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NOAA Technical Memorandum ERL ARL-162

FISCAL YEAR 1986 SUMMARY REPORT OF NOAA METEOROLOGY DIVISION SUPPORT TO THE ENVIRONMENTAL PROTECTION AGENCY

Herbert J. Viebrock
Evelyn M. Poole-Kober
(Editors)

Air Resources Laboratory
Silver Spring, Maryland
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UNITED STATES DEPARTMENT OF COMMERCE

C.William Verity
Secretary

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Environmental Research Laboratories

Vernon E. Derr,
Director

NOTICE

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PREFACE

This document presents for Fiscal Year 1986 a summary of the research and operational efforts and accomplishments of the Meteorology Division (MD) working under interagency agreement EPA DW13932000-01-0 between the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA). The summary includes descriptions of research and operational efforts in air pollution meteorology, air pollution control activities, and abatement and compliance programs.

Established in 1955, the Meteorology Division is part of the Air Resources Laboratory and serves as the vehicle for implementing the agreement with the EPA, which funds the research efforts in air pollution meteorology. The MD conducts research activities inhouse and through contract and cooperative agreements for the Atmospheric Sciences Research Laboratory (ASRL) and other EPA groups. With a staff consisting of NOAA, EPA, and Public Health Service Commissioned Corps (PHS) personnel, the MD provides technical information, observational and forecasting support and consultation on all meteorological aspects of the air pollution control program to many EPA offices, including the Office of Air Quality Planning and Standards (OAQPS) and Regional Offices. The primary groups within the MD are Atmospheric Modeling Branch, Fluid Modeling Branch, Data Management Branch, Terrain Effects Branch, Environmental Operations Branch, and Air Policy Support Branch. The staff is listed in Appendix D. Publications and other professional activities are listed in Appendixes A, B-1, and B-2.

Any inquiry on the research or support activities outlined in this report should be sent to the Director, Meteorology Division (MD-80), Environmental Research Center, Research Triangle Park, NC, 27711.

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ABSTRACT

The Meteorology Division provided meteorological research and operational support to the U.S. Environmental Protection Agency. Basic meteorological operational 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. Modeling emphasis was on the dispersion of photochemical oxidants and particulate matter on urban and regional scales, dispersion in complex terrain, and the transport, transformation, and deposition of acidic materials.

Highlights during FY-1986 included preliminary evaluation of a regional acid deposition model; conduct of a mesoscale acid deposition field study near Philadelphia, PA; completion of the RELMAP user's guide; conduct of terrain studies in the Fluid Modeling Facility; development of a new model for the autocorrelation function of wind components; completion of preparations for the Integrated Air Cancer Program field study; and release of UNAMAP Version 6.

FISCAL YEAR 1986 SUMMARY REPORT OF NOAA METEOROLOGY DIVISION SUPPORT TO THE ENVIRONMENTAL PROTECTION AGENCY

1. INTRODUCTION

During Fiscal Year 1986, the Meteorology Division (MD) continued to provide meteorological research and support to the U.S. Environmental Protection Agency (EPA). The primary effort of the Division was to conduct research in the basic processes affecting the dispersion of atmospheric pollutants and to model the dispersion on all temporal and spatial scales. The major modeling emphasis was on oxidant dispersion on the urban and regional scales, particulate dispersion on the regional scale, dispersion in complex terrain, and acid precipitation related processes. Work on the study and modeling of boundary layer processes continued. Physical modeling experiments were conducted in the Fluid Modeling Facility on the flow in complex terrain, building downwash, and the effects of building wakes. Participation continued in the Integrated Air Cancer Program, and on the use of dispersion models on the North Slope of Alaska. The research effort is described in Sections 2.1, 2.2, 2.3, 2.4, and 2.5. Section 2.1 also discusses the Division's participation in several major international activities.

Meteorological support was provided to various EPA offices, including the Office of Air Quality Planning and Standards (OAQPS) and the Regional offices. This work is discussed in Sections 2.6 and 2.7.

2. PROGRAM REVIEW

2.1 Office of the Director

2.1.1 American Meteorological Society Steering Committee

Since 1979 the Meteorology Division and the American Meteorological Society (AMS) have collaborated in an effort to improve the scientific bases of air quality modeling. Under a cooperative agreement administered by an AMS Steering Committee, this joint effort has resulted in topical workshops and model evaluation exercises.

2.1.1.1 Workshop on Dispersion in Complex Terrain

During May 1983, the AMS Steering Committee conducted a workshop in Keystone, Colorado on dispersion in complex terrain. The purpose of the workshop was to encourage atmospheric scientists working in the area of complex terrain dispersion modeling to exchange information on atmospheric processes in mountainous terrain and to make recommendations regarding both the present application of air quality models to complex terrain settings and the research necessary to meet future needs.

A summary of the state-of-the science review concerning phenomena of importance and physical/mathematical modeling capabilities for dispersion in complex terrain is being published in early 1987. The paper includes recommendations on the use of present science and suggestions for future research and development needs.

2.1.1.2 Workshop on Updating Applied Diffusion Models

Because of the gap between the current knowledge of planetary boundary layer processes and the generally inadequate state of regulatory dispersion modeling, the Meteorology Division requested the AMS Steering Committee to conduct a Workshop on Updating Applied Diffusion Models. It was held in Clearwater, Florida during January 1984. The focus was on diffusion from a point source at arbitrary height in the boundary layer and over distances less than twenty kilometers. Interest was generally on one-hour average concentrations. The purposes of the workshop were to review current understanding of the planetary boundary layer and its use in diffusion models, and to recommend improved models, i.e., models with better physics and hopefully better performance. The intent was to have the Chairman summarize the workshop in one comprehensive journal article (Weil, 1985). Six journal papers were published in addition to the Chairman's summary (Wyngaard, 1985; Deardorff, 1985; Sawford, 1985; Briggs, 1985; Hunt, 1985; van Ulden and Holtslag, 1985).

2.1.1.3 International Workshop on Model Uncertainty

Under a separate cooperative agreement, the American Meteorological Society conducted a workshop in September 1984 that was funded jointly by the United States, and the Canadian provincial and federal governments. The subject of the workshop was Sources and Evaluation of Uncertainty in Long-Range Transport Models. This effort was an outgrowth of the modeling activities performed in previous years under the United States/Canadian Memorandum of Intent on Transboundary Air Pollution (Schiermeier and Misra, 1983). Workshop participants from the United States, Canada, England, Denmark and Norway joined in the attempt to identify and quantify uncertainty in long-range transport model predictions. An AMS publication is in preparation containing the complete documentation of the workshop including recent developments in model evaluation and sensitivity analysis, and reports of the Eulerian and Lagrangian working groups. An article summarizing the workshop findings and recommendations was published (Demerjian, 1985).

2.1.2 NATO/CCMS Steering Committee

The Meteorology Division Director serves as the United States representative on the Steering Committee for the NATO/CCMS International Technical Meetings (ITM) on Air Pollution Modeling and Its Application. The organization of a biennual symposium dealing with air pollution modeling and its application is one of the main activities within the NATO/CCMS pilot study on Air Pollution Control Strategies and Impact Modeling. The meetings are rotated among different NATO member countries with every third ITM held in North America and the two intervening ITMs held in European countries. The Division Director served as International Conference Chairman for the 15th NATO/CCMS International Technical Meeting which was held in St. Louis, Missouri during April 1985. The proceedings of the ITM are now being published (De Wispelaere et al., 1986). The Steering Committee has completed selection of papers to be presented at the 16th International Technical Meeting to be held during April 1987 in Lindau, Federal Republic of Germany.

2.1.3 United States/Japan Environmental Agreement

The Meteorology Division Director serves as Chairman of the Air Pollution Meteorology Panel under the United States/Japan Environmental Agreement. The purpose of this 1975 agreement is to facilitate the exchange between the two countries of scientific and regulatory research results pertaining to control of air pollution through mutual visits and reciprocal assignments of personnel.

In February and March 1986, the panel Chairman visited the Japan Environment Agency and the Japan Meteorological Agency in Tokyo and four research institutes in Tsukuba Science City. During the meeting of the Air Pollution Meteorology Panel, two presentations were made covering Division research activities in the areas of acid deposition and complex terrain dispersion modeling (Schiermeier, 1986a and b), and plans were made for a visit to the United States in 1987 by Japanese panel members.

2.1.4 United States/Soviet Union Joint Environmental Committee

The Meteorology Division Director was appointed the United States Project Leader for Air Pollution Modeling and Standard Setting, which is part of the US/USSR Working Group 02.01-10 on Air Pollution Modeling, Instrumentation, and Measurement Methodology. In this capacity, he is responsible for coordinating reciprocal visits between the two countries for the purpose of working together on selected modeling activities.

During May 1986, the Project Leader and another Division scientist attended the WMO Leningrad Conference on Air Pollution Modeling and Its Application at which a co-authored paper was presented (Perry and Schiermeier, 1986). The following week was spent at the Voeikov Main Geophysical Observatory in Leningrad discussing mutual progress with Soviet scientists in the research areas of acid deposition and complex terrain dispersion modeling. A presentation was made to the Soviet delegation on development of regional acid deposition models in the United States (Schiermeier, 1986c), and a protocol was drafted outlining future exchanges of visits and scientific information.

2.1.5 National Acid Precipitation Assessment Program

The national effort designed to produce answers to the acidic deposition problem is centered in the interagency National Acid Precipitation Assessment Program (NAPAP). The Meteorology Division performed research under the NAPAP Atmospheric Processes Task Group C until the NAPAP reorganization in February 1986, and thereafter under the Atmospheric Transport Task Group 3. Until the February reorganization, the Meteorology Division Director served as Chairman of the NAPAP Atmospheric Processes Task Group C. During this period, the Chairman was responsible for monitoring the ongoing FY-1986 research activities performed by NOAA, EPA, Department of Energy (DOE), and Tennessee Valley Authority (TVA) and for coordinating this research with the remaining nine NAPAP Task Groups. The Task Group C Chairman also served on the NAPAP Committee for Dry Deposition Research, the NAPAP Design Committee for Model Evaluation Field Study, and the EPA Acid Deposition Atmospheric Sciences Guidance Group.

2.2 Atmospheric Modeling Branch

The Atmospheric Modeling Branch develops, evaluates and validates analytical, statistical, and numerical models used to describe the relationships between air pollutant source emissions and resultant air quality, to estimate the distribution of air quality, and to describe and predict the state of the planetary boundary layer. Model scales range from local to global. Studies are conducted to describe the physical processes affecting the transport, diffusion, transformation, and removal of pollutants in and from the atmosphere.

2.2.1 Acid Deposition Studies

2.2.1.1 Development of a Regional Eulerian Acid Deposition Model

A comprehensive Regional Acid Deposition Model (RADM) is being developed as an integral component of the National Acid Precipitation Assessment Program (NAPAP). The project was initiated in 1983 through agreement with the National Center for Atmospheric Research (NCAR). The principal objective is to develop an Eulerian model suitable for describing nonlinear source-receptor relations and assessing effects of changes of emissions of sulfur and other primary pollutants on regional patterns of acidic deposition. The modeling system incorporates a mesoscale dynamic meteorological model (MM4) to drive a 6-level Eulerian transport/transformation/deposition model on 80km grids covering the entire United States and Southern Canada. The rationale and approach to the modeling effort are contained in two companion NCAR reports (National Center for Atmospheric Research, 1983a and b). Version I of the RADM (National Center for Atmospheric Research, 1985), containing first generation submodels of gas- and aqueous-phase chemistry and simple parameterizations of subgrid-scale cloud processes and dry deposition was completed in 1985.

During FY-1986, the Version I RADM was subjected to preliminary evaluation studies which consisted of: 1) sensitivity tests of the full RADM, 2) comparisons of model results against Oxidation and Scavenging Characteristics of April Rains (OSCAR) experimental chemistry data, and 3) evaluation of RADM submodels. In the latter classification, the RADM gas-phase chemistry was evaluated against smog chamber data and the cloud and aqueous-phase chemistry submodel was checked against some field data. The results of these studies (National Center for Atmospheric Research, 1986), while not conclusive because of inadequate existing evaluation data bases, suggest that RADM is a state-of-the-art assessment modeling system.

A sulfur engineering model simplification of RADM was developed. The model is a scaled-down version of RADM employing RADM transport and deposition processes with highly parameterized chemical transformations and cloud processes in a three-level Eulerian framework model, and is executable on a VAX-class computer.

A complex parameterization of Dicarbonyl species was added to the RADM chemical mechanism and is greatly improving the modeling of smog-chamber data. Evaluation of the mechanism is continuing. A detailed analysis of subgrid variability of dry deposition due to land use variations within RADM grid areas was performed. Fluxes of acidic materials to different land surfaces within a grid can be significantly different from the grid average value. A subgrid-scale deposition model will need to be employed in the evaluation and some application of RADM.

The RADM code has been streamlined in terms of both computer efficiency and ease of implementation. Full (covering all of the U.S. and southern Canada) and half domain versions of RADM are operational on the CRAY-XMP computer. The RADM code was executed on CRAY computers in Pennsylvania and Germany.

All of the mesoscale meteorological model runs to be used in the RADM aggregation and meteorological model evaluation were completed and are being evaluated. RADM was executed for three OSCAR cases, a summer 1979 Northeast Regional Oxidant Study (NEROS) case and six of the seven Cross Appalachian Tracer Experiments (CAPTEX). NCAR conducted sensitivity runs and special analyses of OSCAR results to assist in the design of a field program for the evaluation of the RADM. Model outputs and processing routines were provided to clients for additional analysis.

The individual CAPTEX surface tracer plumes were compared to MM4 trajectories and RADM runs using an inert tracer. These results suggest the need for more precise definition of the transport and precipitation fields for the evaluation of episodic realizations of RADM.

2.2.1.2 Development of a Non-Precipitating Cumulus Cloud Transport Module for the RADM

A CUmulus VENTing (CUVENT) module that determines the vertical pollutant mass flux for acidic species by non-precipitating cumulus cloud activity was developed for use in the Regional Acid Deposition Model (RADM). The model formulation is based on an entrainment model by Ritter and Stedman (1985) modified to permit subgrid-scale closure for the cloud parameter fields. A preliminary version of CUVENT (Vukovich and Ching, 1985) was completed and delivered for direct incorporation into the RADM Version 1. A second generation CUVENT, which incorporates improvements in the basic parameterization of cloud entrainment, distinguishes between clouds limited to the mixed layer vs. those that extend well beyond the mixed layer, and provides profiles of cloud liquid water, will be completed in early FY-1987.

2.2.1.3 Experimental Study of Non-Precipitating Cumulus Clouds

Cumulus clouds VENTing EXperiment (VENTEX) field studies were conducted in FY-1983 and FY-1984 to investigate the vertical transport of pollutants by non-precipitating cumulus clouds and the formation of sulfate and nitrate aerosols in these clouds.

The vertical exchange of pollutant between the mixed layer and the cloud layer by cumulus clouds was studied utilizing tracer data from VENTEX-83. An aircraft released SF_6 tracer gas either within or above the mixed layer and another aircraft sampled for the tracer at various levels within or above the mixed layer in the active cumulus convective cloud zone. Sampling was also conducted on the ground. The results provide strong inference that mixed layer pollutants are vented above the entrainment zone of the mixed layer into the overlying cloud layer by fields of active cumulus convective elements and further, that such active cloud fields may force cloud layer air downward into the mixed layer (Ching and Alkezweeny, 1985). The formation of sulfate and nitrate aerosols was studied based on data from VENTEX-84 (Alkezweeny, 1986).

Analyses of data collected by DC-3 and Cessna 411 aircraft and by ground sampling show ratios of sulfate concentration to the total sulfur concentration (the sum of sulfate and sulfur dioxide) to be larger at the top of the cloud fields than at their bases. In-cloud oxidation rates were in excess of 100%/hr. The ratio of the total nitrate concentration (the sum of nitric acid and nitrate aerosols) to the total sulfur concentration at cloud tops was higher than at cloud bases on many days. This result suggests that nitrate can form in the clouds but not as rapidly as sulfate. Ground concentrations of ammonia declined around midday followed by an increase in the afternoon. Sulfur dioxide concentrations exhibit an opposite trend. A case study of morning and afternoon soundings of ozone indicated vertical transport of pollutants from the mixed layer to the cloud layer.

2.2.1.4 Development of an Acid Deposition Dry Deposition Module

The development of a dry deposition parameterization methodology and computerized module for use in the Regional Acid Deposition Model (RADM) was accomplished through an interagency agreement with Argonne National Laboratories through the U.S. Department of Energy. This module computes surface dry deposition velocities for sulfur dioxide, sulfate, ozone, NO plus $N0_2$, and nitric acid vapor for much of the North American continent. Input data requirements for this module include geographic location, season, height of application, solar irradiation, wind speed, atmospheric stability, and boundary layer heights. A project report provides documentation of this effort and of the Module (Sheih, et al., 1986).

2.2.1.5 Regional Acid Deposition Model Evaluation

A major program to evaluate the Regional Acid Deposition Model (RADM) is being developed. This program will consist of field measurements during 1988 and 1989 (Durham et al., 1986) and comprehensive analysis of observed and model predicted concentration and deposition fields continuing through 1990.

During FY-1986, three workshops were held to focus the field study design and respond to recommendations of the September 1985 National Acid Precipitation Assessment Program (NAPAP) (Pennell, 1986; Barchet, 1986: Olson, 1986). These workshops were sponsored jointly by the Environmental Protection Agency (EPA), the Canadian Government, and the Electric Power Research Institute (EPRI). The basic design of the field study, developed from the workshops, consists of a 72-station primary surface network measuring selected ambient and precipitation chemical species over the northeastern United States and southeastern Canada; a subgrid-scale variability network; special chemistry sites; and aircraft monitoring during intensive measurement periods. Importantly, the field study design was driven by extensive analysis of existing data bases and ongoing consideration of the developing structure of the evaluation program. The primary surface network design was approved and a request for a proposal was prepared for the EPA portion of this program.

Model evaluation protocol studies indicated that point-by-point comparisons produce limited information and lose important spatial detail for regional model evaluation. Hence, techniques which can compare patterns must be used. Several statistical techniques for comparison of regional patterns were investigated for use in the model evaluation. Kriging continues to be by far the best technique for estimating the uncertainty about the mean regional magnitude of deposition. Spatial correlation was superior to the other techniques tested for quantification of spatial shifts between patterns.

2.2.1.6 Mesoscale Studies for Acid Deposition

The purposes of the mesoscale acid deposition program are to determine the effect of emissions from a large urban-industrial area on the wet acidic deposition downwind from the source; to determine the importance of local primary sulfate emissions; and to examine the chemical, transport, and deposition processes on a finer scale than is done in the regional acid deposition modeling program. A major field study was conducted in the Philadelphia area, including southern New Jersey and southeastern Pennsylvania. The major result of the study was that the urban-industrial emissions had an important effect on the deposition of nitrate downwind of the city. A significant, but smaller effect, was observed for sulfate. These results led to the hypothesis that mobile sources are a major contributor to the observed nitrate deposition.

During FY-1986 plans were made for a similar-field study to sample a series of autumn frontal storms in the Washington, DC area. The sampling design includes one set of sequential collectors for complete ionic balance analysis as well as a separate set for determining hydrogen peroxide concentration. Aircraft measurements of gaseous and aqueous species will complement the surface base network. The design calls for the network to be established in a standby mode from October through early December 1986, and from late February through early May 1987. When a weather forecast indicates that conditions are favorable for a rainfall event in the Washington, DC area, the network and aircraft operations will be activated.

MesoSTEM, the mesoscale acid deposition model, is being used to simulate three cases observed in the Philadelphia study mentioned above. These are the May 1985 case which contains sequential precipitation chemistry plus rainfall concentrations of hydrogen peroxide; an April 1984 case which is representative of several cases showing very strong nitrate and moderate sulfate increases; and the December 1983 case which shows neither nitrate nor sulfate increases, but shows a very large increase in dissolved sulfur dioxide in the rainwater.

2.2.1.7 International Sulfur Deposition Model Evaluation

Jointly conducted by the United States and Canada, the International Sulfur Deposition Model Evaluation (ISDME) assessed the seasonal and overall performance of eleven long-term statistical and deterministic deposition models for the year of 1980. In conjunction with this program, innovative evaluation procedures were explored and developed.

The evaluation focused on the ability of the models to replicate both spatial and temporal patterns of the observations of sulfur wet deposition over the northeastern quadrant of the United States and southeastern Canada. Evaluation criteria were established for the area of significant differences, location and magnitude of the maximum, location of the centroid, orientation of the major axis, and the seasonal distribution about the annual sulfur wet deposition.

Spatial patterns were generated via a technique known as simple Kriging (Finkelstein, 1983) which provided uncertainty limits of the observations. This involves interpolated observations from a set of measurements (screened for data completeness and regional representativeness) and the predictions at as many as 65 sites across eastern North America and quantified both interpolation and measurement errors.

Results indicated that the predicted patterns resembled concentric ellipses, showed less detail than the patterns of the observations (e.g., secondary maxima generally were not apparent), and tended not to mimic the observed seasonal shifting of the location of the maximum. Unlike the observed patterns, the predicted patterns tended to coincide with the spatial patterns of the sulfur dioxide emissions. All but three models predicted each seasonal maxima within 50% of the observed value.

An intercomparison of model generated sulfur dry deposition at up to 65 sites indicated that, with few exceptions, the predictions of the models were generally very similar. Seasonal deposition averaged from 1 to 6 kg S/ha.

Despite considerable differences in the approaches of the statistical and deterministic models, there were few consistent differences in the performance of each model type. Several statistical models performed as well as, or better than most deterministic models. However, the spatial patterns of the statistical models tended to be oriented along axes that, 1) differed most from that of the observed pattern and 2) showed the least seasonal fluctuation.

2.2.2 Photochemical Modeling

2.2.2.1 Regional Oxidant Model (ROM)

The development of the Regional Oxidant Model (ROM) began in the late 1970's as a part of the Northeast Corridor Regional Modeling Project (NECRMP). The NECRMP was initiated because ozone and its precursor species generated by the major urban areas of the Northeast affect air quality over such large areas that it is impossible for states to develop viable emissions control plans without taking into account the influx of ozone and precursor species from outside sources. ROM was to provide a scientifically credible basis for simulating the regional transport and collective fate of emissions from all sources in the Northeast, and to serve thereby as a basis for developing regional emissions control policies for attaining the primary ozone standard in the most cost effective way.

The first-generation version of the model, ROMl, became operational in 1985 and was used in a number of preliminary studies, some of which are described below. The second-generation model, ROM2, is currently undergoing tests and is expected to be operational in early 1987. The new version of the model provides for more sophisticated treatment of meteorological processes and contains the recently developed Carbon Bond-IV chemical mechanism, which includes explicit treatment of biogenic hydrocarbons.

Although full scale ROM applications and model evaluation studies will not begin until FY-1987 when ROM2 is operational, two separate preliminary studies were conducted in 1986 using ROM1. These studies were a projection of 1987 ozone levels in the northeastern United States (Lamb, 1986) and an investigation of the effects of model grid size on the accuracy of ozone simulations.

The first of these applications consisted of two simulations, one using the 1980 NAPAP 4.2 emissions data (base case) and the other using projected 1987 emissions based on the 1980 base inventory and emissions controls specified in 1982 State Implementation Plans (SIPs) (control case). Both simulations used meteorological conditions from the 9-day period 23-31 July 1980. The results of the two nine-day model runs showed that the emissions changes lowered ozone levels everywhere in space and time; however the percentage reductions in peak hourly ozone concentrations were larger near the major sources of hydrocarbons and nitrogen oxides, about 25% reductions, than in remote regions, where peak ozone levels dropped by less than 10%.

The effects of grid size were investigated by comparing ozone concentrations predicted by the model using an 18 × 18 km grid mesh with corresponding values obtained from simulations using meshes of 2, 3, 4 and 6 times 18 km. The results showed that the predictability of peak ozone is strongly affected by the grid size. For example, the maximum ozone concentration generated by the 36 × 36 km mesh model after 40 simulated hours was about 30% lower than that produced by the 18 × 18 km grid. Moreover, it was found that the sensitivity of the model to emissions changes is a function of the grid size. In general, the coarser the grid, the more the model underestimates the effects of emissions changes on ozone.

2.2.2.2 Regional Oxidant Model Chemical Kinetic Mechanism Development

A compressed version of the explicit Carbon Bond X (CBM-X) chemical kinetic mechanism for photochemical oxidant modeling was received from Systems Applications Inc. (SAI) in September 1986. The compressed mechanism, Carbon Bond IV (CBM-IV), contains 70 reactions and 28 chemical species, including eight reactive hydrocarbon classes, one of which is an explicit treatment of isoprene, a biogenic organic compound. An in-house review of the photolytic rate constant methodology was conducted to assure currently accepted literature values were being used in the calculation of these time-varying quantities. Also, the Regional Oxidant Model, into which CBM-IV was integrated, was adjusted so that the photolytic rate constants are calculated dynamically during model simulation to reflect their vertically integrated value through the depth of each individual grid cell. Including the vertical variation of the rate constants is important because the reactivity of the chemical kinetics is sensitive to them and there can be as much as a 25% variation in the values from the bottom to the top of the boundary layer in clear sky conditions.

2.2.2.3 Evaluation of the Regional Oxidant Model

The first generation Regional Oxidant Model (ROMl) was tested and evaluated for ozone predictions on a two-day test case episode in the northeast United States (Schere, 1986). The period, August 3-4, 1979, was characterized by relatively high ozone concentrations in the southern Great Lakes area where clear skies persisted. Intermittent periods of relatively high ozone levels existed near some of the eastern seaboard cities. The highest observed hour-average ozone level monitored at a surface site during the period was 159 ppb.

Evaluation results for this test episode showed that the ROMl had approximately a 6% average underprediction of ozone when all hours and surface monitoring sites were considered. When the data were restricted to only those where observed and predicted pairs of ozone were greater than 50 ppb the average performance improved to a 1% underprediction. The evaluation aspect concerned with estimating maximum daily ozone values showed an 8% average underprediction of the maximum value for the restricted data subset. An analysis of individual ozone plumes during the episode showed average model performance for predicting the plume maximum concentration level to be between 22% underprediction and 38% overprediction.

The second generation model (ROM2) contains a number of improvements over the first generation version of the model, including the realistic treatment of terrain features, dynamic response of the cell depths to the simulated physical processes, an improved chemical kinetic mechanism that incorporates reactions of biogenic hydrocarbons, and a more thorough representation of vertical fluxes by convective clouds. A program plan was developed to evaluate the ROM2 on the ambient air quality data base collected during the Northeast Regional Oxidant Study (NEROS) in the summer of 1980. The model evaluation will focus on the ability of the model to correctly estimate regional spatial patterns of ozone and plumes emanating from major metropolitan source emission areas in the model domain.

The model will be run for the period July 12, 1980 to August 22, 1980. Evaluation statistics will be calculated for episodic air pollution periods that occur during that period. Analyses of the ambient data base will be made to guide the evaluation of the ROM2. Cumulative frequency distributions and box plots of the ozone data at selected sites will help determine the specific episodes and spatial areas to be examined. Analysis of the aircraft flight data taken during NEROS will also help determine the background boundary layer burden of pollutants as well as defining the downwind extent of major urban source plumes. The model's ability to predict the daily maximum and the daily daylight average (0900h-1600h) at surface monitoring sites will be evaluated. The Kriging technique will be used to help compare the spatial patterns of observed and predicted ozone. Finally, the model's limits of predictability will be evaluated by analyzing the differences in model predictions from ROM2 simulations using 5-10 alternately probable wind fields during one of the episode periods.

2.2.2.4 Mass Balance Validation of Urban NO_x and VOC Emission Estimates

A recent study showed that the median value of the ratio of nonmethane hydrocarbons to nitrogen oxides ($NMHC/NO_x$) measured during the early morning hours in the central business district of 22 major American cities is 13.9 (Richter et al., 1985). The range in the ratio among the cities was from 8.3 to 50.0. The corresponding ratio in the best available emissions inventories shows a median value of 3.9, with a typical range of 3.0 to 6.0. There appears to be a systematic problem with the compilation of urban source emission inventories for NMHC and NO_x.

A mass balance approach was proposed to reconcile the urban emissions estimates with the corresponding ambient air concentrations, using existing emissions and air quality data bases to demonstrate the feasibility of applying the approach. However, existing ambient data bases were not assembled with this goal in mind so there are uncertainties and gaps in the required data for this project. Air quality modeling will be a necessary part of the project to account for the sources, sinks, and transformations that occur during the period after the original emissions release and before the ambient measurement. Based on the feasibility study, recommendations will be made on the design and requirements of a data gathering program for a mass flow rate experiment specifically designed with the goal of reconciling urban source emissions.

2.2.2.5 Development of Custom Computing Equipment to Accelerate Regional Scale Model Simulations

The change in focus of model applications that has occurred in the last ten years from two-day, urban scale simulations to 200-day, regional scale modeling has magnified the size of models by a much larger factor than the increase in computer capacity that has occurred during the same period. This disparity between the growth rate of model size and computer power motivated a study to determine the feasibility of building a custom digital hardware device that could be attached to a minicomputer to accelerate the execution of the ROM. The study, which was performed by the Research Triangle Institute (McHugh et al., 1986), showed that a 100-fold increase in speed is feasible using an accelerator based on a loosely-coupled processor architecture. The study showed that the vector architecture, which is the basis of most of the modern high speed mainframe machines, is not well suited to the ROM, because the "stiffness" of the differential equations that form the modeling basis has large spatial and temporal variability, induced mainly by the highly segregated nature of air pollutant sources on the regional scale. Research studies of this type will continue in an effort to make regional scale models more practical to apply and more accessible to the user community.

2.2.3 Boundary Layer Studies

2.2.3.1 Convective Diffusion Field Study

A project report on a convective diffusion field experiment with remote plume sensing was completed (Kaimal et al., 1986). This experiment, called CONDORS (Convective Diffusion Observed by Remote Sensors), was carried out with the participation of the Wave Progogation Laboratory and the Field Research Division of the Air Resources Laboratory. It was designed to provide full-scale, three-dimensional observations of passive diffusion in convective conditions to verify laboratory and numerical modeling results that are at variance with regulatory Gaussian plume models. Releases of metalicized threads called "chaff" were mapped up to 4 km from the source by doppler radar, and releases of oil fog were mapped at about six azimuths up to 3 km distance by lidar. Release heights ranged from the surface to 285 m. During the main experiment, in August-September 1983, an arc of 29 samplers was operated during releases of SF_6 and Freon gases along with the chaff and oil fog. Extensive meteorological measurements were made using sonic anemometers and other high quality instruments on a 300 m tower, and rawinsonde releases. Most of these measurements, in processed form, are included in the report, which also includes a complete description of the experiment, quality assurance measures, and some preliminary data analyses; these analyses tend to support the laboratory and numerical modeling results for convective diffusion.

Further validation of these results was obtained in subsequent analyses of CONDORS project report data. All quantities were nondimensionalized using convective scaling. The growth of observed vertical diffusion coefficients, in this scaling, was well ordered and showed less scatter than usual in analyses of field experiment data; it also closely agreed with the laboratory-scale modeling measurements made in the 1970's. The observed lateral diffusion coefficients showed somewhat larger scatter and tended to maintain faster growth than was seen in the laboratory, except agreement was good at the smaller distances (< 1km). It seems likely that at larger distances the larger directional wind shear at the CONDORS site (near the Rocky Mountains) increased lateral diffusion. The observed near-surface crosswinds integrated plume concentrations agreed well with the laboratory results on the whole, although a few averaging periods deviated up to a factor of 3 from this norm. It is notable that the observed peak values were about 70% larger than predicted by Gaussian models, for elevated releases at about 1/3 the mixing depth.

2.2.3.2 Boundary Layer Experimental Measurement Data Bases

An effort is underway to archive various experimental boundary layer data sets obtained from field programs. Turbulence measurements collected during the Tennessee Plume Study of 1978 were documented and prepared in a single data base. The mean and turbulence quantities, and derived variables of the three dimensional wind components and temperature at 2, 4 and 10 m on a tower in a soybean field and at 25, 40, 60, 100 and 120 m on a tower on a forested ridge were computed. Similar turbulence parameter and flux data were obtained by a research aircraft in the daytime convective boundary layer. Results are stored on magnetic tape and PC-compatible diskettes.

Review and archive procedures of an extensive data base of high resolution vertical profiles of temperature, dewpoint temperature, $S0_2$, and aerosol scattering coefficient obtained from a helicopter are underway. These measurements were made during the RAPS urban boundary layer experiments in St. Louis, Missouri. The uniformly formatted data base will encompass measurements from 150 individual experiments conducted over 5-6 week periods during 4 summer, 3 winter, and 1 fall seasons from 1973-76. These experiments were performed during the postsunset hours and after sunrise to document the time and spatial variations of the evening development and morning erosion of the nocturnal inversion layer over the urban area. A report will document these field studies and measurements and describe the data base to be contained on magnetic tape and PC diskettes. These data bases are useful for applications in boundary layer research and model evaluation analyses.

2.2.3.3 Wide Area Ozone Dry Deposition Study

Ozone vertical fluxes were computed from measurements of ozone fluctuations and turbulence obtained by aircraft sampling runs. Specially designed flight patterns were followed during the 1979 Northeast Regional Oxidant Study (NEROS) field program to investigate ozone deposition over representative land use areas. Low level horizontal runs at about 100 m were made during the morning, mid-day, and afternoon periods above relatively level agricultural cropland and over forested ridges and adjacent valleys in the region around Lancaster, Pennsylvania.

The statistical results will be presented in early FY-1987. Maximum negative ozone flux and largest deposition velocity were reached during the highly convective mid-day period, as mean values were –0.39 ppb m/s and 0.90 m/s, respectively. Variability from the ensemble means for these area measurements was provided by the standard deviations which were near 50% of the means. An insufficient number of runs in the ridge and valley region did not permit similar statistics, however, comparisons of ridge and valley run pairs revealed lower deposition and smaller ozone fluxes in the valley than on the ridge due to the presence of a lake in the valley floor. There was also a strong height dependence of ozone flux as values from runs in the middle of the mixed layer were 50% smaller than those near the surface.

Surface deposition velocity extrapolated from the two aircraft levels was 40% greater than from concurrent point measurements on a 5-m tower in a soybean field. Results are particularly relevant to regional scale model deposition parameterization schemes. The model computes grid area averaged deposition velocity, which is derived primarily from measurements made at a single location over a particular land use type on level terrain. Further analyses will be pursued to study inhomogeneities in multiple land use areas and transition zones between different land use types, and turbulence scales contributing to the ozone fluxes.

2.2.4 Model Development and Evaluation

2.2.4.1 Evaluation and Testing of the MESOPUFF II Model System

The MESOPUFF II model (Scire et al., 1984) is a regional scale episodic Lagrangian puff model. The model and preprocessor programs simulate the transport, dispersion, transformation, and deposition processes over multiple diurnal cycles. The purposes of this in-house research effort are to evaluate the model's performance using tracer measurements from the Cross-Appalachian Tracer Experiment (CAPTEX '83) and to perform a series of sensitivity tests on the dry deposition and chemical transformation modules.

The model evaluation using the CAPTEX '83 data is limited to studying the performance of the transport and dispersion methods because of the conservative nondepositing nature of the tracer. Model runs were performed for the first 3 tracer releases from Dayton, Ohio to simulate multi-day transport and dispersion across the northeast United States. In particular, several model runs were made to examine the variations in plume position and transport time and modeled tracer concentrations by selecting various optional wind fields available in the meteorological preprocessor. Results, at the 300 km arc on the first day, revealed that plume travel and centerline position were best simulated by using a mixed layer average wind field instead of either a single level wind field derived from surface winds only or 850 mb winds only. However, all model results continued to diverge from the observed tracer plume path on subsequent days. Statistical measures and graphical displays of measured and modeled concentration fields were produced to diagnose model behavior.

Sensitivity test runs also were performed to assess the impact of 24-hour concentrations from point source emissions by varying resistances in the dry deposition module and changing technical parameters in the chemical transformation module. A report in FY-1987 will contain the complete results of the model evaluation and sensitivity tests.

2.2.4.2 Lagrangian Modeling of Particulate Matter

The REgional Lagrangian Model of Air Pollution (RELMAP) is a mass conserving, regional scale Lagrangian model that simulates ambient concentrations as well as wet and dry deposition of $S0_2$, $S0_4^=$, and more recently fine (diameters < 2.5 μm) and coarse ($2.5 \leq$ diameter ≤ 10.0 μm) particulate matter over the eastern third of the United States and southeastern Canada. The simulations of fine and coarse particulate matter, which involved simple parameterizations, were incorporated into the model in response to impending federal regulatory standards for inhalable particulate matter and the subsequent need for size discriminate models. These new parameterizations, which include the transformation of SO_2 into $S0_4^=$, and the wet and dry deposition of fine and coarse particulate matter were allowed to vary within ± 50% of their respective nominal values in order to determine the model's sensitivity to them. Graphical analysis of the resulting ambient concentrations of fine and coarse particulate matter revealed that the model was most sensitive to wet deposition. Inducing a 50% variance in the wet deposition resulted in a 30 to 50% variation in the model's output concentration. A 50% variance in the dry deposition resulted in an average of 5 to 10% variation in the output, while a 50% variance in the transformation rate produced a 6 to 12% variation in the output.

Current research is concentrating on refining the parameterizations involving the wet deposition of both fine and coarse particulate matter. Not only has wet deposition proven to be the most influential parameterization employed by RELMAP, it is also the least understood. Although the model proved to be somewhat less sensitive to the other parameterizations, additional research will also be conducted in these areas with the results appearing in a final report during FY-1987.

A RELMAP User's Guide (Eder et al., 1986) was completed. The guide discusses the theoretical and computer aspects of the model and provides the users with application procedures, sample results and a model evaluation.

2.2.4.3 Support of Air Toxics Program

With the release of toxic materials into the atmosphere and the subsequent fate of these materials a major societal concern emerged. There are two major aspects of the problem. The first aspect is the acute effects which are of immediate danger to the public health. These require evacuation or mitigation, a technique for interfering with the effluent either chemically or physically to decrease the danger. The second aspect is the chronic effect of long term exposure to very low levels of toxic materials. These two aspects, acute and chronic, require very different responses from a meteorological research program.

To address the concern for releases which have immediate acute effects, a joint EPA-DOE workshop on methods for estimating atmospheric dilution for emergency preparedness is planned for early FY-1987. The purposes of this workshop are to assess the state of science in dispersion modeling for emergency preparedness, to recommend the types of models which can be used immediately for this purpose, and to define the role of the meteorologist in hazard identification, emergency preparedness planning, and in emergency response.

To address the concern for releases having chronic effects, a small program to estimate the strength of inaccessible sources was carried out for the last two fiscal years. The first phase of the program was designed to model the situation of releasing a tracer from a moving point source downwind of an area source of a toxic material. In the simulation, the receptors have concentrations of the tracer and the material emitted from the area source. Within the modeling framework used, an estimate of the strength of the area source is available from the ratio of the two receptor concentrations. Since the area source strength is known in advance, an estimate of the accuracy of the technique is possible. A second phase of the program was designed to conduct a field study of the technique; however funding was unavailable.

2.2.5 Technical Support

2.2.5.1 WHO Assistance to the National Air Pollution Control Agency of Greece

The Government of Greece, through their National Air Pollution Agency, requested assistance and advice on air pollution modeling of the Greater Athens Area (GAA) through the World Health Organization (WHO). A meteorologist, during a 3-week visit, made a thorough study of the meteorological characteristics and available data bases of the GAA. The ambient monitoring network and source emissions compilations were also studied. Recommendations were made concerning the placement of monitoring sites and the use of particular air quality models. All findings were documented in a final report to the WHO and the Greek government.

The GAA contains over 2 million people within a relatively small spatial area. The complex wind flow and the density of emission sources often lead to stagnation conditions and pollution episodes. The air quality monitoring network and the source emissions inventories of the GAA are in early stages of development and, thus, the use of complex, spatially-resolved air quality models are not yet warranted. However, their future use was encouraged because of the complexity of the problem in Athens. For now such models as RAM, VALLEY, CRSTER, and EKMA/OZIPP are being implemented for performing simulations of the GAA.

2.2.5.2 Southern California Air Quality Study (SCAQS)

The Air Resources Board of the State of California is sponsoring the Southern California Air Quality Study (SCAQS) project to develop a comprehensive and properly archived air quality and meteorological data base for the South Coast Air Basin of California, including the Los Angeles metropolitan area. The data base will be used to test, evaluate, and improve elements of air quality simulation models for oxidants, $N0_2$, PM-10, fine particles, visibility, toxic substances, and acidic species. The field study periods are scheduled for mid-June through July and mid-November to mid-December of 1987. These periods were chosen to be representative of the worst oxidant (first period) and the worst aerosol (second period) conditions in the Basin.

A Model Working Group (MWG) was established under the SCAQS to aid in planning the measurement program so the resulting data base would meet the needs of the model developers and evaluators. A meteorologist from the Division participated in the MWG. A final report was prepared on the MWG's activities. Recommendations were made concerning the characterization of the wind field across the Basin, including the location and frequency of upper-air measurements, surface measurements, and a tracer program. Also a series of recommendations was made concerning the proposed chemical measurements during SCAQS, such as the degree of speciation of ambient hydrocarbons, the most important radical and product species that should be measured, and the locations and averaging times of particulate measurements, including the types of aerosol monitors to be used.

2.2.5.3 Support of Airshed Model Use by State Air Pollution Agencies

Technical assistance in the use of the Urban Airshed Model, a 3-D gridded urban photochemical model, was provided to the New York State Department of Environmental Conservation as part of the Oxidant Modeling for the New York Metropolitan Area Project (OMNYMAP). This was the second and final year of assistance. The technical assistance ended with a successful completion of the implementation and application of the Urban Airshed Model by New York. In this second year several on-site visits were made to address technical problems and help New York keep to the tight applications schedule. Technical meetings were also held to provide continued guidance on protocols for generation of model inputs. The technical support was important to the successful implementation and application of Airshed and it was a successful example of technology transfer.

2.2.5.4 National Acid Precipitation Assessment Program

A meteorologist of the Division serves as chairman of the National Acid Precipitation Assessment Program (NAPAP) Task Group 3 on Atmospheric Transport Processes. During FY-1986, as part of the general reorganization of NAPAP into 7 task groups, Task Group 3 was created as a split of the old Task Group C, with most of the basic science effort transferring to Task Group 2. One of the main tasks accomplished was to mold Task Group 3 into a well-focused research effort with respect to regional and mesoscale model development and model application and evaluation. A major effort was expended in dividing, focusing and technically rationalizing the "new" Task Group budget in terms of the 1990 goals of NAPAP.

2.2.5.5 Technical Assistance to the People's Republic of China (PRC)

A meteorologist provided technical assistance to the People's Republic of China (PRC) under the sponsorship of the United Nations World Health Organization (WHO). The focus of this assistance was a series of 19 lectures on the latest theoretical understanding of the atmospheric boundary layer and diffusion within it, including the experimental data supporting this understanding. Topics included stability and turbulence, new methods for diffusion modeling, diffusion experiments, plume rise, lofting effects of buoyant releases, and diffusion models for very low wind speeds. The host for this lecture series was the Atmospheric Environment Monitoring and Research Centre in Nanjing; this rapidly expanding laboratory is under the PRC Ministry of Water Resources and Electric Power, and is responsible for most environmental impact research pertaining to power plants in the PRC. Many new plants are planned or under construction. Three other laboratories in Xian and Beijing were visited.

2.3 Fluid Modeling Branch

The Fluid Modeling Branch conducts physical modeling studies of air flow and pollutant dispersion in such complex flow situations as in complex terrain; and near buildings, near roadways, and near storage piles. The Branch operates the Fluid Modeling Facility consisting of large and small wind tunnels and a large water channel/towing tank. The meteorological wind tunnel has an overall length of 38 m with a test section 18.3 m long, 3.7 m wide, and 2.1 m high. It has an airflow speed range of 0.5 to 10 m/s and is generally used for simulation of transport and dispersion in the neutral atmospheric boundary layer. The towing tank has an overall length of 35 m with a test section 25 m long, 2.4 m wide, and 1.2 m high. It has a speed range of 0.1 to 1 m/s and the towing carriage a range of 1 to 50 cm/s. It is generally used for simulation of strongly stable flow.

2.3.1 Complex Terrain Studies

In conjunction with the complex terrain model development project, the Fluid Modeling Branch conducted three separate modeling studies. In the first study, an extensive series of comparisons was made between predictions of the Complex Terrain Dispersion Model (CTDM) and previous data collected at the Fluid Modeling Facility on flow and diffusion over two- and three-dimensional hills in both neutral and stratified flow conditions. The results (Snyder, 1986) showed several shortcomings of the model and suggested several ways in which the model could be improved. Subsequent improvements to the model and further comparisons with laboratory data, particularly for neutral conditions, are to be published.

The second study resulted from discussions at the Complex Terrain Workshop in February, 1986. From various evaluations presented at the workshop, the CTDM clearly did not produce sufficient plume deformations or deflections, and not enough plume material was being transported to the hill surfaces. In response, the Fluid Modeling Facility conducted a series of wind-tunnel measurements of detailed plume shapes in flat terrain and over a three-dimensional hill. These data were analyzed to provide desired information on horizontal and vertical plume deflections and deformations over the hill, and on the effectiveness of a "hill surface boundary layer" in mixing of material from an elevated plume onto the hill surface. Detailed results were delivered to the contractor developing the CTDM model, and they will be summarized in a paper. The major results are that (1) the postulate of a hill-surface boundary layer is untenable and (2) strong plume deformations in the lateral direction are affected by the hill; the maximum ratio of the plume width over the hill to that in its absence was 1.9 (this for a ground-level source).

The third study was a continuation of work begun earlier. An additional set of streamline trajectories over an axisymmetric hill was measured in the stratified towing tank to supplement the set collected previously. A stereographic analysis of photographs of dye streak-lines from centerline and offset source positions was used to obtain three-dimensional coordinates of streamlines over the hill. This new set of experiments was performed for intermediate stabilities (Froude numbers of 1.0 to 8.0), with the objective of determining the minimum Froude number for which the streamline patterns were essentially the same as those for neutral flow. The measurements suggest that, for practical purposes, flow with Froude number above 6 could be treated as neutral flow, whereas for smaller Froude numbers, streamline deflections departed significantly from those of neutral flow.

A cooperative project was completed with the Los Alamos National Laboratory to examine the conditions under which flushing of a valley between two ridges will occur, i.e., to answer the question of when a stable crosswind will sweep the valley clean and when the flow will separate from the top lee side of the first ridge, reattach at the top windward side of the second ridge, and thus form a nearly stagnant region in the valley beneath. In this series of towing-tank studies, three experimental parameters were varied: the steepness of the ridge/valley slopes (40°, 27° and 13°), the separation distance between the ridges, and the Froude number that characterizes the stability of the crosswind. In broad terms, the characteristics of the flow between the ridges may be explained using criteria for boundary-layer separation from the lee side of a single ridge. The downstream ridge appears to induce separation from the lee side of the upstream ridge only when it is steep-sided (Lee, Lawson and Marsh, 1986). As an offshoot of this work, the conditions conducive to the onset of severe downslope winds on the lee sides of mountains was investigated. The results showed that an intrusion (breaking wave associated with severe downslope winds) existed when the Froude number based on the ridge height was in the range $0.2 \leq Fr \leq 0.6$ for a steep-sloped ridge (maximum slope 40°) and $0.2 \leq Fr \leq 1.1$ for a low-sloped ridge (13°).

In a study originally requested by the EPA Office of Air Quality Planning and Standards, terrain amplification factors were measured for a large matrix of source positions (locations and heights) both upstream and downstream of each of two idealized hills, an axisymmetric hill and a two-dimensional ridge. The results showed that "windows" of 40% excess concentration extend to 1.8 hill heights (h) in the vertical, 14h upstream and 10h downstream for the three-dimensional hill and 2.2h in the vertical, 8h upstream and 15h downstream for the two-dimensional ridge. Maximum terrain amplification factors were found on the downstream sides of the hills, with values of 6.8 and 5.6 for the 2-D and 3-D hills respectively (Lawson and Snyder, 1985).

Results of a prior year wind-tunnel study were written up and accepted for journal publication. In this study, the flow fields around moderately steep hills of triangular cross section and varying crosswind aspect ratio were examined using models immersed in a simulated neutral atmospheric boundary layer. Concentration patterns resulting from sources placed upwind of each of these hills showed strong plume deformations, and terrain amplification factors generally increased with decreasing aspect ratio. Additional measurements were made to examine the effects of wind-direction variations on the dispersion from sources downwind of these same hills.

Another study conducted in a prior year was written up for presentation and publication. A series of experiments was conducted in the stably stratified towing tank where the density gradient was linear and the dividing-streamline height H_D was half the hill height. Effluent was released at three elevations above H_D. Pairs of tows were made such that, in one tow, the hill (upside-down) was fully-immersed in the water and the towing speed was adjusted to provide a "natural" H_D surface. In the second tow of the pair, the hill was raised out of the water to the point where only the top half of the hill was immersed, thus, forcing a flat H_D surface. Concentration distributions were measured on the hill surface during each pair of tows and compared to ascertain effects of an assumed flat H_D surface used in some mathematical models. The results suggest that the assumption is a reasonable approximation, at least for predicting the locations and values of maximum concentrations and areas of coverage on the windward side of the hill.

Earlier measurements examined unsteadiness in the towing tank when simulating strongly stratified flows over long or two-dimensional hills. These measurements were done through the tedious processes of analysis of large numbers of photographs of dye streaks to obtain velocities in the upstream flow field, and of analyzing large numbers of samples collected during the tows to obtain the upstream density fields. A new method was developed to examine the unsteadiness. Data were collected for a wide range of hills. This method utilized a strain-gage force balance to measure the drag on the hills, and the work has been submitted for publication.

Finally, numerical computations were made of density-stratified flows around an isolated three-dimensional hill for direct comparison with laboratory experiments. The numerical model integrated the Navier-Stokes equations for incompressible stratified flow using a finite difference scheme. Numerical calculations were made for Reynolds numbers (based on the hill height) of 100 and 400 and for Froude numbers between 0.5 and 2, as well as for neutral flow ($Fr = \infty$). These were compared with experimental results (neutral wind tunnel and stratified towing tank) conducted at Reynolds numbers between 100 and 40,000 and for the same Froude numbers as used in the numerical calculations. For the small-Reynolds number cases, the numerical model qualitatively reproduced the experimental results, although there were some substantial quantitative differences, particularly near the hill surface. For the larger-Reynolds number cases, the comparisons were less good. The numerical computations at $Re = 100$ compared better (than those at $Re = 400$) with the large scale ($Re = 40{,}000$) laboratory experiments, although there were substantial differences near the hill surface and in the wake of the hill.

2.3.2 Miscellaneous Studies

Under a cooperative agreement with the Department of Marine, Earth and Atmospheric Sciences, North Carolina State University, the mixing efficiency of grid-generated turbulence was measured in a series of experiments in the stably stratified towing tank. The mixing efficiency refers to the fraction of available turbulent kinetic energy that is converted to potential energy, and has important consequences with regard to plume growth in a stratified atmosphere. The results suggest that the mixing efficiency increases monotonically with increasing stability, with some indication that it approaches a constant as the flow becomes strongly stable.

Under a cooperative agreement with Georgia Institute of Technology, a series of stratified towing tank studies was conducted using models of submerged multiport diffusers emitting buoyant effluent to study mixing of wastewater into a density stratified current. The purpose was to improve the basic understanding of initial dilution performance of ocean sewage outfalls. An extensive series of experiments examined the effects of port spacing, effluent buoyancy flux (jet Froude number), current speed and direction. The most important source parameter affecting dilution was found to be the buoyancy flux per unit length, b. The effect of the current speed, u, was expressed by the ratio $F = u^a/b$. Dilution was unaffected by current for $F < 0.1$, but thereafter increased with current speed as the rise height decreased. At $F = 100$, the dilution of a diffuser perpendicular to the current was four times higher than when stagnant and twice as large as a diffuser parallel to the current. A portion of the results were submitted for publication.

Additional measurements of the concentration fields in the wakes of automobiles were made in a specially-constructed, moving-floor wind tunnel. The results, along with some earlier data which support the use of the ROADWAY dispersion model, was submitted for publication.

The results of a cooperative project with the Los Alamos National Laboratory were published (Lee et al., 1986). Detailed measurements of flow characteristics downstream of a turbulence-generating grid were used as a basis for the calculation of particle diffusion. Results of the calculations were compared with total diffusion measured by a hydrocarbon tracer technique and with relative diffusion determined from analysis of near-instantaneous photographs of smoke plumes. Comparisons between a one-particle diffusion model and the present two-particle model showed that the two-particle model provided a more accurate description of plume meandering and relative diffusion.

The Fluid Modeling Facility began its first project on the behavior of dense gas plumes. The basic nature of the transport and dispersion of a dense gas plume in the simulated neutral atmospheric boundary layer of the wind tunnel was investigated, both in flat terrain and over a ramp. Measurements were made of the concentration fields downstream of ground-level, circular sources of moderate diameter; these measurements consisted of longitudinal ground-level, vertical, and crosswind profiles at various distances downwind. Both neutrally buoyant (air) and negatively buoyant (CO_2) source gases were used so that the specific effects of the density difference could be observed. Similarly, measurements were made in both flat terrain and over the ramp (14° slope followed by an elevated plateau) so that specific effects of the terrain could be observed. Flow visualization was done to ascertain that the dense plume was turbulent, hence, that molecular properties were insignificant. For the particular value of the buoyancy parameter used in these experiments, the plume buoyancy was significant; the resulting dense plume was significantly wider in the lateral direction and much narrower in the vertical direction, yet the longitudinal ground-level concentration profile downwind was essentially identical to that from the neutral plume. The lateral concentration profiles of the neutral plumes were essentially Gaussian in character, whereas the dense gas plumes exhibited top-hat distributions for considerable distances from the source. The vertical concentration profiles of the neutral plumes were not Gaussian, but displayed variations of the form $C/C_{mx} = \exp[-Az^n]$, with $n \cong 1.5$. On the other hand, the dense gas plumes displayed vertical variations of the form $C/C_{mx} = \exp[-z/zbar]$, where zbar is the centroid of the distribution. The net effect of the ramp on the dense gas plume was a small reduction in ground-level concentration (less than a factor of two, even for a source relatively close to the base of the ramp). This reduction was quite similar to that observed for the neutral plume.

2.4 Data Management Branch

The Data Management Branch coordinates all ADP activities within the Meteorology Division, including the design, procurement, and implementation of data base management, computer systems analysis, and ADP studies. The Branch provides data management and programming services that are done primarily through ADP service contracts.

2.4.1 Automation of Regional Oxidant Model (ROM) Processor Executions

The Regional Oxidant Model (ROM) consists of two major components: 1) a network of processors which range in function from simple reformatting of emissions data to generating the complex families of wind fields which drive atmospheric transport, and 2) the core model which solves the coupled set of generalized finite difference equations that describe the governing processes in each layer of the model. The operation of the ROM processors on a VAX computer was automated by the development of a software management system called FOREMAN (Formulation Manager). FOREMAN automatically becomes active at half hour intervals to initiate, monitor, and direct the execution of the ROM processors. FOREMAN generates runstreams, assigns filenames, initializes disk space, and submits batch jobs as needed during the hierarchical execution of the processors. Certified software libraries and standardized file naming conventions have been implemented. Quality control reports are automatically generated. These reports and other graphical analysis are reviewed in accordance with written quality assurance procedures to ensure that the data contained in approximately 100 files generated by the ROM processors are reasonable, consistent, and within preset criteria for all values. The increased speed of execution and the consistent quality and traceability of resulting data files are major benefits gained by automation.

2.4.2 Development of Analysis Software for ROM Air Quality Predictions

ROM estimates gridded air concentrations of 28 chemical species for each half-hour time step of model simulation. However, ROM air quality predictions would interface more easily with existing economic benefits models if aggregated to county level with hourly temporal resolution. A selection and aggregation (SLAG) program was implemented to read the ROM concentration output file and produce a condensed file of selected chemical species and time periods for any or all of ROM's three predictive layers and layer 0, the diagnostic layer. SLAG can convert the gridded data produced by ROM to county data, aggregate values recorded each time step into hour averages, and compute concentrations in layer 0. This program is generally run as the first step in any analysis procedure.

This basic data set is then used by several specialized analysis routines to study the effects of urban control strategies on rural ozone. Much of the analysis relies on the assignment of each county to one of four "receptor classes" - urban, suburban, agricultural, and natural - based on land use, population, and emissions. Analysis routines were developed to accumulate statistics and produce graphical outputs for each "receptor class".

A separate program combines ROM predicted concentrations with SAROAD observed monitoring site data. The Statistical Analysis System (SAS) is used to compare ROM output with observed concentration data. A variety of additional programs were developed to display and analyze model predictions including color contours of ROM predictions.

2.4.3 Biogenic Emission Inventory Enhancements and Data Production

The Biogenic Emissions Software System (BESS) which provides gridded hourly biogenic hydrocarbon emission estimates for input into the Regional Oxidant Model (ROM), was modified to incorporate the effects of solar energy attenuation due to clouds. Solar transmittance values defined by Coulson (1975) as functions of zenith angle and cloud type were used to adjust incident solar radiation, thus affecting isoprene emission factors.

Biogenic hydrocarbon emissions for an individual vegetative species are estimated by multiplying an hourly emission factor ($\mu g/g/h$) by individual species biomass (dry foliar weight in grams) per grid cell. Total emission per grid cell is the sum of individual species emissions. Using hourly gridded temperature and solar radiation data biogenic emissions were calculated for July 12 - July 26, 1980. Biogenic total non-methane hydrocarbon emissions for a high ozone day, July 26, 1980, for the ROM domain are estimated to be 2.6×10^7 kg/day. Approximately 18% of these emissions are isoprene; 40% are monoterpenes. The remaining 42% are unidentified hydrocarbons which are treated as non-reactive hydrocarbon by the carbon-bond chemistry module in ROM. This chemistry module treats isoprene explicitly and monoterpene as separate paraffin and olefin components. Biogenic sources contribute approximately 60% of the total non-methane hydrocarbons in the region and 54% of the reactive hydrocarbon.

2.4.4 Development of a Data Acquisition System for Collection of Micrometeorology

A real-time software system was developed to drive the sonic anemometer system to acquire meteorological data during intensive field studies in support of the Air Cancer Assessment Study. This software provides for the initiation and termination of sampling periods and a means to archive the data for later analysis. The system consists of two ultra-sonic three-axis anemometers, analog-to-digital converters and a personal computer. Data may be collected at several rates up to 10hz. Sample durations range from about 34 minutes at 10hz to more than a day at the lowest rate, the limiting factor is ramdisk capacity - 32764 samples with one anemometer, 20135 samples with two anemometers. This capacity can be much higher if ramdisk is not used, however the hard disk cannot keep pace with a constant 10hz rate and most sampling is being done at 10hz. About 37 seconds is required to save a full ramdisk to the hard disk, then another sample period can be started.

Sigmas, means and co-variances are calculated and displayed each sample period along with the starting and ending date and time of the sample. The starting and ending date and time, number of anemometers active, and number of samples are also saved as part of each sample file.

2.4.5 Modification of the Advanced Statistical Trajectory Regional Air Pollution (ASTRAP) Model

The Advanced Statistical Trajectory Regional Air Pollution (ASTRAP) Model which uses statistical methods to estimate long term sulfur and nitrogen deposition and concentration on a regional scale was revised significantly to make it more flexible and easier to use for a variety of research applications. The existing National Meteorological Center polar stereographic grid system was converted to a latitude-longitude based grid system with the user having control over the grid size and location by the use of "parameter" statements. This new grid system also allows ASTRAP to interface directly with raw data processors developed for the RELMAP model, thus providing a generalized method of preparing the required modeling inputs for any time period and any modeling domain east of the Rocky Mountains. Default values for deposition velocity, eddy diffusivities, etc. are available in the model, but the user can override those values by choosing to read replacement data sets.

2.4.6 Modification of the Regional Lagrangian Model of Air Pollution (RELMAP) for Particulate Modeling

The RELMAP Model has been expanded to include several useful modes of operation. The model now has a check-out mode where all required input values are entered as default variables, a one-layer mode where the atmosphere is considered as one layer as opposed to the typical four layer configuration, a source-receptor mode where the impact of any number of sources on any number of receptors can be calculated, a daily mode whereby the results of the model are available in intervals stated by the user from one to "n" days. The model can be run in almost any combination of modes the user requests and execution requests in different modes can be chained together. Also any constant in the model can be easily altered for model sensitivity studies.

2.5 Terrain Effects Branch

The Terrain Effects Branch researches the effects of complex irregular terrain and man-made surface features on ambient pollutant dispersion, on both an intramural and extramural basis; establishes mathematical relationships among air quality, meteorological parameters, and physical processes affecting the air quality; and conducts research in the areas of air pollution climatology and acidic deposition.

2.5.1 Complex Terrain Modeling

2.5.1.1 Dispersion Model Development for Sources in Complex Terrain

The Complex Terrain Model Development Program continues to develop improved atmospheric dispersion models with known accuracy and defined reliability for large sources in complex terrain. The program's primary effort is focused on the recognized problem of plume impaction on terrain obstacles during stable conditions in the atmospheric boundary layer. The Complex Terrain Dispersion Model (CTDM), is a major product of the model development process combining theoretical concepts, scaled fluid modeling results, and the results from four major atmospheric diffusion field experiments in three distinct terrain settings. The progress of the model development was documented in five milestone reports (Lavery et al., 1982; Strimaitis et al., 1983; Lavery et al., 1983; Strimaitis et al., 1985; and DiCristofaro et al., 1986).

CTDM is a point source plume model designed to estimate windward-side surface concentrations on distinct terrain features during a stably-stratified flow. The model incorporates the critical dividing streamline height, H_c, concept in which effluent above H_c passes over the terrain obstacle and effluent below H_c passes around the sides. Consideration is given in the model to plume meander, source-induced effects on initial diffusion, and alterations to diffusion rates by terrain-induced flow deformation.

In October 1985, an initial version of CTDM was available for testing and evaluation to a wide variety of model developers and users within the EPA and within selected regulatory agencies, air quality consulting firms, and research universities. Each agreed to analyze and exercise the model and to participate in a workshop conducted in February 1986. Key recommendations were agreed upon in three major areas: improvements to the CTDM algorithm based on further theoretical considerations and discussions of field and fluid modeling study results; applications and practical considerations of the regulatory use of CTDM including recommendations for pre- and post-processors, input data requirements, and the essential components of the final users guide; and methods for evaluation of CTDM with recommendations for the types of statistical tests and data bases to be used and the types of information about the model that should result from the evaluation. The recommendations from the workshop have heavily influenced the directions taken in model development and refinement during FY-1986 and will continue to do so in FY-1987.

In response to recommendations from the CTDM workshop, significant improvements have been made in the LIFT portion (for flow above H_c) of the model. The methods for calculating the terrain adjustment factors have been changed to be consistent with the approach of Hunt and Mulhearn (1973). The T-factors are now computed as line integrals along the trajectory of the plume centerline as opposed to the old "receptor-oriented trajectory" approach. In addition, the T-factors are calculated for two layers in the vertical in an effort to improve the representation of vertical structure in the flow. The LIFT equation was modified to include the vertical structure of the straining in the flow to better distinguish between the displacement of plume material by the terrain and the effects of distortion in the flow on the diffusion process.

A new flow field module was developed for the LIFT portion of the model. Computations represent an approximate analytical solution to the linearized non-hydrostatic equations of motion for neutral to weakly stratified flow over a single hill. The routine traces the trajectory of the centerline of the plume and evaluates change in the streamline spacing in the lateral and vertical directions. This information is passed to CTDM for computing the T-factors. Tests of the model with inclusion of T-factor and flow field modifications to LIFT show improvement in the comparisons of the model with fluid modeling results.

The performance of the revised version of CTDM was compared with two other complex terrain models, COMPLEX I and the Rough Terrain Diffusion Model (RTDM), using 128 hours of the Full Scale Plume Study (FSPS) data base. Results of the comparison show that for selected terrain features, CTDM performed best overall with a majority of the maximum hourly predictions lying within a factor of two of the observations. Largest observed concentrations, however, were somewhat underpredicted by CTDM.

An objective terrain pre-processor program (Mills et al., 1986) was developed which mathematically determines a best-fit hill for input to CTDM. The program accepts digitized contour coordinates supplied by the user after extraction from topographic maps. Meteorological pre-processor programs are under development which will take wind, temperature, and turbulence profile data together with surface variables and provide the hourly plume height information required by the model.

Three stable plume rise algorithms were evaluated using observations from the FSPS data base. All three methods use existing Briggs' equations but the operational applications differ among them. Sixty case-hours of observed stable plume rise (using lidar) were used in the evaluation. The results show that the use of wind speed and temperature gradient at an iteratively determined point midway between stack top and final rise gave the best results of the methods being considered for inclusion in CTDM.

An in-house research project was begun with the goal to better understand the structure of turbulence in complex terrain and specifically to better estimate turbulence time scales and diffusion parameters. Initial work will be reported in FY-1987, describing a new model for the autocorrelation function of wind components based on the concept that instantaneous velocities are the combination of the mean velocity and the fluctuations on multiple time or length scales. The autocorrelation function can be represented as a sum of exponential terms each representing the turbulent decay on a different scale. A technique by Wiscombe and Evans (1978) for fitting data with a sum of exponentials will be applied to the autocorrelation function in order to identify the dominant scales of turbulence. This new model for the autocorrelation can provide better access to direct estimates of the diffusion parameters. This research effort will continue in FY-1987.

Work on the CTDM in FY-1987 will continue with model refinement and testing. Formulae for the diffusion parameters will be evaluated and refined; problems with the flow module will be addressed; terrain and meteorological pre-processors will be completed; CTDM will be processed through extensive sensitivity tests; and the model will be evaluated with a number and variety of field study data sets.

2.5.1.2 Complex Terrain Data Base Documentation

A computer data base of meteorological and tracer gas observations from the Full Scale Plume Study was completed and placed on magnetic tape. This August 1984 study was performed at the Tracy Power Plant, Nevada, employing techniques similar to those used at the 1980 Small Hill Impaction Study #1 at Cinder Cone Butte, Idaho, and the 1982 Small Hill Impaction Study #2 at Hogback Ridge, New Mexico, with the exception that one tracer gas was released from the stack of an active power plant. These data were combined with an existing data base of observations taken during a preliminary full scale plume study at the Tracy Power Plant in November 1983. Documentation of both the preliminary and the Full Scale Plume Study is contained in a report (Truppi, 1986), which describes the data tape files of meteorological measurements and tracer concentrations. The data base is available as tape copies or by interactive computer access.

2.5.1.3 Rocky Mountain Acid Deposition Model Assessment

The Rocky Mountain Acid Deposition Model Assessment (RMADA) project is designed to review and select currently available mesoscale meteorological and acid deposition models for incorporation into a Rocky Mountain mesoscale acid deposition modeling system. A contract was awarded to Systems Applications, Inc. Draft reports on the review and selection of models were completed (Morris et al., 1986a and b). Future work will concentrate on delivering a Lagrangian model which will handle dispersion, chemical conversion, dry deposition and wet deposition processes over a mesoscale complex terrain area.

2.5.2 Plume Dispersion in the Wake of Surface Obstacles

An in-house building wake effects research project to evaluate the overall effects of building wakes on plume dispersion is continuing. Additional fluid model studies were conducted during the year. Data from earlier limited industrial-sponsored field studies and comprehensive in-house fluid model studies were processed and catalogued. Velocity and concentration measurements are being evaluated to delineate the effect of building scale, building orientation, wind speed, and boundary layer characteristics on their non-dimensional distributions. A paper on the performance and inherent limitations of a Gaussian plume model for predicting ground level plume centerline concentrations in the wake of buildings was prepared The variability of model error was found to be 50 to 100 percent of the mean-observed concentration. Also a paper looking at the influence of building orientation on plume dispersion was prepared. The lateral plume dispersion was found to be strongly related to the projected downstream building width. In some situations, slight changes in building orientation were observed to have a very significant effect on maximum ground level concentrations. Additional analyses will be reported during FY-1987.

2.5.3 Dispersion Modeling in the Arctic

A cooperatve research agreement was given to Washington State University to study dispersion modeling applicability in the Arctic. All available data were reviewed which could be used to evaluate diffusion models in the Arctic, and it was found that there was not enough to do a thorough study. This problem was anticipated, and an optional field study planned. A field test of the instruments was completed under arctic winter conditions, and the results incorporated into the final study plan. The full scale field experiment will be run at a North Slope oil facility in April 1987.

2.5.4 Integrated Air Cancer Program

In 1985, the EPA initiated a long-term research program to investigate the toxicity of airborne pollutants. The first phase of this research program was a study of the chemical composition and mutagenic effects of woodsmoke. The transport and diffusion of woodsmoke continued to be studied in urban areas to determine the relative effect of nearby sources on the chemical samples taken at a single site and to determine how woodsmoke diffuses.

A field study is being conducted in Boise, Idaho in the winter of 1986-1987. To study the transport and diffusion of woodsmoke, a 30-m tower was instrumented with two sonic anemometers, two bivane anemometers, and a delta T system. The meteorological data will be used in conjunction with tracer studies to be conducted by Dr. Brian Lamb of Washington State University under a cooperative agreement.

2.5.5 Nacozari Smelter

The impact of emissions from smelters in the southwest on regional wet deposition of acid species, primarily sulfate, was the subject of several recent studies, with little agreement on the smelter contributions to regional sulfate deposition. With the proposed start-up of the Nacozari smelter in northern Mexico, which would significantly increase the emissions of sulfur dioxide in that region, suggestions were made that a field measurement program might be able to directly measure the regional impact of these increased emissions. Accordingly, a feasibility study was conducted to assess the effectiveness of proposed field programs. It was concluded that little new knowledge would be gained by field measurements of the plume from the Nacozari smelter, particularly since this plume would be interacting with plumes from smelters located in the United States. Also, it was concluded that attempts to determine the smelter contributions to wet sulfate deposition would likely be inconclusive, because of the spatial variability of regional air flow and precipitation events due in part to the complex topography of the region, and because of the temporal variability of precipitation events and amounts.

2.5.6 Analysis of Acid Deposition Data

Statistical techniques, including Kriging, were used to analyze spatial patterns of wet deposition data from North America, collected between 1980 and 1984. Maps of concentration and deposition were prepared for sulfate, nitrate, and hydrogen ion. Special techniques, including interpolation of area-wide averages using Kriging, were developed. The analysis of this data showed that there were significant decreases in the amount of pollutants in rainfall between 1980 and 1983, with a slight increase in 1984.

2.6 Environmental Operations Branch

The Environmental Operations Branch improves, adapts, and evaluates new and existing air quality dispersion models, makes them available for use, and consults with users on their proper application. The research work of the branch consists of two major areas: model availability and evaluation; and improving characterizations of dispersion meteorology.

2.6.1 Model Availability and Evaluation

2.6.1.1 Air Quality and Effects Modeling

A mathematical model to express crop reduction as a function of ambient O_3 concentrations (Larsen and Heck, 1984 and 1985) was developed as part of an EPA effort to set National Ambient Air Quality Standards to control crop reduction caused by ambient O_3. Analyses showed that increases in O_3 concentrations caused much more plant injury than increases in exposure durations. This observation was used to develop a new O_3 parameter, the effective mean O_3 concentration:

$$m_e = [(\Sigma\, c_h^{-1/v})/n]^{-v}$$

where c_h is the hourly average ambient O_3 concentration for each daytime hour (9:00 A.M.-4:00 P.M) of data available at an air sampling site for summer (June 1-August 31), n is the total number of such available hours, and v is an exposure time-concentration parameter (–0.376).

Six internal reports were prepared of expected crop reductions as functions of potential new ambient O_3 standards, using various types of O_3 parameters. Additional reports are being prepared.

Studies suggest that asthmatics respond adversely to high SO_2 concentrations occurring for short durations (e.g., 10 minutes). One-hour-average SO_2 concentrations are the shortest averaging times stored in the National Aerometric Data Bank (NADB). However, short-duration SO_2 concentrations are available for several sites in St. Louis that operated during the Regional Air Pollution Study (RAPS). St.Louis SO_2 concentrations were studied as a function of various averaging times (such as 10 minutes and 1 hour). Many of the measured 10-minute averages compared favorably with concentrations predicted from 1-hour averages by using an averaging-time model that was developed several years ago.

High, short-duration SO_2 concentrations often occur near tall, isolated sources, such as copper smelters. An internal report analyzing these concentrations was prepared.

2.6.1.2 Analysis of Power Plant Data Bases

This task was initiated in FY-1986 when data from the Electric Power Research Institute (EPRI) Kincaid field experiment were obtained. The objective of this task is to evaluate and improve atmospheric dispersion models by analyzing existing power plant data bases. Thus far, data from Kincaid were analyzed for the purpose of evaluating convective scaling ideas proposed by Briggs (1985). A preliminary evaluation using 15 hours of data showed that convective scaling can improve predictions of diffusion from a buoyant plume in the limited-mixed convective boundary layer. Analysis of the Kincaid data base continues, and data from the Tennessee Valley Authority (TVA) Paradise power plant are also being examined.

2.6.1.3 Relating Error Bounds for Maximum Concentration Estimates To Diffusion Meteorology Uncertainty

There are several sources of uncertainty in all simulations of air quality. One is the inherent lack of predictability of transport and diffusion imposed by the stochastic nature of the atmosphere. Even perfect knowledge of the initial state of the atmosphere would not allow reduction of the imprecision below a fundamental level. A second source of uncertainty arises because the initial state of the atmosphere is always imperfectly known. A direct and quantitative link between the nature and magnitude of the input uncertainty and the modeling results was not investigated previously.

Intuitively, it would be expected that the output of a model is at least as uncertain, and perhaps more so, than those associated with the inputs to the model. It might also be expected that the distribution of the modeled values may be similar to the distribution associated with the input errors. These notions, relating input and model uncertainty, are reasonable if the modeled result is a linear function of the input values. The goal of this study is to investigate whether this view is reasonable for Gaussian plume modeling of diffusion from an elevated point source. It is also intended to quantify the model uncertainty in terms of the assumed input uncertainty.

The primary intent of this work was to relate the magnitude of the error bounds of data, used as inputs to a Gaussian dispersion model, to the magnitude of the error bounds of the model output, which include the estimates of the maximum concentration and the distance to that maximum. The research specifically addresses the uncertainty in estimating the maximum concentration from elevated buoyant sources during unstable atmospheric conditions, as these are most often of practical concern in regulatory decision making. The ability to develop specific error bounds, tailored to the modeling situation, allows more informed application of the model estimates to the air quality issues.

In this study, a numerical uncertainty analysis was performed using the Monte-Carlo technique to propagate the uncertainty associated with the model input. Uncertainties were assumed to exist in four model input parameters: 1) wind speed, 2) standard deviation of lateral wind direction fluctuations, 3) standard deviation of vertical wind direction fluctuations, and 4) plume rise. For each simulation, results were summarized characterizing the uncertainty in four features of the ground level concentration pattern predicted by the model: 1) the magnitude of the maximum concentration, 2) the distance to the maximum concentration, 3 and 4) the areas enclosed within the isopleths of 50% and 25% of the error-free estimate of maximum concentration.

In these analyses, the uncertainty of dispersion model input was characterized using a log-normal distribution of the ratios. The distributions were defined by the median, M, and the 75th percentile value, P75. The intent was to study the effects of input uncertainty on model output. The effects of bias in the model input can to a first order be treated separately. Therefore, for the simulations, the median was assumed to be 1.0 (no bias).

Each simulation of 10,000 sets of calculations yielded a value for the four characteristics which was expressed as a ratio (value over error free value). The ratios were computed for maximum concentration, distance to maximum concentration, area of the 50% isopleth, and area of the 25% isopleth. A separate file of 10,000 values for each characteristic was ordered by sorting so that a cumulative frequency distribution was obtained. Ratio values for specific percentiles were then printed. These values could then be plotted. Figure 1 is a log probability plot typical of the results obtained. The 75th percentile (P75) value was 1.10 for each of the input parameters, the source height was 200 m and the plume rise was 400 m. The input distribution was plotted as the solid line. The ratios for maximum concentration and distance to maximum concentration are indicated as triangles and circles respectively. Figure 2 summarizes the results for the same source and meteorology as in Figure 1 except that the P75 value was 1.3 to define the uncertainty in the model input. Although the source height and plume rise were typical of many sources, a P75 value of 1.10 in the meteorological input was unrealistically small compared to input estimation capabilities. In the comparisons with tower data, P75 values on the order of 1.3 to 1.4 occurred frequently. Hence, it is anticipated that for routine situations, P75 of 1.2 to 1.3 is a conservative estimate of the input uncertainty from routinely available wind speed and turbulence values. With research grade meteorological instrumentation on site, a P75 of 1.1 to 1.2 might be anticipated.

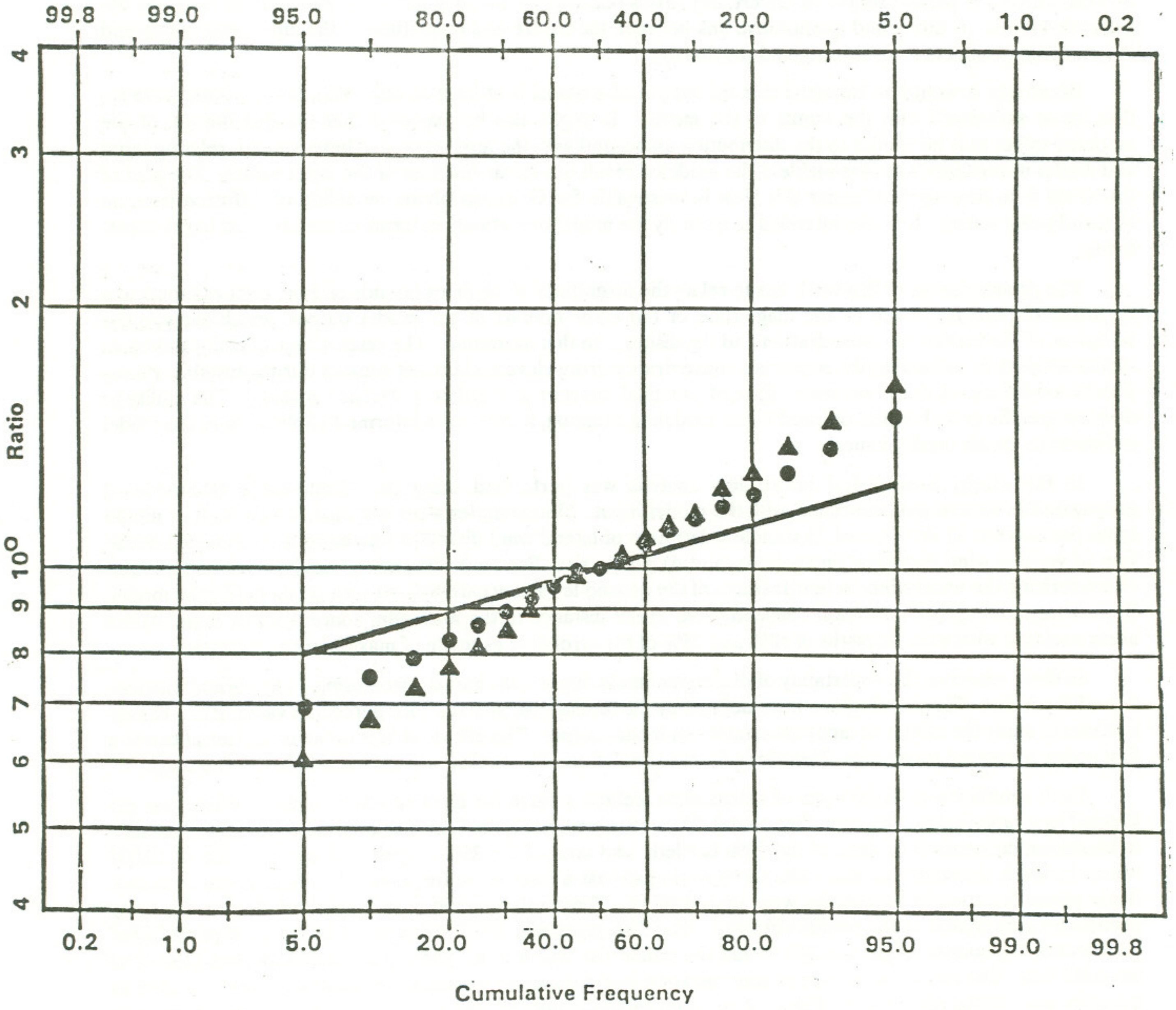

Figure 1. Distribution of ratios of concentration maximum (triangles) and distance to maximum (filled circles) for the case of input uncertainty having P75 equal to 1.1. The line is the input uncertainty distribution.

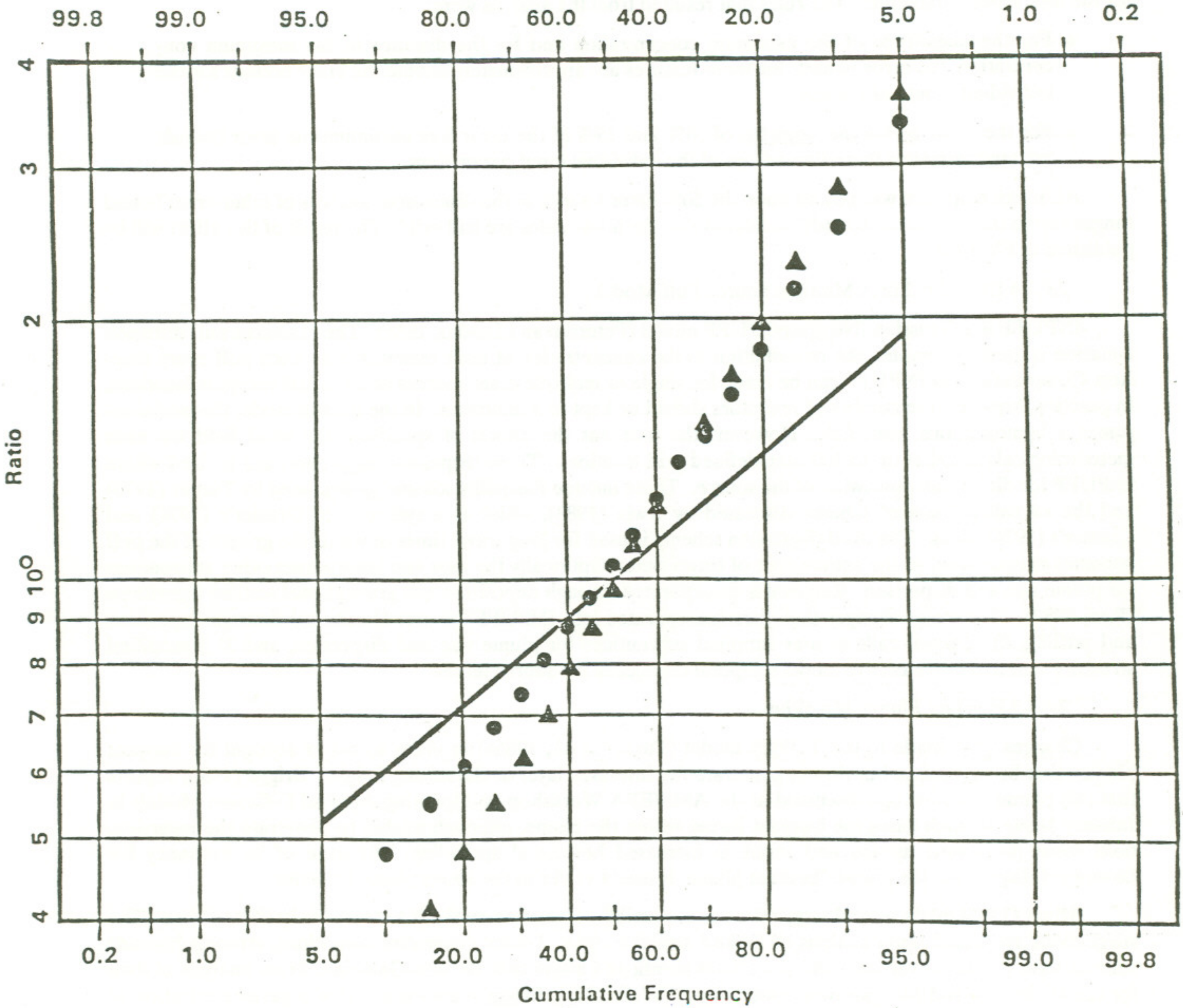

Figure 2. Distribution of ratios of concentration maximum (triangles) and distance to maximum (filled circles) for the case of input uncertainty having P75 equal to 1.3. The line is the input uncertainty distribution.

For unstable meteorological conditions that frequently cause maximum concentrations from medium to large buoyant sources a magnitude of the error bounds on four features of model output were related to the magnitude of the error bounds of four model input parameters, three meteorological parameters (wind speed, and standard deviations of both horizontal and vertical wind angles) and one parameter related to meteorology (plume rise). For error distributions of the input parameters, it was assumed that the ratios of values with errors to error-free values were lognormal. For the investigation, the error bounds of those ratios were assumed equal for the four input parameters. The rules that resulted from the analysis were:

- For the magnitude of the maximum concentration and for the distance to the maximum concentration, the error bounds for these features are approximately double the error bounds for the individual input parameters.
- For the areas within the isopleths of 50% and 25% of the error free maximum the error bounds are approximately three times those of the individual input parameters.

Although emphasis was placed upon the 50% error bounds in the discussion, analysis of other error bound ranges (up to the 95% error bounds) indicated that the above rules are still valid. The result of this effort will be published in FY-1987.

2.6.1.4 INPUFF-2.0: A Multiple Source Puff Model

INPUFF is a Gaussian INtegrated PUFF model (Petersen and Lavdas, 1986). The Gaussian puff diffusion equation is used to compute the contribution to the concentration at each receptor from each puff every time-step. Computations in INPUFF can be made for single or multiple point sources at up to 100 receptor locations. In practice, however, the number of receptors should be kept to a minimum. In the default mode, the model assumes a homogeneous wind field. However, the user has the option of specifying the wind field for each meteorological period at up to 100 user-defined grid locations. Three dispersion algorithms are utilized within INPUFF for dispersion downwind of the source. These include Pasquill's scheme as discussed by Turner (1970) and the so called "on-site" scheme discussed by Irwin (1983), which is a synthesis of Draxler's (1976) and Cramer's (1976) ideas. The third dispersion scheme is used for long travel times in which the growth of the puff becomes proportional to the square root of travel time. Optionally the user can incorporate other subroutines for plume rise and dispersion. Removal is incorporated through deposition and gravitational settling algorithms (Rao, 1982). The major changes that were incorporated into INPUFF 2.0 are: 1) removal through deposition and settling, 2) optional calls to user supplied subroutines for plume rise and dispersion, and 3) a modified structure that makes it easier to model temporal changes in the source terms.

2.6.1.5 Hesitant Plume Algorithm

Changes were made to the TUPOS model (Turner et al., 1986a) in order to better account for buoyant plumes that bump against but do not penetrate the inversion layer at the mixing height. Briggs (1985) reports that this plume behavior was discussed at the AMS/EPA Workshop on Updating Applied Diffusion Models in January 1984. In such cases the buoyant forces within the plume, although unable to penetrate the inversion, both resist downward motion and result in increased horizontal spreading. Because of its hesitancy for downward dispersion, the phrase "hesitant plume" is used to refer to the above plume behavior.

Briggs (1985) made several suggestions as to possible calculation methods to treat the hesitant plume. The suggestions are based upon analysis of limited available data. Under convective conditions, strongly buoyant sources have displayed vertical diffusion effects mentioned above that are non-Gaussian. From analysis of data for the Dickerson and Morgantown power plants (Weil, 1977), Briggs recommends that a parameterization of the ground-level crosswind integrated concentration be employed using the dimensionless parameters F* and X.

In deriving equations for ground-level concentrations beneath the plume axis and crosswind, the spreading of the hesitant plume is assumed to be a function of buoyancy. In order to evaluate the equations it is necessary to estimate the convective scaling velocity, w*. This can be done using

$$w^* = (H^* z_i)^{1/3}.$$

The convective scaling parameter, H^* ($m^2 s^{-3}$), can be found from the surface sensible heat flux, H:

$$H^* = 2.80 \times 10^{-2} H/p$$

where latent heat effects are ignored and where p is atmospheric pressure in mb. H is in watts m^{-2}. The constant has units of m^4 mb $watt^{-1}$ s^{-3}.

The principal criterion to use the hesitant plume calculations is for F* to equal or exceed 0.09. An addendum (Turner, 1986b) to the TUPOS users guide documents the techniques used.

2.6.1.6 Screening Dispersion Code for Personal Computers

Frequently it is necessary to make dispersion estimates rapidly in situations where a mainframe computer is not easily accessible. To meet this need, routines have been written for use on a hand-held programmable calculator. With the current availability of personal computers, it seemed appropriate to code dispersion routines adding some features not included in the hand-held calculator routines. These additional features are contained in the code: Dispersion Screening Calculations (DSC). Although the personal computer is not as portable as the hand-held calculator, it offers other advantages: faster running times and a complete printed record (if desired) of all input values and output with labels so that input can be checked and assured of being error free. Since the code is written in FORTRAN, it provides easy portability to other PC's or mainframes.

The principal anticipated use of this screening model is for rapid screening of ground-level impact from continuous single point sources (from ground-level sources to large stack buoyant releases). It can also be used to compare calculated concentrations resulting from different dispersion techniques. Calculations are made for a single meteorological condition. Calculations for additional meteorological conditions are performed essentially as a new computation.

Dispersion is calculated using the Gaussian equation (Gifford, 1961). Only receptors at ground-level are allowed. No provisions are made for consideration of terrain variations between source and receptor. Effects of mixing height are simulated by multiple eddy reflections from both the ground and the mixing height of that portion of the plume between those two boundaries.

The evaluation of the dispersion parameters can be done by any one of five different methods:

Fluctuations - Irwin (1983)
Briggs Urban - Gifford (1976)
Briggs Rural - Gifford (1976)
Pasquill-Gifford - Pierce et al. (1982)
Brookhaven - Singer and Smith (1953)

Five alternatives are also available for determining receptors. These are:

Maximum Concentrations
Concentrations Beneath Plume Centerline
Coordinates Relative to Plume Position (x,y)
Polar Coordinates Relative to Source
Map Coordinates for Source and Receptor

A paper, (Turner, 1986a) was presented at the 79th Annual Meeting of the Air Pollution Control Association in Minneapolis in June 1986. Although this version of the model is friendly to the user in providing step-by-step questions for data entry, the running of an additional problem with only slight changes to parameter values requires reentry of all data. With modification, a more useful model can be assembled using full-screen editing for most data entry and retention of data values at the conclusion of a run for easier data entry in subsequent runs.

2.6.1.7 UNAMAP

UNAMAP, User's Network for Applied Modeling of Air Pollution, source of air quality simulation model computer codes since 1973, was updated. Version 6 became available in September 1986. UNAMAP exists in basically two forms. Executable codes are on EPA's UNIVAC computer in Research Triangle Park, NC. Virtually all elements of EPA have access to this computer. In addition, others who arrange for an account number can also use this computer. A magnetic tape containing FORTRAN source codes and test data are available through Computer Products, National Technical Information Service, U.S. Department of Commerce, Springfield, VA 22161. To insure ready access of the state air pollution control agencies to UNAMAP, a duplicate of the tape available from NTIS was made available to the states.

Models and processors that are contained in UNAMAP (Version 6) are given below:

Guideline (Appendix A) Models

BLP	Buoyant Line and Point Source Model (Aluminum)
CALINE-3	California Line Source Model
CDM-2.0	Climatological Dispersion Model
RAM	Gaussian-Plume Multiple-Source Model
ISCST	Industrial Source Complex - Short Term
ISCLT	Industrial Source Complex - Long Term
MPTER	Multiple Point Source with Terrain Adjustment
CRSTER	Single Point Source with Terrain Adjustment

Other Models or Processors (New Models)

INPUFF	Puff Model
PBM	Photochemical Box Model
MPDA-1.1	Meteorological Processor
TUPOS-2.0	Model with dispersion dependent on wind fluctuations
TUPOS-P	Analysis package for TUPOS output
PEM-2	Urban Particulate Model
MESOPUFF-2	Regional Short-term Model
PLUVUE-2	Visibility Model
RUNAVG	Processor to find highest and 2nd highest running avg

Other Models or Processors (Old or slightly revised models)

PAL-2	PAL with urban and rural dispersion plus deposition.
PTPLU-2	Combination of PTPLU and PTCITY
HIWAY-2	Highway Model
MPTDS	MPTER with Deposition
ROADWAY-2	Combination of ROADWAY and ROADCHEM
CHAVG	Postprocessor for Averages and Running Averages
UTMCON	Conversion from Long.-Lat. to UTM Coordinates
APRAC-3	Urban CO Model
CALMPRO	Calms Processor

Additional Models for Regulatory Use

VALLEY
SHORTZ
LONGZ
COMPLEX-1

In creating Version 6 of UNAMAP changes were made in existing models requiring preparation of addenda to user guides (Catalano, 1986; Chico and Catalano, 1986; Irwin et al., 1985) and preparation of users guides for new models (Paumier et al., 1986; Petersen and Lavadas, 1986; Pierce, 1986; Turner et al., 1986a and 1986b; Turner, 1986b). Preparation was accomplished either inhouse or by contract. In order to have a document readily available to send to persons requesting information on UNAMAP, a research brief (Turner and Bender, 1986) was prepared.

2.6.2 Improving Characterizations of Dispersion Meteorology

2.6.2.1 Data Archive for Meteorological Air Tracer Field Data

During FY-1986 the effort to archive meteorological air tracer field data continued. This effort was initiated to develop and test a means for archiving invaluable data sets in a timely fashion before the necessary supporting information about the data was lost permanently (Droppo and Watson, 1985). The data are entered into the archive in as close to original form as possible to maintain a clear link with original records. The archived data are contained within a well-defined structure called a data map. The data map allows data to be entered in original formats, while providing the user with a machine readable pathway for accessing the diverse data formats. Presently there are three data sets in the archive; the Minnesota 1973 data (Woodruff et al., 1985), the Hanford 1964 tracer diffusion field data (Glantz et al., 1985), and the Hanford 1967 tracer field data (Droppo, 1986a). During FY-1986 the Minnesota 1973 data were revised to include rawinsonde profiles, the Hanford 1967 data were added to the archive, and the final project report was published (Droppo, 1986b). The final report documents efforts related to the development and implementation of the archive that were not covered in previous reports. The emphasis in this report is on the activities related to development of data archive sets; starting with the selection of a computer and software, and ending with the final quality assurance checks on the archived data. This information is presented to provide guidance to those wishing to add additional data sets to the micrometeorological and tracer data archive.

2.6.2.2 Visiting Fulbright Scholar

Dr. David S. Wratt, Superintendent, Research Section, Boundary Layer Meteorology, New Zealand Meteorological Service, began a six-month research visit on May 23, 1986. Being aware of the development of the meteorological processor MPDA, Dr. Wratt used data that he had collected to test MPDA.

Dr. Wratt completed research and submitted a paper on an experimental investigation of some methods of estimating turbulence parameters for use in dispersion models. The paper examined whether techniques such as those in MPDA could be used to estimate dispersion from routine meteorological data. Currently, some dispersion models exist which can use σ_q and σ_f measurements to estimate σ_y and σ_z. There are also methods available (which are included in MPDA) to estimate σ_q and σ_f when measurements are unavailable, using routine weather observations or using wind measurements and temperature profiles from meteorological towers. Such estimates were compared with direct measurements made at a height of 56 meters, for a sampling time of one hour, for a range of meteorological conditions. The measurements were made at a site in relatively irregular terrain.

The results showed that σ_f measurements made during the daytime agreed well with estimates, with a bias in the estimates of less than 0.4 degrees. The r. m. s. differences between estimates and measurements were 1.1 degrees (profile method) and less than 2 degrees (routine weather observations method). Daytime σ_q estimates were generally too low (bias 5 to 6 degrees), although they were positively correlated with the measurements. At night, σ_q was severely underestimated, and σ_f was also underestimated.

2.6.2.3 Norway Assignment

A meteorologist began a one-year assignment to the Norwegian Institute for Air Research (NILU) on April 14, 1986. The Norwegians have tracer data sets from several field experiments but lack personnel to organize and research the data. Some of these experiments were conducted cooperatively with Sweden and Denmark. The tracer studies are viewed as useful for testing techniques for meteorological characterization and atmospheric dispersion.

Some problems arising during installation of the meteorological processor, MPDA, on the NILU computer were resolved. Tracer studies using SF_6 were conducted at a large power plant that is being investigated because of its $S0_2$ emissions. Eleven experiments are available with nine having data that will be examined. Work is underway to review data collection and analysis procedures, locate and review field notes of SF_6 analyses, resolve questionable data and field note comments with field personnel, establish a data archive in the computer, and verify the computer files.

Initial analysis used a Gaussian fit program to gain insight into the data. This included (1) plots of concentration for each crosswind traverse, including a curve of best fit, and (2) comparisons of the magnitude and positions of maximum concentrations between the measured data and the best-fit curve.

2.6.2.4 Balloon Marker System

Phase II of the development of an adjustable buoyancy balloon tracer of atmospheric motion was completed. The results were reported by Zak et al. (1986). The adjustable balloon is a research tool which will allow electronic tracking of atmospheric flows in both the horizontal and the vertical. The design goals for the balloon specify a lifetime of at least three days, a tracking range greater than 1000 km, a ceiling altitude greater than 500 mb (5.5 km), and the capability to respond to mean vertical flows as low as 1 cm/s. The balloon must measure and telemeter selected meteorological variables, be sufficiently inexpensive to permit use in significant numbers, and be serviced by a ground system capable of handling several balloons at a time. The balloon has applications throughout the atmospheric sciences, but the immediate motivation for this effort was to provide a means to evaluate the accuracy of air pollution transport models for the eastern United States. In Phase II, the authors have completed operational tests on a prototype. The balloon was successfully flown on three trials and responded to electronic commands. In Phase III, additional improvements in the balloon electronics are planned. Also, tests are scheduled to fly the balloon at distances greater than 100 km in FY-1987.

2.7 Air Policy Support Branch

The Air Policy Support Branch (APSB) supports activities of the EPA Office of Air Quality Planning and Standards (OAQPS). General responsibilities include: (1) evaluating, modifying and improving atmospheric dispersion and related models to ensure adequacy, appropriateness and consistency with Agency policy and established scientific principles; (2) preparing guidance on applying and evaluating models and simulation techniques that are used to assess, develop or revise national, regional and local air pollution control strategies for attainment and maintenance of ambient air quality standards; and (3) providing meteorological assistance and consultation to support OAQPS's broad responsibilities for development and enforcement of Federal regulations and standards and assistance to the Regional Offices. The meteorologists are typically involved in interdisciplinary team efforts that include engineers, chemists, statisticians, computer specialists and other technical staff.

2.7.1 Modeling Studies

2.7.1.1 Oxidant Modeling of the New York Metropolitan Area (OMNYMAP)

During FY-1986, the New York State Department of Environmental Conservation completed the acquisition of 1980 VOC (Volatile Organic Compounds) and NO_x emissions data bases from New Jersey and Connecticut. These inventories were merged with the mobile, point, and stationary area source inventories from New York to form the gridded, speciated, and temporally allocated emissions data sets required for input into the Airshed model. Inventories for the 1988 projection year simulations were received from New Jersey and Connecticut.

Efforts to prepare the air quality and meteorological input data were completed using procedures and guidance provided by APSB. Available O_3, NO_x, and VOC ambient data measured on the modeling days were used to generate pollutant concentration fields at the start-hour of the simulation (0400 EST) and for each hour 0400 through 1900 EST at the lateral top boundaries of the modeling domain. The task of developing boundary conditions required more effort than anticipated due to the complexity of specifying pollutant concentrations in four layers of all boundary grids for each time step. Surface and upper air meteorological measurements available from National Weather Service Stations (NWS) were combined with upper air soundings and aircraft data collected during 1980 to prepare the mixing height fields.

Using the 1980 emissions inventories and the aerometric and meteorological inputs, the Airshed model was applied for each of the 5 high ozone days selected for analyses (July 16, 21, and 22 and August 6 and 8, 1980). In general, the results for all 5 days indicate fairly close agreement between observed and predicted O_3 concentrations in terms of the magnitude of O_3 concentrations and both spatial and temporal patterns. The model did tend to underpredict peak concentrations. In addition, the time of the predicted peak was 2 to 3 hours later than the corresponding observed value. The average of the percent difference between observed and predicted daily maximum values (unpaired in space and time) was 16 percent. The range was for 0 to 30 percent across the 5 days. An examination was made of model performance in predicting O_3 concentrations greater than 100 ppb. In this analysis, predictions within ± 30 percent of observed values (paired in time and space) were considered to represent "good" model performance. Considering the ensemble of data from all 5 days, 64 percent of the values were within the ± 30 percent range. The remaining values were fairly evenly distributed between over and under prediction suggesting a lack of bias in the ability of the model to predict high concentrations on these days. The final phase of OMNYMAP will be completed in early FY-1987 when Airshed applications are performed for VOC and NO_x control strategies.

2.7.1.2 Regional Ozone Impact Analyses

A program was initiated in FY-1986 to apply two regional oxidant models, ROM and RTM- III, to qualify the impact of urban emissions control strategies on short-term peak and seasonal mean ozone concentrations in rural areas of the Northeast, Midwest, and Southeast. The results will be used to estimate the monetary benefits of controls, in terms of both agricultural and human health related effects. In addition, the program is designed to support the development of a secondary ozone standard to protect forests and crops from yield loss due to exposure to ambient ozone concentrations.

The region selected for model simulations includes most of the eastern United States east of 99° longitude and north of 28° latitude. Within this modeling region are numerous large population centers such as the Northeast Corridor, Houston, Chicago, and Atlanta and both the important agricultural croplands of the Midwest and the timber production forests of the Southeast. The emissions data obtained for this region include (1) anthropogenic emissions of both VOC and NOx from the NAPAP Version 5 inventory, (2) biogenic emissions of VOC prepared as part of NAPAP for the Midwest and Southeast, and (3) biogenic emissions of VOC for the Northeast that were developed as part of the NEROS project. These data were processed into a consolidated emissions data base with a grid resolution of 1/6° latitude by 1/4° longitude. Model applications using these emissions will be made during early FY-1987 using meteorological conditions from approximately 30 days during the summer of 1980. The days selected for simulation were chosen based upon (1) the occurrence of high ozone (e.g. concentrations greater than 150 ppb near urban areas and greater than 100 ppb in rural areas), (2) the extent of regional transport as estimated from trajectory analyses, and (3) synoptic scale meteorological conditions. In addition to the high ozone days, several days with moderate to low ozone concentrations have also been identified for simulation in order to permit the extrapolation of the model simulated results to a seasonal time period as needed for the economic benefits analyses.

2.7.1.3 Evaluation of Long-Range Transport Model Performance

The performance of eight short-term, long-range transport models (ARRPA, MESOPLUME, MESOPUFF, MESOPUFF-II, MSPUFF, MTDDIS, RADM, and RTM-II) was evaluated using two data bases. The Oklahoma data base contained two data sets in which the source was located at the ground and the emissions were 3-hour plus releases of perfluorocarbon tracer. The concentration data included detailed spatial measurements of the tracer at 100 km and 600 km arcs with ground level measurements made over a total of 21 time-averaging periods. The measured data were taken as 45-minute averages at the 100 km arc and 3-hour time averages at the 600 km arc. The Savannah River Plant data base contained 15 data sets representing spatial measurements over distances of 28 km to 144 km. There were 13 fixed samplers placed about a 62-m stack emitting a tracer gas, krypton-85. Measurements were made over several 10-hour averaging periods for each data set.

Model performance was evaluated by means of graphical and statistical methods. The primary means of quantifying model performance were the American Meteorological Society statistics (Fox, 1981). A comparison of model predictions with the observed data (Policastro et al., 1986) indicates generally consistent results between the two data bases. The spatial and temporal offsets of the predicted and observed plumes lead to predicted concentrations that correlate poorly with concentrations observed at the same time and place. On average, all models overpredicted pairing in space and time. In contrast, statistical comparisons of the peak values predicted by the models were significantly better. Statistics for highest concentration by event (unpaired by location) revealed an overprediction by most models. Statistics for highest concentration at each station (unpaired in time) also revealed overprediction by most models. The best performance was achieved through unpairing in both space and time using the highest 25 predictions and observations.

The geographical comparison for both data bases indicate that the predicted ground-level plume patterns are frequently offset from the observed patterns by as much as 20-45 degrees. The treatment of the meteorological data within the meteorological preprocessors is the primary factor in this spatial discrepancy. The second most important cause of discrepancies between predicted and observed values is the treatment of plume spreading in the models. This spreading may be viewed as superimposed about the trajectory given by the predicted wind field. In addition, most of the models overpredict ground-level plume concentrations.

2.7.1.4 Performance Evaluation of Complex Terrain Models

A preliminary version of the Complex Terrain Dispersion Model (CTDM) and the COMPLEX I screening model were evaluated and compared. CTDM was supplied to OAQPS with the expectation that OAQPS would respond with respect to (1) the accuracy of the model, (2) its utility as a regulatory model, and (3) changes that would be desirable in the final version. The response is contained in the Complex Terrain Model Development Workshop Report (Lavery et al., 1986).

COMPLEX I is a screening model that is currently used for regulatory applications. In principle, a complex terrain air quality model intended as a regulatory model should perform consistently better than a screening model such as COMPLEX I.

Both models were evaluated using the Cinder Cone Butte (CCB) Modelers Data Archive, and the Westvaco Modelers Data Base. These data sets have been incorporated into the Model Evaluation Support Subsystem (MESS) for model evaluation studies.

The conclusions of the study are as follows:

- In general, CTDM shows better performance than Complex I. CTDM shows almost no bias on the CCB data, and overpredictions on the Westvaco data.
- In general, these results were not noticeably dependent on sampler location (at CCB), source-receptor height differences, hour (except for day-night differences), and probably stability class (except for day-night differences). Both models tended toward underprediction (away from overprediction) with higher wind speeds. CTDM tended to predict more accurately at the nearer samplers at Westvaco, while Complex I predicted more accurately at the more distant ones.
- At the high end of the frequency distribution, Complex I overpredicts while CTDM is unbiased for the Westvaco data set. For the CCB data set, the reverse is true.
- Terrain definition for input to this version of CTDM involves much subjectivity. The effect of this subjectivity on the model results is unknown.
- Most of the critical plume level meteorology required by CTDM must be inferred from data taken at much lower levels.
- It is critical to conduct sensitivity analyses to determine how accurate the various input parameters must be to obtain satisfactory results.

2.7.1.5 Particulate Matter Impact Due to Coal Mines

During FY-1986, research continued on the analysis of pit retention meteorology and the development of algorithms to calculate escape fraction of particles released within open coal mine pits. Data used were collected during the first field study specifically designed to examine meteorological conditions inside mine pits in 1983. A published report (EPA, 1986a) on this project examines the relationship between the meteorological parameters in an effort to refine an existing model algorithm to determine the escape fraction. The analysis of the meteorological data indicates that the horizontal turbulence inside the pit is greater than that outside. It is suspected that this enhanced turbulence is induced by mechanical turbulence as air passes over, and in the wake of, the mine pit walls. The degree to which the in-pit turbulence exceeds that outside increases with wind speed, but is not related to stability class. The research effort resulted in the proposal of four methods, generally increasing in complexity, for incorporating the calculation of escape fraction for particulates into the ISC air quality model. Actual field data, including fugitive dust measurements, are needed to provide an independent evaluation prior to any recommendations for regulatory application.

2.7.1.6 Evaluation and Sensitivity Analysis of Coastal Fumigation Models

The draft final report of the sensitivity analysis of coastal fumigation models has undergone technical review. Based on the reviewer's comments, the final report is being expanded to include methods to characterize the Thermal Internal Boundary Layer (TIBL) from available meteorological data and should be published in FY-1987. Two scientific papers were published by North Carolina State University staff as a result of this study (Stunder and SethuRamen, 1986). This research effort can be divided into two distinct segments. The first phase involved determining the proper TIBL characterization. The TIBL, which usually originates at the land-water interface and grows parabolically inland, is the boundary between stable marine air above and unstable air below. The TIBL parameterization is the most sensitive variable in coastal models. The second phase involved evaluating two coastal point source dispersion models, the Lyons and Cole (1973) and the Misra (1980) models. The Misra model was found to be superior. Additional data bases are needed to test this model before it can be considered for regulatory applications.

2.7.2 Model Guidance

2.7.2.1 Guideline on Air Quality Models (Revised)

Final rulemaking that promulgated the EPA Guideline on Air Quality Models (Revised) (EPA 1986c) was announced in the *Federal Register* on September 9, 1986. The guideline revisions reflect outputs from four primary on-going activities. The first is a series of annual EPA Regional Meteorologists workshops conducted for the purposes of ensuring consistency and providing clarification in the regulatory application of models. The second is the cooperative agreement with the scientific community represented by the American Meteorological Society directed toward the improvement of modeling procedures. This agreement provides scientific assessment of procedures and proposed techniques and sponsors workshops on key technical issues. The third is the solicitation and review of new models from the technical community. After extensive evaluation and scientific review, these models, as well as those made available by EPA, are considered for recognition in the guideline. The fourth is the extensive on-going research efforts in air quality and meteorological modeling and monitoring. In revising the guideline, many of the air quality models recommended for specific regulatory applications were also revised and incorporated in the new UNAMAP Version 6 modeling package. Moreover, EPA held the Third Conference on Air Quality Modeling in 1985 to solicit additional public comments on its proposal. Public interest in the guideline has been very high; about 1,000 copies have been distributed to date to users in this country and abroad.

As a result of the public comment on the revised guideline and EPA's continuing solicitation and review of new models, several new models and/or changes to existing models were identified. A separate *Federal Register* notice on September 9, 1986 announced the technical bases for EPA's proposal to add four new models to the revised modeling guideline.

2.7.2.2 Revisions to Regulatory Air Quality Models

Six "guideline" air quality models frequently used in regulatory applications were revised. These models are CRSTER, MPTER, RAM, ISCST, ISCLT, and CDM 2.0. These revised models are part of the recently issued UNAMAP Version 6. A "regulatory default option" was added to each of the above models. The revisions to the models include a treatment of calms derived from CALMPRO (EPA, 1984), revised urban and rural wind speed profile exponents (EPA, 1980), the option of urban dispersion coefficients as in RAM, treatment of plume trapping in terrain as in MPTER, treatment of receptors in terrain below stack base elevation as in RAM, consistent treatment of momentum plume rise for nonbuoyant plumes, exponential decay (half-life) for sulfur dioxide in urban areas set at four hours, treatment of buoyancy-induced dispersion (BID), and calculation of stack tip downwash. In addition, ISCST and ISCLT were modified to permit calculation of concentrations at receptors less than 100 meters from the source, to be consistent with the other models. ISCLT now treats the first wind speed category as 1.5 meters per second, instead of 0.75 meters per second, to be consistent with CDM 2.0.

To estimate the effects of these revisions, along with revisions to the recommended model option settings as published in the Guideline on Air Quality Models (Revised) (EPA, 1986c), a series of tests were run on these models. The high and high second-high concentrations predicted by these models for point and area sources, with the regulatory default option set, were compared to the corresponding concentrations calculated using the models as they have usually been applied under previous guidance.

The short-term models--CRSTER, MPTER, RAM, and ISCST--give essentially identical results for point sources when run using the regulatory default option. These results are typically within about 15 percent of the results obtained when the models were run according to previous guidance. Concentrations obtained from the area sources range from 15 percent higher to 50 percent lower than under previous guidance. The larger reductions are due to the inclusion of the automatic calms processing algorithm in the models.

Long-term model results using ISCLT are within about ± 20 percent of those obtained using previous guidance. CDM 2.0, however, shows much larger increases due to the recent inclusion of the RAM urban dispersion coefficients in CDM. These coefficients were already in use in the earlier versions of the other models compared in this study. Concentrations calculated from area sources showed changes of less than ± 20 percent for ISCLT and reductions of as much as 25 percent for CDM 2.0.

Changes in concentrations for building wake effects using ISCST were within ± 30 percent. This is based on receptors at distances of 800 meters and beyond. Higher values can be expected at distances less than 100 meters, since both ISC models will now calculate concentrations at distances of less than 100 meters from a source.

2.7.2.3 National Air Audit System: Program Effectiveness in Modeling

The EPA delegated many of its functions to the State and local agencies, including the responsibility, and sometimes the final authority, for conducting the requisite air quality dispersion modeling associated with permits and State Implementation Plans (SIPs). With these delegations EPA took on an oversight role of the State/local agency actions. This is accomplished through annual audits of the State/local agency actions. In each audit a series of questions is asked to determine how well the agency is carrying out its responsibilities. Specific questions are designed to determine the State/local agencies' capabilities to perform dispersion modeling as well as how the individual modeling analyses are performed.

During FY-1986 assistance was provided to the National Air Audit Program for the National Air Audit System FY-1985 National Report (EPA, 1985). This report summarizes EPA's audits conducted during FY-1985 and covers modeling analysis done by the State/local agencies during FY-1983. A major difficulty that was overcome in writing the 1985 report involved interpreting the answers from 66 agencies to five major audit questions on modeling and arriving at meaningful conclusions. Contractual assistance was used to summarize, in statistical form, the nature of the responses to each question. Then assistance was provided to the contractor on writing interpretations of these statistics. The final results of these activities indicated that most agencies are knowledgeable and capable of performing and reviewing most routine modeling analyses. However, the State/local agencies generally did not follow EPA procedures in using non-guideline models. The agencies also appeared to have problems in implementing EPA modeling guidance for sophisticated models, as approximately one-third of all modeling analyses submitted to EPA had to be returned for revisions. Modeling analyses for emission trades ("bubbles") were worse than the average, with over four-fifths being returned to the States. It is interesting to note that modeling analyses (all types) performed by industry and submitted to the State/local agencies for concurrence had a similar revision rate of approximately one-third; bubble modeling had a higher return rate of two-thirds.

It is anticipated that the issuance of the revised EPA modeling guideline, and the increasing availability of updated modeling training courses will ease the overall implementation problems currently affecting State/local agencies. The modeling efforts associated with bubble analyses appear incomplete, however. This indicates that more advance interaction is needed among sources, States, and EPA before any modeling provisions of a "generic" bubble rule can be made workable.

A second activity of the audit program involved writing and redesigning questions for the FY-1986-87 audits. The primary emphasis was on improving the clarity of the questions and in focusing the questions on problem areas that were evident from the earlier audits.

2.7.2.4 On-Site Meteorological Data Guidance

In December 1985, a workgroup was formed to prepare a guidance document on the collection, processing, and use of on-site meteorological data in support of regulatory modeling applications. The group is chaired by a meteorologist and its membership includes representatives from four EPA Regional Offices, the State of New York, and a private contractor.

The workgroup held its first meeting on January 22-23, 1986 in Chicago, Illinois. A draft document covering the single variable of wind speed was presented at the Regional/State Modelers Workshop in April 1986. A complete draft document was submitted to the EPA Regional Offices for review in August 1986. The draft document covers siting and exposure, data recording, processing and reporting, quality assurance, and maintenance for the variables of wind speed, wind direction, temperature, temperature difference, dewpoint, precipitation, pressure, and solar radiation. The document also includes a separate section covering these topics for the use of Doppler SODAR to collect elevated wind speed and direction. The document will be published in FY-1987. A paper providing an overview of this emerging on-site meteorological data guidance will be presented at the Sixth Symposium on Meteorological Observations and Instrumentation to be held during January 1987 in New Orleans.

Work was begun on development of ONMET, the on-site meteorological data processor for existing regulatory models. ONMET will be an expanded version of the MPDA-1 code (Paumier et al., 1986), and will produce the same type of output as the existing RAMMET preprocessor for National Weather Service data. ONMET is scheduled to be made available in FY-1987, in conjunction with the on-site meteorological data guidance document.

2.7.2.5 Model Clearinghouse

The FY-1986 activities for the Model Clearinghouse included:

1. Responding to EPA Regional Office requests for review of non-guideline models proposed for use.
2. Reviewing State Implementation Plan submittals
3. Documenting Clearinghouse decisions and discussions
4. Summarizing Clearinghouse activities at various meetings
5. Issuing, internally, a summary report of activities for FY-1985
6. Issuing, externally, a summary report of activities for FY-1981-85 (EPA, 1986b)
7. Visiting four Regional Offices for the purpose of coordinating Model Clearinghouse issues, activities and future plans.

During FY-1986 there were a total of 99 modeling issues referred to the Model Clearinghouse from the Regional Offices requiring approximately 13 person-months to respond. Nineteen of these issues required a written response; 73 issues received an oral response or were outside the purview of the Clearinghouse; and seven issues involved only the EPA staff.

During FY-1986 the Clearinghouse conducted or participated in a number of activities that involved coordination and information exchanges with the Regional Offices. One of the first activities was to prepare and distribute to the Regional Offices in October the Clearinghouse annual report, which served as a "newsletter," informing Clearinghouse users about the issues and requests which occurred in FY-1985. The Clearinghouse continued its policy of sending copies of its written responses (along with incoming requests) to all the Regional Offices keeping them aware of decisions made that may affect some of their modeling activities.

The Model Clearinghouse policy is to request comments from the Regions on particularly sensitive issues with national implications. During FY-1986 two such cases arose, both involving referrals from Region IV. In each case the proposed Clearinghouse response, containing a detailed description of the issue and its risks, was sent to all the Regions for comment before the response was finalized.

At the Regional and State Modelers Workshop in April 1986 the Clearinghouse distributed a list of significant issues referred to the Clearinghouse in the first six months of the fiscal year. At the Southern Pines workshop in July 1986, a general presentation was made describing the operation of the Clearinghouse. The nature of problems referred to the Clearinghouse and their method of resolution were also described.

During June and July 1986, the Clearinghouse began a series of visits to the ten Regional Offices. Regions I, II, III, and V were visited. Similar to the visits that took place in 1981-82, the primary objective of the meetings was to gather information on the historical usage of models by the Regional Offices and to identify current and upcoming modeling problems which may come to the attention of the Clearinghouse. A secondary purpose was to communicate information to the Regions on the operation of the Clearinghouse.

A report (EPA, 1986b), prepared by APSB personnel, summarizes the activities of the EPA Model Clearinghouse during its first five years of operation. Included are a summary of the number of cases and the nature of issues reviewed by the Clearinghouse, a description of major recurring and generic issues referred to the Clearinghouse, and a series of example cases illustrating the various modes of operation of the Clearinghouse.

A total of 306 significant issues were referred to the Model Clearinghouse by the ten EPA Regional Offices during the five-year period. A majority of the referrals involved the modeling of SO_2 and TSP emissions from power plants, power boilers and other large point sources for purposes of setting emission limits. Many of the referrals involved the proposed application of nonguideline models in complex terrain. An additional 217 proposed *Federal Register* actions containing modeling analyses were reviewed by the Clearinghouse for completeness and adherence to policy.

Coordination of Clearinghouse issues with the ten Regional Offices was accomplished through the preparation of annual summary reports, presentations at annual meetings, visits to the Regional Offices, and the distribution of various memoranda and reports that document Clearinghouse opinions and determinations.

Major recurring or generic issues with which the Clearinghouse dealt include performance evaluations, modeling of large numbers of sources, multisource modeling to determine net prevention of significant deterioration (PSD) increment consumption, and modeling the impacts of point sources on tall buildings. The resolution of issues dealing with generic modeling guidelines, composite wind roses, long range transport, and the effective date of modeling guidance was also undertaken.

Four case examples illustrating several procedures used by the Clearinghouse to resolve issues are described. Three of the examples involved a Regional Office asking for an advance opinion on the use of a modeling technique or data base for an impending regulatory action. The fourth example involved consideration of modeling issues inherent in a proposed regulation that was undergoing internal review before publication in the *Federal Register*.

2.7.3 Additional Support Activities

Technical support was provided for the expansion of the Model Evaluation Support System (MESS) to include data bases from tracer studies, the EPRI Plains Site (Kincaid Power Plant), and complex terrain sites, Cinder Cone Butte and Westvaco Lake Mill Plant. This system provides a structure for handling those data bases that will be used for planned in-house performance evaluations of air quality models. Two specific evaluations were made possible by the expansion of the MESS. These were the evaluation of complex terrain models described above and evaluation of the TUPOS model in which the Meteorological Processor Diffusion Analysis (MPDA) (Paumier et al., 1986) was also tested using data collected around the Clifty Creek power plant near Madison, IN. The statistical results from TUPOS were compared with those from the MPTER model. Some apparent discrepancies were noted between the 10 meter meteorological data input to MPDA and 10 meter values output. MPDA was revised since this study was conducted. TUPOS performed poorly in this evaluation. As a result, TUPOS was revised to eliminate identified deficiencies.

A workshop for information exchange with the Regional Meteorologists and Modeling Contacts was held in Philadelphia, Pennsylvania, April 15-18, 1986. Meteorologists from the States of Florida, Illinois, New York and Oregon also participated. Special emphasis was placed on ADP issues and computer support, the Complex Terrain Dispersion Model Program, air toxics and draft guidance on on-site meteorological data.

A number of task groups were formed to develop or revise existing regulations and programs or generate sound technical options and potential positions on key issues facing policy-makers, which include: (1) the Work Group to Revise the Modeling Guideline; (2) the Technology Transfer Work Group; (3) the Emissions Trading Policy Work Group; (4) the Visibility SIP Work Group; (5) the Stack Height Remand Task Force; (6) the GEP Stack Height Emissions Balancing Work Group (until September 1986); (7) On-site Meteorological Data Work Group; and (8) the OMNYMAP Technical Review Committee.

3. REFERENCES

Alkezweeny, A.J. A study of the formation and transport of acidic species by non-precipitating cumulus clouds during VENTEX-84. EPA/600/3-86/039 (PB86-220357), Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, 32 pp. (1986).

Barchet, R. Draft Chairman's report: Workshop on field study design for regional scale acid deposition model evaluation. Electric Power Research Institute, Seattle, WA, (1986).

Briggs, G.A. Analytical parameterizations of diffusion: The convective boundary layer. *Journal of Climate and Applied Meteorology* 24: 1167-1186 (1985).

Catalano, J.A. Addendum to the users manual for single source (CRSTER) model. EPA/600/8-86/041, Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, 138 pp. (1986).

Chico, T., and J.A. Catalano. Addendum to the user's guide for MPTER. EPA/600/8-86/021, Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, 80 pp. (1986).

Ching, J.K.S., and A.J. Alkezweeny. Vertical transport by cumulus clouds. Preprints, Seventh Symposium on Turbulence and Diffusion, November 12-15, 1985, Boulder, Colorado. American Meteorological Society, Boston, 63-66 (1985).

Coulson, K.L. *Solar and Terrestrial Radiation*. Academic Press, Inc., New York, NY, 92-93 (1975).

Cramer, H.E. Improved techniques for modeling the dispersion of tall stack plumes. Proceedings of the Seventh International Technical Meeting on Air Pollution Modeling and Its Application, Arlie, Virginia, September 1976, No. 51, (PB-270799), NATO/CCMS, 731-780 (1976).

Deardorff, J.W. Laboratory experiments on diffusion: The use of convective mixed-layer scaling. *Journal of Climate and Applied Meteorology* 24: 1143-1151 (1985).

Demerjian, K.L. Quantifying uncertainty in long-range transport models: A summary of the AMS workshop on sources and evaluation of uncertainty in long-range transport models, Woods Hole, Massachusetts, September 18-21, 1984. *Bulletin of the American Meteorological Society* 66: 1533-1540 (1985).

De Wispelaere, C., F.A. Schiermeier, and N.V. Gillani (editors). *Fifteenth NATO/CCCM International Technical Meeting on Air Pollution Modeling and Its Application Volume 8*. Plenum Publishing Company, London, England (in press) (1986).

DiCristofaro, D.C., D.G. Strimaitis, B.R. Greene, R.J. Yamartino, A. Venkatram, D.A. Godden, T.F. Lavery, and B.A. Egan. EPA complex terrain model development program: Fifth milestone report - 1985. EPA/600/3-85/069, Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, 277 pp. (1986).

Draxler, R.R. Determination of atmospheric diffusion parameters. *Atmospheric Environment* 10: 99-105 (1976).

Droppo, J.G. The Hanford 67 series: Atmospheric field diffusion measurements - Micrometeorological and tracer data archive set 003. Documentation Report. EPA/600/3-86/059, Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, 49 pp. (1986a).

Droppo, J.G. Development of a micrometeorological and tracer data archive. EPA/600/3-86/053, Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, 18 pp. (1986b).

Droppo, J.G., Jr., and C.R. Watson. Introduction to micrometeorological and tracer data archive procedures. EPA-600/3-85/053, Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, 58 pp. (1985).

Durham J., R. Dennis, N. Laulainen, D. Renne, W. Pennell, R. Barchet, and J. Hales. Regional Eulerian field study and evaluations: Proposed management and technical approaches. Internal Report, Office of Acid Deposition, Environmental Monitoring and Quality Assurance, ORD, U.S. Environmental Protection Agency, Washington, DC, (1986).

Eder, B.K., D.H. Coventry, T.L. Clark, and C.E. Bollinger. RELMAP: A Regional Lagrangian Model of Air Pollution user's guide. EPA/600/8-86/013, Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, 125 pp. (1986).

Environmental Protection Agency. Continued analysis and derivation of a method to model pit retention. EPA-450/4-86-003, Office of Air Quality Planning and Standards, Research Triangle Park, NC, 133 pp. (1986a).

Environmental Protection Agency. Activities of the EPA model clearinghouse, a summary report: FY81-FY85. EPA-450/4-86-006, Office of Air Quality Planning and Standards, Research Triangle Park, NC, 48 pp. (1986b).

Environmental Protection Agency. Guideline on air quality models (Revised). EPA-450/2-78-027R, Office of Air Quality Planning and Standards, Research Triangle Park, NC, 290 pp. (1986c).

Environmental Protection Agency. National air audit system FY-1985 national report. EPA-450/2-85-009, Office of Air Quality Planning and Standards, Research Triangle Park, NC, 129 pp. (1985).

Environmental Protection Agency. Calms processor (CALMPRO) user's guide. EPA- 901/9-84-001, U.S. Environmental Protection Agency, Region I, Boston, MA, 45 pp. (1984).

Environmental Protection Agency. Recommendations on modeling (October 1980 Meetings). Appendix G: Summary of comments and responses on the October 1980 proposed revisions to the guideline on air quality models. Meteorology and Assessment Division, Office of Research and Development, Research Triangle Park, NC, 1-5 (1980).

Finkelstein, P.L. The spatial analysis of acid precipitation data. *Journal of Climate and Applied Meteorology* 23: 52-62 (1983).

Fox, D.G. Judging air quality model performance. *Bulletin of the American Meteorological Society* 62:599-609 (1981).

Gifford, F.A., Jr. Turbulent diffusion - typing schemes: A Review. *Nuclear Safety* 17: 68-86 (1976).

Gifford, F.A., Jr. Use of routine meteorological observations for estimating atmospheric dispersion. *Nuclear Safety* 2: 47-57 (1961).

Glantz, C.S., R.K. Woodruff, and J.G. Droppo. The Hanford 1964 atmospheric boundary layer experiment. Micrometeorological and tracer data archive. EPA-600/3-85/055, Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, 24 pp. (1985).

Hunt, J.C.R. Diffusion in the stably stratified atmospheric boundary layer. *Journal of Climate and Applied Meteorology* 24: 1187-1195 (1985).

Hunt, J.C.R., and P.J. Mulhearn. Turbulent dispersion from sources near two-dimensional obstacles. *Journal of Fluid Mechanics* 61: 245-274 (1973).

Irwin, J.S. Estimating plume dispersion - a comparison of several sigma schemes. *Journal of Climate and Applied Meteorology* 22: 92-114 (1983).

Irwin, J.S., T. Chico ,and J. Catalano. CDM-2.0: Climatological dispersion model -- User's guide. EPA/600/8-85/029, Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, 148 pp. (1985).

Kaimal, J.C., W.L. Eberhard, W.R. Moninger, J.E. Gaynor, S.W. Troxel, T. Uttal, G.A. Briggs, and G. E. Start. Project CONDORS - convective diffusion observed by remote sensors. EPA/600/3-86/040, Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, 305 pp. (1986).

Lamb, R.G. Numerical simulations of photochemical air pollution in the northeastern United States: ROMl applications. EPA/600/3-86/038 (PB86-219201), Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, 162 pp. (1986).

Larsen, R.I., and W.W. Heck. An air quality data analysis system for interrelating effects, standards, and needed source reductions: Part 9. Calculating effective ambient air quality parameters. *Journal of the Air Pollution Control Association* 35: 1274-1279 (1985).

Larsen, R.I., and W.W. Heck. An air quality data analysis system for interrelating effects, standards, and needed source reductions: Part 8. An effective mean O_3 crop reduction mathematical model. *Journal of the Air Pollution Control Association* 34: 1023-1034 (1984).

Lavery, T.F., A. Bass, D.G. Strimaitis, A. Venkatram, B.R. Greene, P.J. Drivas, and B.A. Egan. EPA complex terrain model development program: First milestone report - 1981. EPA-600/3-82/036, Environmental Sciences Research Laboratory, Research Triangle Park, NC, 304 pp. (1982)

Lavery, T.F., D.J. Strimaitis, and B.A. Egan. A workshop report on the complex terrain model development project (February 4-6, 1986). EPA/600/9-86/026, Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, 86 pp. (1986).

Lavery, T.F., D.G. Strimaitis, A. Venkatram, B.R. Greene, D.C. DiCristofaro, and B.A. Egan. EPA complex terrain model development program: Third milestone report - 1983. EPA-600/3-83/101, Environmental Sciences Research Laboratory, Research Triangle Park, NC, 291 pp. (1983).

Lawson, R.E., Jr., and W.H. Snyder. Stack heights and locations in complex terrain. Preprints, Seventh Symposium on Turbulence and Diffusion, November 12- 15, 1985, Boulder, Colorado. American Meteorological Society, Boston, 223-226 (1985).

Lee, J.T., R.E. Lawson, Jr. and G.L. Marsh. Flow visualization experiments on stably stratified flow over ridges and valleys. Preprints, Third International Workshop on Wind and Water Tunnel Modeling of Atmospheric Flow and Dispersion, September 1986, Lausanne, Switzerland (1986).

Lee, J.T., G.L. Stone, R.E. Lawson, Jr. and M.S. Shipman. Monte Carlo simulation of two-particle relative diffusion using Eulerian statistics. *Atmospheric Environment* 20: 2185-2197 (1986).

Lyons, W.A., and H.S. Cole. Fumigation and plume trapping on the shores of Lake Michigan during stable onshore flow. *Journal of Applied Meteorology* 21: 494-510 (1973).

McHugh, J., J. Pierce, D. Rich, J. Dunham, D. McLin, and N. Kanopoulos. A computer architecture for research in meteorology and atmospheric chemistry. Research Triangle Institute, Research Triangle Park, NC, 121 pp. (1986).

Mills, M.T., R.J. Paine, and B.A. Egan. The complex terrain dispersion model (CTDM) terrain preprocessor program - program description and user's guide. Environmental Research and Technology, Inc., Cambridge, MA, (1986).

Misra, P.K. Dispersion from tall stacks into a shoreline environment. *Atmospheric Environment* 16: 239-243.

Morris, R.E., C. Daly, D.A. Latimer, and M.K. Liu. Review and selection of an appropriate acid deposition model for the Rocky Mountain region. Draft report prepared by Systems Applications, Inc., San Rafael, CA, 99 pp. (1986b).

Morris, R.E., C.H. Yu, G.E. Moore, and D.A. Latimer. Review and selection of appropriate mesoscale meteorological models for information into a Rocky Mountain acid deposition model. Draft report prepared by Systems Applications, Inc., San Rafael, CA, 75 pp. (1986a).

National Center for Atmospheric Research. Preliminary evaluation studies with the regional acid deposition model (RADM). NCAR-TN-265+STR, National Center for Atmospheric Research, Boulder, CO, 198 pp. (1986).

National Center for Atmospheric Research. The NCAR Eulerian acid deposition model. NCAR-TN-256+STR, National Center for Atmospheric Research, Boulder, CO, 178 pp. (1985).

National Center for Atmospheric Research. Regional acid deposition: Design and management plan for a comprehensive modeling system. NCAR/TN-215+PPR, National Center for Atmospheric Research, Boulder, CO, 33 pp. (1983a).

National Center for Atmospheric Research. Regional acid deposition: Models and physical processes. NCAR/TN-214+STR, National Center for Atmospheric Research, Boulder, CO, 386 pp. (1983b).

Olsen, A.R. Regional model evaluation quality assurance workshop: Chairman's report. Ontario Ministry of the Environment, Toronto, Canada (1986).

Paumier, J., D. Stinson, T. Kelly, C. Bollinger, and J.S. Irwin. MPDA-1: A meteorological processor for diffusion analysis - User's guide. EPA/600/8-86/011, Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, 190 pp. (1986).

Pennell, W.T. Workshop on model evaluation protocols: Chairman's report. February 11-13, 1986. Atmospheric Science Research Laboratory, Research Triangle Park, NC, 21 pp. (1986).

Perry, S.G., and F.A. Schiermeier. The EPA complex terrain model: Theoretical basis and performance evaluation. Proceedings, WMO Conference on Air Pollution and Its Application, Leningrad, USSR, May 1986. WMO, Geneva, 20 pp. (1986).

Petersen, W.B., and L.G. Lavadas. INPUFF - 2.0 - A multiple-source Gaussian puff dispersion algorithm - User's guide. EPA/600/8-86/024, Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, 105 pp. (1986).

Pierce, T.E. An efficient algorithm for determining non-overlapping running averages. *Environmental Software* 1: 124-127 (1986).

Pierce, T.E., D.B. Turner, J.A. Catalano, and F.V. Hale III. PTPLU - A single source Gaussian dispersion algorithm - User's guide. EPA-600/8-82-014, Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, 110 pp. (1982).

Policastro, A.J., M. Wastag, L. Coke, R.A. Carhart, and W.E. Dunn. Evaluation of short-term long-range transport models. EPA-450/4-86-016, Office of Air Quality Planning and Standards, Research Triangle Park, NC, 450 pp. (1986).

Rao, K.S. Analytical solutions of a gradient-transfer model for plume deposition and sedimentation. EPA-600/3-82-079, Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, 75 pp. (PB82-215 153) (1982).

Richter, H.G., F.F. McElroy, and V.L. Thomson. Measurement of ambient NMOC concentrations in 22 cities during 1984. Proceedings of the 78th Annual Meeting of the Air Pollution Control Association, Detroit, Michigan, June 1985. Air Pollution Control Association, Pittsburgh (1985).

Ritter J.A., and D.H. Stedman. The vertical redistribution of a pollutant tracer due to cumulus convection. EPA/600/3-85/0/0 (PB85-172-971), Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, 157 pp. (1985).

Sawford, B.L. Lagrangian statistical simulation of concentration mean and fluctuation fields. *Journal of Climate and Applied Meteorology* 24:1152-1166 (1985).

Schere, K.L. EPA Regional Oxidant Model: ROM1 evaluation for 3-4 August 1979. EPA/600/3-86/032, Atmospheric Sciences Research Labortory, Research Triangle Park, NC, 131 pp. (1986).

Schiermeier, F.A. Operational and diagnostic evaluation of regional acid deposition models. Ninth Meeting of US/Japan Air Pollution Meteorology Panel, Japan Meteorological Agency, Tokyo, Japan. (1986a).

Schiermeier, F.A. Mathematical concepts and fluid modeling simulations of dividing-streamline height in complex terrain. Ninth Meeting of US/Japan Air Pollution Meteorology Panel, Japan Meteorological Agency, Tokyo, Japan. (1986b).

Schiermeier, F.A. Development of regional acid deposition models for evaluation of emission control strategies. US/USSR Project Meeting on Air Pollution Modeling and Standard Setting, Main Geophysical Observatory, Leningrad, USSR. (1986c).

Schiermeier, F.A., and P.K. Misra. Evaluation of eight linear regional-scale sulfur models by the Regional Modeling Subgroup of the United States/Canadian Memorandum of Intent Work Group 2. In, *Transaction, APCA International Specialty Conference on the Meteorology of Acidic Deposition*. Air Pollution Control Association, Pittsburgh, 330-345 (1983).

Scire, J.S., F.W. Lurmann, A. Bass, and S.R. Hanna. User guide to the MESOPUFF II model and related processor programs. EPA/600/8-84/013, Environmental Sciences Research Laboratory, Research Triangle Park, NC, 214 pp. (1984).

Sheih, C.M., M.L. Weseley, and C.J. Walcek. A dry deposition module for regional acid deposition. EPA/600/3-86/037 (PB86-218 104), Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, 63 pp. (1986).

Singer, I.A., and M.E. Smith. Relation of gustiness to other meteorological parameters. *Journal of Meteorology* 10: 121-126 (1953).

Snyder, W.H. Comparisons of CTDM calculations with fluid modeling observations. Complex Terrain Workshop, Research Triangle Park, NC, February 4-6, 1986, 45 pp. (1986).

Strimaitis, D.G., T.F. Lavery, A. Venkatram, D.C. DiCristofaro, B.R. Greene, and B.A. Egan. EPA complex terrain model development program: Fourth milestone report - 1984. EPA/600/3-84/110, Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, 319 pp. (1985).

Strimaitis, D.G., A. Venkatram, B.R. Greene, S. Hanna, S. Heisler, T.F. Lavery, A. Bass, and B.A. Egan. EPA complex terrain model development program: Second milestone report - 1982. EPA/600/3-83/015, Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, 375 pp. (1983).

Stunder, M., and S. SethuRaman. A statistical evaluation and comparison of coastal point source dispersion models. *Atmospheric Environment* 20: 301-315 (1986).

Truppi, L.E. Complex terrain model development: Description of a computer data base from the Full Scale Plume Study, Tracy, Nevada. EPA/600/3-86/068, Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, 105 pp. (1986).

Turner, D.B. A user-friendly screening model for point-source impact assessment. Proceedings of the 79th Annual Air Pollution Control Association Meeting, Minneapolis, Minnesota, June 1986. Air Pollution Control Association, Pittsburgh, 14 pp. (1986a).

Turner, D.B. Addendum to TUPOS - Incorporation of a hesitant plume algorithm. EPA/600/8-86/027, Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, 34 pp. (1986b).

Turner, D.B. Workbook of atmospheric dispersion estimates. Office of Air Programs Publication No. AP-26 (PB-191482), U.S. Environmental Protection Agency, Research Triangle Park, NC, 84 pp. (1970).

Turner, D.B., and L.W. Bender. Description of UNAMAP (Version 6). EPA/600/M-86/027, Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, 26 pp. (1986).

Turner, D.B., T. Chico, and J.A. Catalano. TUPOS -- A multiple source Gaussian dispersion algorithm using on-site turbulence data. EPA/600/8-86/010, Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, 171 pp. (1986a).

Turner, D.B., T. Chico, and J.A. Catalano. TUPOS-P -- A program for analyzing hourly and partial concentration files produced by TUPOS. EPA/600/8-86/012, Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, 106 pp. (1986b).

van Ulden, A.P., and A.A.M. Holtslag. Estimation of atmospheric boundary layer parameters for diffusion applications. *Journal of Climate and Applied Meteorology* 24:1196-1207 (1985).

Vukovich, F.M., and J.K.S. Ching. Modeling transport by convective clouds for regional air pollution models. Preprints, Seventh Symposium on Turbulance and Duffusion, November 12-15, 1985, Boulder, Colorado. American Meteorological Society, Boston, 3-6 (1985).

Weil, J.C. Updating applied diffusion models. *Journal of Climate and Applied Meteorology* 24:1111-1130 (1985).

Weil, J.C. Evaluation of the Gaussian plume model at Maryland power plants. PPSP-MP-16, Maryland Power Plant Siting Program, Martin Marietta Corporation, Baltimore, MD, (1977).

Wiscombe, W.J., and J.W. Evans. Exponential-sum fitting of radiative transmission functions. *Journal of Computational Physics* 24:416-444 (1977).

Woodruff, R.K., J.G. Droppo, and C.S. Glantz. The Minnesota 1973 atmospheric boundary layer experiment. Micrometeorological and tracer data archive. EPA/600/3-85/054, Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, 21 pp. (1985).

Wyngaard, J.C. Structure of the planetary boundary layer and implications for its modeling. *Journal of Climate and Applied Meteorology* 24:1131-1142 (1985).

Zak, B., H. Church, E. Litchfield, and M. Ivey. Development of an adjustable buoancy balloon tracer of atmospheric motion, Phase II: Development of an operational prototype. EPA/600/3-86/050, Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, 129 pp. (1986).

APPENDIX A: METEOROLOGY DIVISION PUBLICATIONS

Briggs, G.A. Analytical parameterizations of diffusion: The convective boundary layer. *Journal of Climate and Applied Meteorology* 24: 1167-1186 (1985).

Chico, T., and J.A. Catalano. Addendum to the user's guide for MPTER. EPA/600/8-86/021, Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, 80 pp. (1986).

Ching, J.K.S., and A.J. Alkezweeny. Vertical transport by cumulus clouds. Preprints, Seventh Symposium on Turbulence and Diffusion, November 12-15, 1985, Boulder, Colorado. American Meteorological Society, Boston, 63-66 (1985).

Ching, J.K.S., J.H. Novak, F.A. Schiermeier, and K.L. Schere. Reconciliation of urban emissions and corresponding ambient air concentrations of VOC and NO_x using mass flow rate techniques. U.S. Environmental Protection Agency, Office of Research and Development, Research Triangle Park, NC, 59 pp. (1986).

Clark. T.L., R.L. Dennis, D. Palka, M.P. Olson, and E.C. Voldner. Effects of gridded precipitation bias on wet deposition predictions. Proceedings of the 79th Annual Meeting of the Air Pollution Control Association, Minneapolis, Minnesota, June 1986. Air Pollution Control Association, Pittsburgh, (1986).

Clarke, J.F., F.S. Binkowski, J.K.S. Ching, and J.M. Godowitch. The length scale of turbulence above rough surfaces. Preprints, Seventh Symposium on Turbulence and Diffusion, November 12-15, 1985, Boulder, Colorado. American Meteorological Society, Boston, 207-210 (1985).

Demerjian, K.L. Quantifying uncertainty in long-range transport models: A summary of the AMS Workshop on Source and Evaluation of Uncertainty in Long-Range Transport Models, Woods Hole, Massachusetts, September 11-21, 1984. *Bulletin of the American Meteorological Society* 66: 1533-1540 (1985).

Dennis, R.L., M.C. Dodge, and S.K. Seilkop. Conceptual design and chemical data needs for evaluation of regional acidic deposition models. Proceedings of the 79th Annual Meeting of the Air Pollution Control Association, Minneapolis, Minnesota, June 1986. Air Pollution Control Association, Pittsburgh, paper no. 86-29.6 (1986).

Droppo, J.G. Development of a micrometeorological and tracer data archive. EPA/600/3-86/053, Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, 18 pp. (1986).

Droppo, J.G. The Hanford 67 series: Atmospheric field diffusion measurements - Micrometeorological and tracer data archive set 003. Documentation Report. EPA/600/3-86/059, Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, 49 pp. (1986).

Eberhard, W.L., W.R. Moninger, T. Uttal, S.W. Troxel, J.E. Gaynor, and G.A. Briggs. Field measurements in three dimensions of plume dispersion in the highly convective boundary layer. Preprints, Seventh Symposium on Turbulence and Diffusion, November 12-15, 1985, Boulder, Colorado. American Meteorological Society, Boston, 115-118 (1985).

Eder, B.K., D.H. Coventry, T.L. Clark, and C.E. Bollinger. RELMAP: A Regional Lagrangian Model of Air Pollution user's guide. EPA/600/8-86/013, Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, 125 pp. (1986).

Environmental Protection Agency. Continued analysis and derivation of a method to model pit retention. EPA-450/4-86-003, Office of Air Quality Planning and Standards, Research Triangle Park, NC, 133 pp. (1986).

Environmental Protection Agency. Activities of the EPA model clearinghouse, a summary report: FY81-FY85. EPA-450/4-86-006, Office of Air Quality Planning and Standards, Research Triangle Park, NC, 48 pp. (1986).

Eskridge, R.E., and S.T. Rao. Turbulent diffusion behind vehicles: Experimentally determined turbulence mixing parameters. *Atmospheric Environment* 20: 851-860 (1986).

Godowitch, J.M. Characteristics of vertical turbulent velocities in the urban convective boundary layer. *Boundary Layer Meteorology* 35: 387-407 (1986).

Huber, A.H., and S.P.S. Arya. An investigation of transient aspects of atmospheric dispersion processes in the wake of a building through video image analysis. Preprints, Seventh Symposium on Turbulence and Diffusion, November 12- 15, 1985, Boulder, Colorado. American Meteorological Society, Boston, 18-21 (1985).

Irwin, J.S., T.M. Asbury, and W.B. Petersen. Description of the Savannah River Laboratory meteorological data base for 1975 to 1979. EPA/600/3-86/017, Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, 126 pp. (1986).

Irwin, J.S., T. Chico and J. Catalano. CDM-2.0: Climatological dispersion model -- User's guide. EPA/600/8-85/029, Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, 148 pp. (1985).

Kaimal, J.C., W.L. Eberhard, W.R. Moninger, J.E. Gaynor, S.W. Troxel, T. Uttal, G.A. Briggs, and G.E. Start. Project CONDORS - convective diffusion observed by remote sensors. EPA/600/3-86-040, Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, 305 pp. (1986).

Ku, J., and K.S. Rao. Evaluation of the PEM-2 using the 1982 Philadelphia Aerosol Field Study data base. EPA/600/3-86/016, Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, 90 pp. (1986).

Lamb, R.G. Numerical simulations of photochemical air pollution in the northeastern United States: ROMl applications. EPA/600/3-86/038 (PB86-219201), Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, 162 pp. (1986).

Lamb, R.G., and S.K. Hati. Applications of decision theory techniques in air pollution modeling. EPA/600/S3-86/036 (PB86-216793), Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, 74 pp. (1986).

Larsen, R.I., and W.W. Heck. An air quality data analysis system for interrelating effects, standards, and needed source reductions: Part 9. Calculating effective ambient air quality parameters. *Journal of the Air Pollution Control Association* 35: 1274-1279 (1985).

Lawson, R.E., Jr., and W.H. Snyder. Stack heights and locations in complex terrain. Preprints, Seventh Symposium on Turbulence and Diffusion, November 12- 15, 1985, Boulder, Colorado. American Meteorological Society, Boston, 223-226 (1985).

Lee, J.T., R.E. Lawson, Jr. and G.L. Marsh. Flow visualization experiments on stably stratified flow over ridges and valleys. Proceedings, Third International Workshop on Wind and Water Tunnel Modeling of Atmospheric Flow and Dispersion, September 1986, Lausanne, Switzerland (1986).

Lee, J.T., G.L. Stone, R.E. Lawson, Jr. and M.S. Shipman. Monte Carlo simulation of two-particle relative diffusion using Eulerian statistics. *Atmospheric Environment* 20: 2185-2197 (1986).

Lee, J.T., G.L. Stone, R.E. Lawson, Jr. and M.S. Shipman. Monte Carlo simulation of two-particle diffusion using Eulerian statistics. Preprints, Seventh Symposium on Turbulence and Diffusion, November 12-15, 1985, Boulder, Colorado. American Meteorological Society, Boston, 96-99 (1985).

Lusis, M.A., W.H. Chan, P.K. Misra, E.C. Voldner, R.J. Vet, A.R. Olsen, D. Bigelow, and T.L. Clark. A unified wet deposition data base for eastern North America: Data screening and calculation procedures and results. Proceedings of the 79th Annual Meeting of the Air Pollution Control Association, Minneapolis, Minnesota, June 1986. Air Pollution Control Association, Pittsburgh, paper no. 86-29.1 (1986).

Novak, J.H., and P. Middleton. Application of the NAPAP Emission Inventories to Eulerian Modeling. Proceedings: Second Annual Acid Deposition Emissions Inventory Symposium (November 1985). EPA/600/9-86/010, Air and Energy Engineering Research Laboratory, Research Triangle Park, NC, 55-60 (1985).

Novak, J.H., and J.A. Reagan. A comparison of natural and man-made hydrocarbon emission inventories necessary for regional acid deposition and oxidant modeling. Proceedings of the 79th Annual Meeting of the Air Pollution Control Association, Minneapolis, Minnesota, June 22-27, 1986. Air Pollution Control Association, Pittsburgh, 18 pp. (1986).

Paumier, J., D. Stinson, T. Kelly, C. Bollinger, and J. Irwin. MPDA-l: A meteorological processor for diffusion analysis – User's guide. EPA/600/8-86/011, Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, 192 pp. (1986).

Perry, S.G., and F.A. Schiermeier. The EPA complex terrain model: Theoretical basis and performance evaluation. Proceedings, WMO Conference on Air Pollution and Its Application, Leningrad, USSR, May 1986. World Health Organization, Geneva, Switzerland, 20 pp. (1986).

Petersen, W.B. A demonstration of INPUFF with the MATS data base. *Atmospheric Environment* 20: 1341-1346 (1986).

Petersen, W.B., and L.G. Lavadas. INPUFF - 2.0 – A multiple-source Gaussian puff dispersion algorithm - User's guide. EPA/600/8-86/024, Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, 105 pp. (1986).

Pierce, T.E. An efficient algorithm for determining non-overlapping running averages. Environmental Software 1:124-127(1986).

Policastro, A.J., M. Wastag, L. Coke, R.A. Carhart, and W.E. Dunn. Evaluation of short-term long-range transport models. EPA-450/4-86-016, Office of Air Quality Planning and Standards, Research Triangle Park, NC, 450 pp. (1986).

Rao, S.T., G. Sistla, R.E. Eskridge, and W.B. Petersen. Turbulent diffusion behind vehicles: Evaluation of roadway models. *Atmospheric Environment* 20: 1095- 1103 (1986).

Schere, K.L. EPA Regional Oxidant Model: ROMl evaluation for 3-4 August 1979. EPA/600/3-86/032, Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, 131 pp. (1986).

Snyder, W.H., R.S. Thompson, and M.S. Shipman. Streamline trajectories in neutral and stratified flow over a three-dimensional hill. EPA/600/3-85/069, EPA Complex Terrain Model Development: Fifth Milestone Report - 1985, Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, pp. 240-277 (1986).

Truppi, L.E. Complex terrain model development: Description of a computer data base from the Full Scale Plume Study, Tracy, Nevada. EPA/600/3-86/068, Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, 105 pp. (1986).

Turner, D.B. Addendum to TUPOS - Incorporation of a hesitant plume algorithm. EPA/600/8-86/027, Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, 34 pp. (1986).

Turner, D.B. Comparison of three methods for calculating the standard deviation of wind direction. *Journal of Climate and Applied Meteorology* 25: 703-707 (1986).

Turner, D.B. A user-friendly screening model for point-source impact assessment. Proceedings of the 79th Annual Air Pollution Control Association Meeting, Minneapolis, Minnesota, June 1986. Air Pollution Control Association, Pittsburgh, 14 pp. (1986).

Turner, D.B., and L.W. Bender. Description of UNAMAP (Version 6). EPA/600/M-86/027, Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, 26 pp. (1986).

Turner, D.B., T. Chico, and J.A. Catalano. TUPOS – A multiple source Gaussian dispersion algorithm using on-site turbulence data. EPA/600/8-86/010, Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, 171 pp. (1986).

Turner, D.B., T. Chico, and J.A. Catalano. TUPOS-P – A program for analyzing hourly and partial concentration files produced by TUPOS. EPA/600/8-86/012, Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, 106 pp. (1986).

APPENDIX B-1: PRESENTATIONS

Baines, W.D. (visitor). Jets and plumes, University of Toronto, Toronto, Canada. Seminar at the Fluid Modeling Facility, April 16, 1986.

Briggs, G.A. Analysis of diffusion field experiments. Lecture presented at the American Meteorological Society Short Course on Air Pollution Modeling, San Diego, CA, March 18-21, 1986.

Castro, I.P. (visitor). Some features of separated flows, University of Surrey, Guildford, England. Seminar at North Carolina State University, September 8, 1986.

Clark, T.L. An approach to evaluating regional sulfur deposition models. Seminar at Atmospheric Environment Service, Environment Canada, Downsview, Ontario, Canada, January 1986.

Clark, T.L. Peer Review Workshop, the International Sulfur Deposition Model Evaluation. Research Triangle Park, NC, April 23-24, 1986.

Dennis, R.L. NAPAP at midpoint. Invited presentation for the APCA Specialty Conference on Acid Rain, Albany, NY, March 18-19, 1986.

Dennis, R.L. Measuring the effectiveness of inspection and maintenance programs on carbon monoxide reductions. Invited presentation for the llth Annual North American Motor Vehicle Emissions Control Conference, Baltimore, Maryland, April 20-23, 1986.

Dennis, R.L. Task Group 3 Atmospheric Transport Program results to date. National Acid Precipitation Assessment Programs Annual Meeting, Washington, DC, June 12-15, 1986.

Dennis, R.L. Regional Model Evaluation Field Study Program. Briefing to EPA Headquarters Staff, Washington, DC, July 1, 1986.

Dennis, R.L. Regional Model Evaluation Field Study Program. Briefing to NAPAP Interagency Science Committee, Office of the Director of Research and Task Group Leaders, Washington, DC, July 11, 1986.

Dennis, R.L. Southeast Dry Deposition Siting Study. Briefing to OADEMQA Headquarters Staff, Washington, DC, July 31, 1986 (with J. Novak).

Dennis, R.L. Mobile sources and acid rain. Invited presentation for the 2nd Annual Mobile Sources/Clean Air Conference, Estes Park, Colorado, September 9-11, 1986.

Lawson, R.E., Jr. Diffusion in complex terrain: Physical modeling at the Fluid Modeling Facility. Los Alamos National Laboratory, Los Alamos, NM, March 20, 1986.

Lawson, R.E., Jr. Stack heights and locations in complex terrain. Presentation at the AMS Seventh Symposium on Turbulence and Diffusion, Boulder, CO, November 12-15, 1985.

Ohba, R. and Kakishima, S. (visitors). Wind tunnel modeling of diffusion in stably stratified flow around Steptoe Butte, WA. Mitsubishi Heavy Industries, Nagasaki, Japan. Seminar at Fluid Modeling Facility, Research Triangle Park, NC, September 22, 1986.

Petersen, R.L. (visitor). Application of fluid modeling to building ventilation/air quality and more. Cermak/Peterka and Associates, Fort Collins, CO. Seminar presented at the Fluid Modeling Facility, May 28, 1986.

Petersen, W.B. Uncertainty in model estimates of maximum concentrations. Poster Session, Headquarters, U.S. Environmental Protection Agency, Washington, DC, November 3, 1986.

Schiermeier, F.A. Operational and diagnostic evaluation of regional acid deposition models. Presented at Ninth Meeting of US/Japan Air Pollution Meteorology Panel, Japan Meteorological Agency, Tokyo, Japan, February 27, 1986.

Schiermeier, F.A. Mathematical concepts and fluid modeling simulations of dividing-streamline height in complex terrain. Presented at Ninth Meeting of US/Japan Air Pollution Meteorology Panel, Japan Meteorological Agency, Tokyo, Japan, February 27, 1986.

Schiermeier, F.A. Development of regional acid deposition models for evaluation of emission control strategies. Presented to US/USSR Project Meeting on Air Pollution Modeling and Standard Setting, Main Geophysical Observatory, Leningrad, USSR, May 28, 1986.

Snyder, W.H. Comparison of CTDM calculations with fluid modeling observations. Presentation at the Complex Terrain Workshop, Research Triangle Park, NC, February 4, 1986.

Tabuchi, S. (visitor). Air pollution in Japan and sights of Sapporo, Wokkaido Research Institute, Sapporo, Wokkaido, Japan. Seminar at the Fluid Modeling Facility, September 11, 1986.

APPENDIX B-2: WORKSHOPS

This section lists the workshops in which Meteorology Division personnel participated and the names of the Division participants.

1. EPA Regional Offices Workshop on Implementing the Stack Height Regulations, Chicago, IL, October 1985.

   J.L. Dicke

2. EPA Workshop on Global Atmospheric Changes, Raleigh, NC, November 13-14, 1985.

   F. Pooler, Jr.

3. UCAR Workshop on STORM Chemistry Model Evaluation Experiment, Boulder, CO, November 14-15, 1985.

   F.A. Schiermeier

4. Design Workshop for the EPRI Operational Evaluation Network, Electric Power Research Institute, Seattle, WA, November 19-21, 1985.

   R.L. Dennis

5. EPA/APCA/ASME Environmental Information Exchange, Research Triangle Park, NC, December 1985.

   J.L. Dicke

6. On-Site Meteorological Work Group, Chicago, IL, January 1986.

   R. Brode
   J.L. Dicke

7. Regional Scale Acid Deposition Model Evaluation Protocols Workshop, Raleigh, NC, January 1986.

   J.K.S. Ching
   J.F. Clarke
   R.L. Dennis
   F.A. Schiermeier

8. EPA Workshop on Complex Terrain Dispersion Model Development, Durham, NC, February 4-6, 1986.

   P.L. Finkelstein
   R. Lee
   S.G. Perry
   F.A. Schiermeier
   W.H. Snyder

9. EPA Workshop on Model Evaluation Protocols, Raleigh, NC, February 11-13, 1986.

   R.L. Dennis

10. EPA Rural Ozone Workshop, Durham, NC, February 1986.

    N. Possiel

11. EPRI Workshop on Regional Scale Acid Deposition Model Evaluation, Seattle, WA, March 11-13, 1986.

    R.L. Dennis

12. NAPAP Workshop on Dry Deposition Processes, Harpers Ferry, WV, March 25-27, 1986.

    R.L. Dennis

13. EPA Regional/State Modelers Workshop, Philadelphia, PA, April 1986.

    R. Brode
    J.L. Dicke
    R. Lee
    D. Wilson

14. NCAR Regional Acid Deposition Model (RADM) Review, Boulder, CO, April 29-30, 1986.

    R.L. Dennis

15. EPA GEP Stack Height Emission Balancing Work Group, Washington, DC, May 1986.

    D. Wilson

16. Joint US/USSR Working Group 02.01-10 on Air Pollution Modeling, Instrumentation and Measurement Methodology, Leningrad, USSR, May 26-30, 1986.

    S.G. Perry
    F.A. Schiermeier

17. Regional Model Evaluation Quality Assurance Workshop, Toronto, Ontario, Canada, June 11-13, 1986.

    R.L. Dennis

18. NOAA Workshop on Present and Future Plans for Long-Range Transport and Dispersion Experiments, Silver Spring, MD, June 24-25, 1986.

    F.A. Schiermeier

19. EPA Regional Officers Annual Workshop, Southern Pines, NC, July 1986.

    D. Wilson

20. EPA Region IV/State New Source Review Workshop, Atlanta, GA, July 1986.

    J.L. Dicke

21. Oxidant Modeling for the New York Metropolitan Area Project (OMNYMAP) Workshop, Albany, NY, August 14, 1986.

    R.L. Dennis
    N. Possiel

22. EPA Region V/State Modelers Workshop, Chicago, IL, September 1986.

    J.L. Dicke

23. EPA Region IV/State Workshop on Toxic Releases, Research Triangle Park, NC, September 23-25, 1986.

    C.B. Baker
    W.B. Petersen
    T.E. Pierce
    D.B. Turner

APPENDIX C: VISITING SCIENTISTS

1. R.E. Britter, Lecturer
   Department of Engineering
   University of Cambridge
   Cambridge, England

Spent three months at the Fluid Modeling Facility under a cooperative agreement with North Carolina State University conducting a wind-tunnel study of dense-gas dispersion over a ramp.

2. I.P. Castro, Lecturer
   Department of Mechanical Engineering
   University of Surrey
   Guildford, Surrey, England

Spent two and one-half months at the Fluid Modeling Facility under a cooperative agreement with North Carolina State University conducting experiments on (1) effects of wind direction variations on dispersion from sources downwind of hills (wind tunnel study) and (2) unsteadiness of stably stratified flow over hills in towing-tank through measurements of the drag on the hills.

3. H. Jongdyke, Research Scientist
   Federal Highway Administration
   Washington, DC

Spent one day at the Fluid Modeling Facility discussing highway modeling.

4. J.T. Lee, Research Scientist
   Atmospheric Sciences Group
   Los Alamos National Laboratory
   Los Alamos, NM

Spent 2 one-month periods at the Fluid Modeling Facility conducting towing-tank studies on flushing of valleys under stably stratified conditions.

5. T. Mizuno, Research Scientist
   National Research Institute for Pollution and Resources
   Ministry of International Trade and Industry
   Yatabe, Ibaraki, Japan

Spent one day at the Fluid Modeling Facility discussing atmospheric diffusion modeling.

6. P.J.W. Roberts, Professor
   Department of Civil Engineering
   Georgia Institute of Technology
   Atlanta, GA

Spent 2 one-month periods at the Fluid Modeling Facility conducting towing-tank experiments on merging buoyant jets (ocean outfalls) in density stratified currents. This was done under a cooperative agreement with the Ocean Sciences Division, US EPA, Corvallis, Oregon.

7. J.W. Rottman, Senior Research Associate
   Department of Marine, Earth and Atmospheric Sciences
   North Carolina State University
   Raleigh, NC

Spent a full year at Fluid Modeling Facility (under a cooperative agreement with North Carolina State University) conducting theoretical and experimental studies on three projects: (1) turbulence in stratified flow behind a grid, (2) comparison of numerical and laboratory observations of pollutant transport and dispersion in complex terrain, and (3) conditions leading to severe downslope winds on the lee sides of mountains.

8. R.B. Smith, Professor
   Yale University
   New Haven, CT

Spent two days at the Fluid Modeling Facility observing stably-stratified towing-tank experiments on severe downslope winds generated on the lee sides of mountains.

9. S. Tabuchi, Research Scientist
   Hokkaido Research Institute for Environmental Pollution Control
   Sapparo, Hokkaido, Japan

Spent three weeks at the Fluid Modeling Facility studying reports and discussing atmospheric diffusion modeling.

10. David S. Wratt
    Superintendent, Research Section Boundary Layer Meteorology
    New Zealand Meteorological Service
    Wellington, New Zealand

Spent six months as a visiting Fulbright Scholar with the Environmental Operations Branch, May 26 to November 27, 1986.

11. Xifu Zhong
    Atmospheric Diffusion Laboratory
    Institute of Atmospheric Physics
    Academia Simica
    Deshingmen Wai
    Beijing, People's Republic of China

Spent three weeks with the Terrain Effects Branch reviewing results of the 1984 EPA/PRC diffusion experiment and planning a new study for 1988.

12. Xu Dahai
    Academy of Meteorological Science
    People's Republic of China

Spent 15 months with the Terrain Effects Branch working on complex terrain modeling and new methods for analysis of turbulence data.

APPENDIX D. METEOROLOGY DIVISION STAFF - FISCAL YEAR 1986

All personnel are assigned to the U.S. Environmental Protection Agency from the National Oceanic and Atmospheric Administration, except those designated (EPA) = Environmental Protection Agency employees or (PHS) = Public Health Service Commissioned Corps personnel.

Office of The Director

Francis A. Schiermeier, Meteorologist, Director
Herbert Viebrock, Meteorologist, Assistant to the Director
Dr. Kenneth Demerjian, Physical Scientist (until January 1986)
Marc Pitchford, Meteorologist (Las Vegas, NV)
Evelyn M. Poole-Kober, Technical Information Clerk
Joan Emory, Secretary

Atmospheric Modeling Branch

Dr. John F. Clarke, Meteorologist, Chief
Dr. Francis Binkowski, Meteorologist
Dr. Gary Briggs, Meteorologist
Terry Clark, Meteorologist
Dr. Jason Ching, Meteorologist
Dr. Robin Dennis, Physical Scientist
Brian Eder, Meteorologist
James Godowitch, Meteorologist
Dr. Robert Lamb, Meteorologist
Kenneth Schere, Meteorologist
Alvina Boyd, Secretary

Fluid Modeling Branch

Dr William H. Snyder, Physical Scientist, Chief
Lewis Knight, Electronics Technician
Robert Lawson, Physical Scientist
Joseph Aquino, Engineering Aid
Joseph Smith, Mechanical Engineering Technician
Ralph Soller, Mechanical Engineering Technician
Roger Thompson (PHS), Environmental Engineer
Anna Cook, Secretary

Data Management Branch

Joan H. Novak, Computer Systems Analyst, Chief
William Amos (EPA), Computer Programmer
Adrian Busse, Computer Specialist
Dale Coventry, Computer Systems Analyst
Alfreida Rankins, Computer Programmer
James Reagan (PHS), Statistician
John Rudisill, Meteorological Technician
Barbara Hinton (PT)(EPA), Secretary

Terrain Effects Branch

Dr. Peter L. Finkelstein, Meteorologist, Chief
Dr. Robert Eskridge, Meteorologist
George Holzworth, Meteorologist
Alan Huber, Meteorologist
Dr. Steven Perry, Meteorologist
Dr. Francis Pooler, Jr., Meteorologist
Lawrence Truppi, Meteorologist
Hazel Hevenor (EPA), Secretary

Environmental Operations Branch

D. Bruce Turner, Meteorologist, Chief
Dr. Clifford B. Baker, Meteorologist (since August 1986)
Valentine Descamps, Meteorologist (Boston, MA) (until August 1986)
Mark Garrison, Meteorologist (Philadelphia, PA)
John Irwin, Meteorologist
Dr. Ralph Larsen (PHS), Environmental Engineer
Lewis Nagler, Meteorologist (Atlanta, GA)
William Petersen, Meteorologist
Thomas Pierce, Jr., Meteorologist
Everett Quesnell, Meteorological Technician
E. Diane Ramsey, Physical Science Aid
David Dodd, Physical Science Aid
Sylvia Coltrane, Secretary

Air Policy Support Branch

James L. Dicke, Meteorologist, Chief
Russell Lee, Meteorologist
Norman Possiel, Jr., Meteorologist
Jawad Touma, Meteorologist
Dean Wilson, Meteorologist
Roger Brode, Meteorologist