear results in a reduced size of the cavity directly behind the building. The accuracy of numerical simulations is verified by comparing the predicted mean flow fields with the available wind-tunnel measurements of Castro and Robins (1977). Comparing our results with experimental data, we show that the TEMPEST model can reasonably simulate the mean flow.

ZHOU, M., N. Lu, J. MILLER, F.P. PARUNGO, C.T. NAGAMOTO, and S. Yang. Characterization of atmospheric aerosols and of suspended particles in seawater in the western Pacific Ocean. *Journal of Geophysical Research 97(D7)*:7553-7567.

Aerosol samples were collected to study the variabilities of marine aerosols at different times and in different ocean areas. The samples were collected during the first three cruises (December 12, 1985 to February 21, 1986; November 11, 1986 to March 1, 1987; September 27 to November 4, 1987) operated by the cooperative program between the United States and the Peoples Republic of China. The concentrations of crustal and pollution elements in aerosols were high over the ocean area close to the China coast and decreased very rapidly with increasing distance from land. For the third cruise, in the ocean area northeast of the Philippines, the concentrations of crustal and pollution elements in aerosols were high, especially Fe, whose values reached 3.15×10^{-5} g m^{-3}. For all three cruises, the mass size distributions of crustal elements and pollution elements in aerosols showed more large particles. The morphology and elemental composition of aerosol particles showed that sea-salt particles may conglomerate with small crustal and pollution particles from land to form large particles. The size distributions of suspended particles ($d > 0.3\ \mu m$) in surface seawater approximately fitted the Junge size distribution. The concentration of suspended particles in surface seawater decreased with increasing distance from land except at the equator, where particle concentrations were high. In addition, results from rain chemistry show that the relative importance between wet deposition and dry deposition varies with trace elements.

4.2 Other Formal Reports

BOATMAN, J.F., C.C. Van Valin, S.W. WILKISON. The relationship between ozone concentrations and air transport over western Arizona. NOAA TM ERL ARL-197, 30 pp.

The high concentrations (>100 ppbv) of O_3 measured near the surface in Yuma, Arizona, are primarily the result of the transport of O_3 and its precursors from the heavily populated southern California coastal region extending from Oxnard to San Diego. The highest O_3 concentrations are measured when the wind speeds are low, resulting in transport times of 36 to 48 hours for the distance from the coastal regions to the vicinity of Yuma. High daytime O_3 concentrations are associated with low nighttime concentrations (<10 ppbv) caused by the destruction of O_3 by NO, most of which is added to the atmosphere from vehicular traffic near the O_3 monitoring station. The continuous record shows a sharp decline in O_3 concentrations that coincides with the morning rush hour and vehicular activity in an adjacent parking lot. The least diurnal variability in O_3 concentrations, i.e., the lowest incidence of atmospheric pollutants, usually occurred during conditions of

brisk wind, when the transport time to the Yuma area from the southern California coastline was 12 hours or less. However, the same condition of relatively little diurnal variability of O_3 was observed when transport was rapid from the Baja California or inland desert regions. Analysis of the relationship between O_3 concentrations measured in the Yuma area and air mass back trajectories showed that the most common wind direction for both polluted and nonpolluted times in Yuma was westerly. During the polluted times, transport was across the heavily populated southern California coastal regions. During nonpolluted times, air mass transport was commonly from Pacific Ocean areas across Baja California. Wind speed, as a regulator of the degree of air mass dilution during transport, was sometimes a determining factor in the occurrence of high O_3 concentrations at Yuma. Analysis of air mass back trajectories indicated that the central and northern parts of the western Arizona border are also subject to the impact of pollution from southern California.

Brydges, T.G., B.B. HICKS, C.A. Franklin, I.K. Morrison, P.W. Summers, K.L. Demerjian, D.L. Radloff, M.L. Wesely, and B.M. Levinson. Integrated Monitoring in the U.S. - Canada Transboundary Region "Monitoring for Integrated Analysis." Final Report to the International Air Quality Advisory Board by the Expert Group on Monitoring, International Joint Commission, Washington, DC, 48.

DRAXLER, R.R. Hybrid single-particle lagrangian integrated trajectories (HY-SPLIT): Version 3.0 - User's guide and model. NOAA TM ERL ARL-195, 79 pp.

The algorithms and equations used in the calculation of long-range pollutant transport and dispersion are presented from the meteorological data sources through the calculation of air concentrations. The model calculation methods are a hybrid between Eulerian and Lagrangian approaches. A single pollutant particle represents the initial source. Advection and diffusion calculations are made in a Lagrangian framework. However, meteorological input data can either be gridded from rawinsonde observations or archived from other sources, such as the analyses fields or forecast outputs from Eulerian primitive equation models. As the dispersion of the initial particle spreads it into regions of different wind direction or speed, the single particle is divided into multiple particles to provide a more accurate representation of the complex flow field. Air concentrations are calculated on a fixed three dimensional grid by integrating all particle masses over the sampling time. The model code can be run on a personal computer. Calculations consist of simple trajectories from a single source to complex multiple source emissions. A flow chart of the calculations as well as several examples are given. The code is structured so that concentration calculations or simple trajectory (forward or backward) calculations can be performed on sigma (terrain following) or pressure coordinates.

ECKMAN, R.M., R.J. DOBOSY, and W.R. PENDERGRASS. Preliminary analysis of wind data from the Oak Ridge survey. NOAA TM ERL ARL-193, 51 pp.

From October 1989 until the end of 1990, the Atmospheric Turbulence and Diffusion Division (ATDD) conducted a meteorological site survey of the area around Oak Ridge, Tennessee. Twenty-eight meteorological towers were used to

obtain one-minute and 15-minute averages of wind speed, wind direction, temperature, relative humidity, and rainfall. A preliminary analysis of the wind data from this survey is presented in this report. The analysis indicates that approximately eight meteorological towers can provide adequate coverage of the regional-scale surface winds around Oak Ridge when the wind speed exceeds 2ms^{-1}. For wind speeds of 0.5 to 2ms^{-1}, roughly 16 towers can adequately resolve the along-valley component of the surface wind, but the cross-valley component requires an impractical number of towers to be resolved in these light winds. The towers should be located either on local ridge tops or in local valley bottoms. Ridge-top sites should be roughly 16-18km apart, whereas valley-bottom sites should be about 6-8km apart. The U.S. Department of Energy (DOE) already has three meteorological measurement sites in the Oak Ridge area. To provide better coverage of the regional wind field, ATDD has produced a list of ten recommended sites for supplemental towers. Five of the recommended sites are on ridge tops, and four are in valley bottoms. The tenth site is in the Cumberland Mountains to the west of Oak Ridge. The ridge-top sites have an average separation of about 20km, and the valley-bottom sites have an average separation of 8km.

Engelmann, R.J., W.R. PENDERGRASS, J.R. White, and M.E. Hall. Sheltering effectiveness against plutonium provided by stationary automobiles. Final Report, prepared for the U.S Air Force and the National Aeronautics and Space Administration. (NASA), under DOE Interagency Agreement 1926-0914-A1 of 9/29/89 and AF Project Order ESMC 9-0074.

The protection offered occupants of stationary automobiles against airborne gases and respirable particles, such as might results from an accidental release, was measured and found to be substantial. Four of the five autos tested were equipped with air conditioning systems; when those were tested with the air conditioning (AC) system on and in recirculate position, the equilibrium ratios of inside to outside concentrations (I/O) for 2 μm particles were less than 0.2, and some ratios were as small as 0.014. With both the AC compressor and the system fan off, the I/O for the five autos ranged from 0.04 to 0.18. The highest I/O value was found to occur for the auto with no AC system. These low I/O ratios are primarily a result of deposition within the autos. However, three of the four autos with AC had substantially higher I/O ratios when the AC fan was on than when off, indicating significant added intake of outside air. Air exchange rates were on the order of 0.5 hr^{-1} with AC off, and 2.5 hr^{-1} with AC on. Whether it is advisable to operate the vehicle's AC or not depends upon the time duration of the plume, whether the contaminant is gaseous or particulate, and the risk that operating the system fan may induce substantial intake of outside air. An insufficient number of autos have been tested to adequately evaluate the latter aspect. This report presents the basic equations that determine the interior concentration of contaminants when a vehicle is enveloped by a constant concentration. Parameters determined in the experiments can be used directly or adjusted as appropriate, and used in the equations to predict the interior concentrations versus time, and the I/O ratios, with and without AC systems operating.

GUNTER, R.L., and J.F. BOATMAN. Acid-modes II (1990): Summary data report NOAA king air aircraft measurements of selected pollution species. NOAA TM ERL ARL-196, 52 pp.

During April and May 1990 in support of the second intensive of the Acid Model Operational Diagnostic Evaluation Study (Acid-MODES), cloud water samples were taken and chemical, meteorological, and aerosol measurements were made using the NOAA King Air C-90. Battelle Northwest Laboratory's G-1 was also involved. This report lists the objectives of Acid-MODES II; the instrumentation used and the data obtained with the NOAA King Air; and the data processing, quality and availability of the data from the King Air.

HICKS, B.B. Book Review. Air Pollution Modeling and Its Application VIII, Proceedings of the 18th NATO/CCMS International Technical Meeting on Air Pollution Modeling and Its Applications, published by Plenum Press as Volume 15 of the NATO Series: Challenges of Modern Society, US. *Boundary-Layer Meteorology 60*:201-203.

IRWIN, J.S. (Ed.). Interagency Workgroup on Air Quality Modeling (IWAQM) work plan rationale. EPA-454/R-92-001, Office of Air Quality Planning and Standards, Research Triangle Park, NC, 23.

This document presents a status report and workplan rationale for the operation of the Interagency Workgroup on Air Quality Modeling (IWAQM). The workgroup was formed to provide a focus for development of technically sound regional air quality models for regulatory assessments of pollutant source impacts on Federal Class I Areas. This report was published in an effort to inform the sponsoring agencies and other interested parties about IWAQM activities.

MATT, D.R. Flux measurements during ASCOT 1990. NOAA TM ERL ARL-192, 51 pp.

During the 1990 ASCOT Experiment, eddy correlation flux systems were operated at two sites, one in a forest on the Walker Branch Watershed (WBW) at 30.5 m AGL and one in a pasture at the Damewood Farm (DWF) at 5 m AGL. Half hour averaged fluxes of sensible heat (H), latent heat (LE), and momentum perpendicular to the streamline flow were reported. The systems began operating on March 5 and continued until March 15, with the exception of precipitation events. The micrometeorologically measured fluxes were compared for a four day period from March 11 to March 15. The available incident energy was found to be partitioned differently at the two sites.

PIERCE, T.E. User's guide to the personal computer version of the biogenic emissions inventory system (PC-BEIS). EPA/600/8-90/084 (PB91-136549), Atmospheric Research and Exposure Assessment Laboratory, Research Triangle Park, NC, 43 pp.

The personal computer version of the biogenic emissions inventory system (PC-BEIS) has been developed to allow users to estimate hourly emissions of biogenic non-methane hydrocarbon emissions for any county in the United States. PC-BEIS has been compiled using Microsoft FORTRAN and tested on IBM- compatible personal computers. The source code was written in ANSI FORTRAN 77 and

should be transportable to most other computers. Emission rates depend on land use, leaf biomass, and emission factors. PC-BEIS also includes adjustments due to temperature and sunlight. A simple leaf energy balance module is included to allow more refined calculations of leaf temperature and sunlight through forest canopies. This user's guide briefly describes the technical background, provides an overview of computer aspects, and shows an example test case.

POOLE-KOBER, E.M., and H.J. VIEBROCK (Eds). Fiscal Year 1991 summary report of NOAA Atmospheric Sciences Modeling Division support to the U.S. Environmental Protection Agency. NOAA TM ERL ARL-194, 77 pp.

The Atmospheric Sciences Modeling Division provided meteorological research and operational support to the U.S. Environmental Protection Agency during FY-1991. Meteorological support consisted of the application of dispersion models, and the conduct of dispersion studies and model evaluations. The primary research effort was the development and evaluation of air quality simulation models using numerical and physical techniques supported by field studies. This included development of the Regional Acid Deposition Model - Version 2.6, the Tagged Species Engineering Model, and the Asymmetrical Convective Model; examination of the effect of oxidant limitations on emission changes; publication of the Regional Oxidant Model user's guides; study of the effect of biogenic emissions on ozone concentrations; incorporation of a new method describing aerosol dynamics into the Regional Particulate Model; participation in a field study of sustained stagnation conditions; conduct of a wind tunnel study of the dispersion of dense gas jets; and a study of flow and dispersion through an urban industrial complex.

Porch, W.M., W.E. Clements, and J.A. HERWEHE. Analysis of tethered balloon-borne measurement in Mexico City, September 1990 and February 1991. Los Alamos National Laboratory Technical Report LA-UR-92-1295, Los Alamos National Laboratory, Los Alamos, NM, 31 pp.

Tethered balloon-borne meteorological and pollution (ozone) instrumentation were used to determine vertical profiles of characteristics important to understanding pollution evolution in the Mexico City air basin. The principal feature derived from the temperature (and humidity at times) profiles is the mixing height. The mixing height is strongly related to pollution concentrations in Mexico City. The wind profiles showed nocturnal jets associated with nighttime ground based inversions which may be due to topographic induced slope flows from the surrounding mountains.

START, G.E., R.G. CARTER, D.J. HOOVER, J.F. SAGENDORF, R.C. JOHNSON, D.H. GEORGE, K.L. CLAWSON, J.L. BRUNN, and N.HUKARI. Utah Valley 1991-1992 Study. Final Report. State of Utah Department of Environmental Quality, Salt Lake City, UT, 1543pp (two volumes).

Field measurements were made from December 1991 through February 1992 to collect data to better understand CO behavior in the Utah Valley during wintertime inversion conditions. Three intensive 48 hour test windows were selected in which to release two different inert gaseous chemical tracers (SF6 and 1211) coincident

with identified industrial sources. Stack-released CO was measured at one source. CO was estimated at the second source. An array of 39 samplers collected 1-hour samples for 24 or 48 hours during each intensive. Ten 10 m instrumented towers, a radar wind profiler with RASS temperature capability and tethersonde temperatures supplemented data from NWS upper air and surface weather network observations and the Utah Department of Air Quality temperature and CO network. Analyses of transport and diffusion calculations using a simple puff-trajectory model indicated that the model could not account for the locations of sampled tracer maxima. Meteorological analyses indicate that mountain slope flows and lake-land breezes are major factors in the transport, diffusion and dissipation of tracer and CO accumulations in the Utah Valley. Simple models which cannot diagnose local circulations are unlikely to adequately describe Utah Valley pollution episodes.

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