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DEPARTMENT OF COMMERCE ★ UNITED STATES OF AMERICA ★

NOAA Technical Memorandum ERL ARL-67

FISCAL YEAR 1976 SUMMARY REPORT OF NOAA METEOROLOGY LABORATORY SUPPORT TO THE ENVIRONMENTAL PROTECTION AGENCY

Herbert J. Viebrock, Editor

Air Resources Laboratories
Silver Spring, Maryland
July 1977

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UNITED STATES
DEPARTMENT OF COMMERCE
Juanita M. Kreps, Secretary

NATIONAL OCEANIC AND
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Richard A. Frank, Administrator

Environmental Research
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PREFACE

The work reported herein was funded by the Environmental Protection Agency (EPA) under agreement EPA-IAG-D6-0305 between the EPA and the Air Resources Laboratories (ARL), National Oceanic and Atmospheric Administration (NOAA). The Meteorology Laboratory (ML) staffed with both NOAA and EPA personnel serves as the vehicle for implementing the agreement. This relationship was established in 1955 and has continued since that time.

The EPA research, development, and operational effort in air pollution meteorology is primarily performed and managed by the ML. Research activities define, describe, and study the meteorological factors important to air pollution control activities; operational support activities apply meteorological principles to assist the EPA in the evaluation and implementation of air pollution abatement and compliance programs. Research activities, which are sponsored by the Environmental Sciences Research Laboratory, EPA, and other EPA groups, are conducted within the ML and through contract and grant activities. The ML provides technical information, observational and forecasting support, and consultation on all meteorological aspects of the EPA air pollution control program to all the EPA offices, including the EPA Office of Air Quality Planning and Standards and the Regional Offices, as appropriate.

Any inquiry on the research or support activities outlined in this report should be directed to the Director, Meteorology Laboratory, Environmental Protection Agency, Research Triangle Park, N.C. 27711.

CONTENTS

FIGURES

TABLES

FISCAL YEAR 1976 SUMMARY REPORT OF NOAA METEOROLOGY LABORATORY
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ENVIRONMENTAL PROTECTION AGENCY

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During Fiscal Year 1976, the Meteorology Laboratory continued to provide research and operational support to the Environmental Protection Agency. Operational support provided to the Office of Air and Waste Management, the Environmental Protection Agency Regional Offices, and other Environmental Protection Agency components included review of the meteorological aspects of environmental impact statements, implementation plans, and grant and contract proposals; the application of dispersion models; and conduct of dispersion studies and evaluations. Research support was in the areas of model development and application, and climatic analysis. Dispersion models for inert and reactive pollutants on all temporal and spatial scales continued under development and evaluation. Work was begun on long-distance dispersion model development. Boundary layer meteorological field experiments leading to the development of boundary layer models were conducted. The Fluid Modeling Facility conducted experiments in neutral atmospheres in the wind tunnel, and began experiments on dispersion in stratified atmospheres using the newly completed water channel/towing tank. The 25-station observing network in the St. Louis metropolitan area was in full operation as part of the Regional Air Pollution Study. Climatic studies undertaken included an analysis of the relationships between various pollutants, such as carbon monoxide and ozone, and meteorological parameters; estimation of the production of ozone and oxides of nitrogen during thunderstorms; continuation of the preparation of a climatology of effective chimney heights; and an analysis of the relationship between air pollution and solar radiation based on field studies in Los Angeles and St. Louis.

1.0 INTRODUCTION

The Environmental Protection Agency's (EPA) research and development effort in air pollution meteorology is performed and managed primarily by the NOAA Meteorology Laboratory (ML). The ML also provides operational meteorological support and technical assistance to various EPA organizational components. The ML effort during the fifteen-month fiscal year 1976 was approximately evenly divided between research and operational support, even though the research effort will receive greater coverage in this report. During the fiscal year, the ML research program, which was sponsored by the Environmental Sciences Research Laboratory, EPA, was divided into two major areas: model development and evaluation, and air quality and meteorology.

2.0 MODEL DEVELOPMENT AND EVALUATION

2.1 Basic Studies - Field Programs

2.1.1 Complex terrain field study

This project was developed in response to the proliferation of large power plants, especially in areas of complex terrain, and to the need for aerometric data in such settings. The project is being carried out by Geomet, Inc. under a Contract signed October 31, 1975. The scope of work calls for three phases over 2 years. Phase I (6 months) is essentially a literature survey, an appraisal and summary of relationships among SO_2 emissions and concentrations, meteorological conditions, topographical effects, and of airborne $SO_2 \rightarrow SO_4^=$ transformation and depletion processes.

Phase II (12 months), an aerometric survey, was begun June 1, 1976. It is centered on Appalachian Power Company's Clinch River Power Plant, located in south western Virginia at Carbo (see Figure 1). This coal-fired plant has a capacity of 712 megawatts, three boilers, and two 453-foot (138 meter) chimneys equipped with electrostatic precipitators. The sulfur content of the coal averages 0.7 percent. Figure 1 shows the eight fixed monitoring stations relative to the power plant and the terrain features. All of the stations monitor SO_2, NO, NO_2, wind, and temperature continuously except two stations, Lambert and Johnson, which only measure SO_2 and wind. This information, along with in-chimney measurements of SO_2 and NO, is telemetered in real time to the project central facility at the power plant for display and archiving on magnetic tape. Also, the stations at Nash's Ford, Hockey, Johnson, Castlewood, and Kent's Ridge are equipped with 24-port sequential samplers that collect (upon command from the central facility) 1-hour particulate samples for sulfate analysis. In addition to the aerometric measurements the central facility also receives weather analyses and forecasts via facsimile that are used to direct two radio-equipped vans to optimum sampling locations. Mobile I is equipped to measure SO_2, NO, NO_2, O_3, wind, temperature, and particulate samples. Mobile II monitors only SO_2 and wind. These vans operate 4 days per week, 5 hours per day. At quarterly intervals a helicopter participates in week-long intensive sampling exercises. It is equipped as Mobile I, except that it does not collect particulate samples or measure the wind. As part of the routine monitoring, pibal measurements are taken daily, and vertical profiles of temperature are measured on selected days. Routine operation of the aerometric network requires five full-time on-site personnel. An independent audit of the aerometric data is planned for early in 1977.

Phase III (6 months) calls for providing magnetic tapes of all field data and for analyzing these data. The data tapes will include hourly averages and peaks as appropriate for each item measured. The analyses will include (1) statistical descriptions of pollutant concentrations at each site, (2) relationships among SO_2 emissions, concentrations, and meteorology (including concentration calculations), and (3) appraisal of the applicability of the results to power plants in other complex terrain settings.

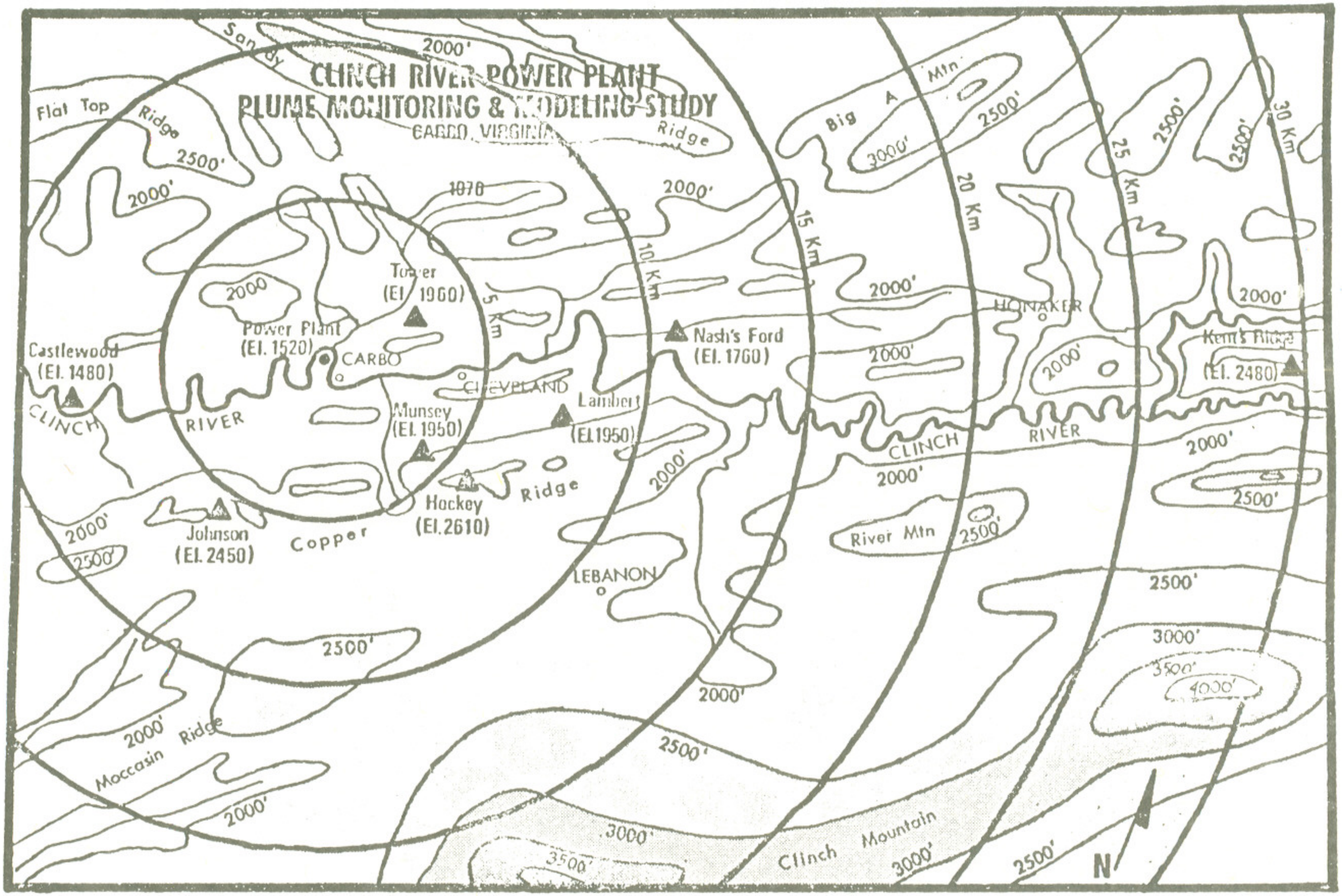


Figure 1. Aerometric monitoring stations relative to the Clinch River Power Plant and terrain elevations.

2.1.2 New York State field study

The objective of the "Research On Automobile Pollutant Dispersion" (ROAD) project is to collect accurate data on particulate and gaseous pollutant concentrations and detailed micrometeorological data in the vicinity of a major highway. The ROAD project is being conducted under a grant to the New York State Department of Environmental Conservation. A site on a relatively undeveloped section of the heavily travelled Long Island Expressway is being used for the collection of data over a period of one year. A data base this large will allow concentration to be compared with standards, as well as provide an adequate data base from which to see the interrelationships of two or more variables upon the measured concentrations. These data will be used to (1) document the distribution of carbon monoxide, lead, sulfate, and total particulates adjacent to a highway; (2) study in detail the micrometeorology of highways, with special attention to those parameters important in the determination of the wind fluctuation statistics, stability values and highway-generated turbulence; (3) re-evaluate highway air pollutant emission factors; and (4) determine the applicability of existing air pollutant dispersion models.

Figure 2 shows the location of the meteorological instrumentation and air quality sampling. All the sampling towers were erected and instrumented by the end of FY-1976, with data collection and instrument testing now underway.

2.1.3 Urban/rural oxidant studies

During FY-1976, field monitoring studies continued to assess the extent and causes of oxidant (ozone) concentration levels above the Federal ambient air quality standard (NAAQS) found over large portions of the Eastern United States. The NAAQS for oxidants, measured as ozone, is 160 $\mu g/m^3$ (0.08 ppm) one-hour average. Previous studies sponsored by EPA's Office of Air Quality Planning and Standards (Environmental Protection Agency, 1974, 1975a) focused on an area of the eastern Midwest experiencing ozone concentrations above the standard at some urban and rural sites on almost half the days during the warm season. The studies seemed to implicate the rather dense precursor (non-methane hydrocarbon and oxides of nitrogen) sources in the region along with meteorological characteristics associated with slow-moving high pressure systems as principal factors in the buildup of high regional ozone levels. Migrating high pressure air mass systems traversing the eastern Midwest during the warm season are usually characterized by abundant solar radiation, light winds, and warm temperatures. These conditions are conducive to ozone formation and accumulation. Ozone formed from urban precursor emissions showed evidence of being transported at low levels over long distances without appreciable depletion. This could have accounted for the high rural oxidant readings.

During the warm season of 1975, EPA undertook a much more extensive set of field studies covering (1) a broad area of the northern United States from the Rocky Mountains to the Atlantic Ocean; and (2) along the northwestern Gulf Coast from Texas to the western panhandle of Florida. The purpose of

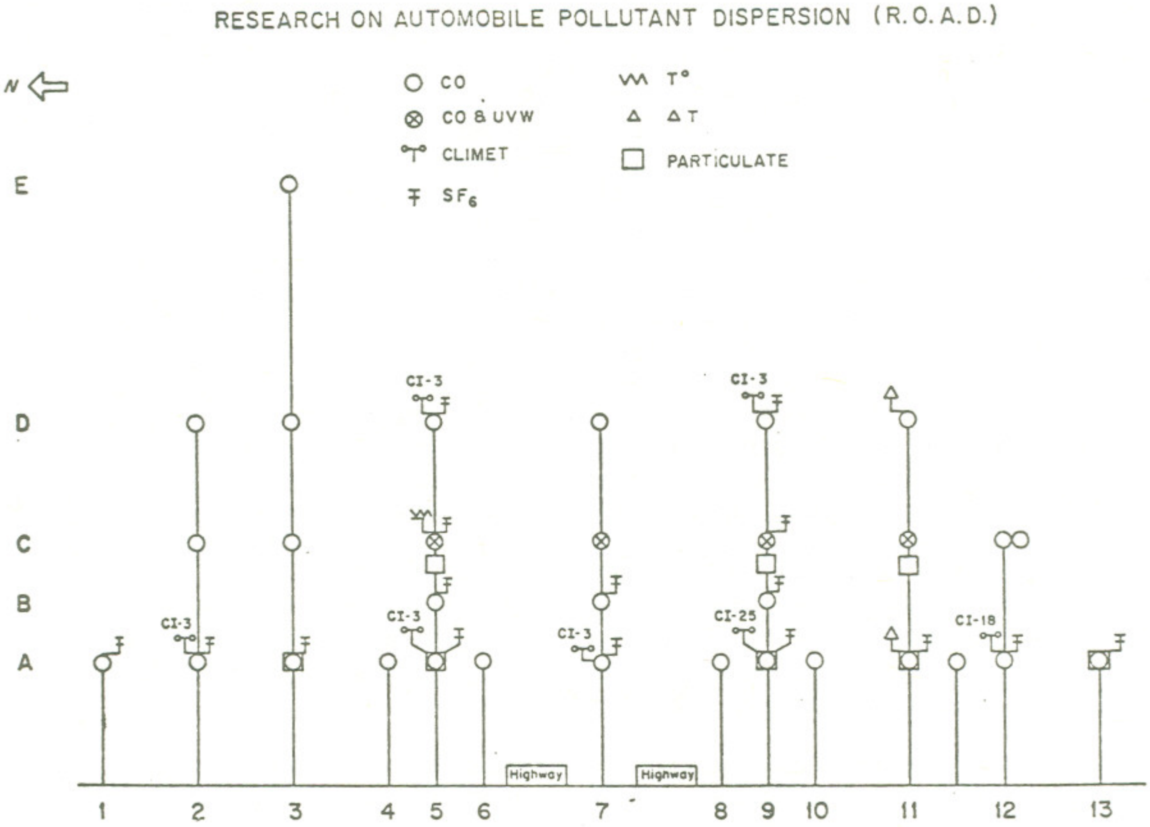


Figure 2. Meteorological and air quality instrumentation around the highway.

the northern U.S. study was to trace the development of high ozone concentrations in high pressure air masses which enter the United States from Canadian regions of origin and progress eastward through the Midwest and Northeast. The Gulf Coast study was intended to characterize the spatial distribution of oxidant levels in that region and determine the relative impact of large petrochemical industry sources in the area. A network of ground-level monitoring sites as depicted in Figure 3 was utilized, and two instrumented aircraft were used for low-level measurements over the study areas. Parameters measured at the surface and aloft included ozone, ozone precursors and air temperature. Synoptic scale data were obtained for selected National Weather Service surface and upper air stations. In addition, serial ozonesonde releases (3-times daily) to assess the possible stratospheric contribution to ground-level ozone levels were made at Huron, South Dakota, during September 25-27, 1975. The field studies were performed for the most part under contract with the Research Triangle Institute, Inc., with contributions by governmental agencies, subcontractors, and industrial concerns in various phases of the data collection.

The northern study provided verification that high ozone concentrations tend to develop in high pressure air mass systems as they move eastward into more densely populated and pervasive areas of precursor sources. Table 1 summarizes the frequency of concentration levels above the ambient oxidant standard at four rural stations situated along the preferred path of migrating highs. Although warm season ozone levels were low relative to previous years, a definitive gradient in high ozone incidences is evident increasing from west to east. Along the Gulf Coast, high oxidant concentrations were generally found downwind of major areas of anthropogenic, precursor emissions. In cases with onshore airflow, a recent history over source areas was usually evident. No evidence of appreciable downward transport of stratospheric ozone was discerned from the ozonesonde data obtained in South Dakota or Louisiana. A detailed description of the 1975 field studies and conclusions reached has been published (Research Triangle Institute, 1976a).

ML meteorologists have been active in overseeing the meteorological aspects of the field studies as well as in summarizing and providing guidance to EPA management on the significance of the results upon nationwide strategies to control petrochemical oxidants. Several technical papers and reports have resulted from these efforts (Environmental Protection Agency, 1975b; Angus and Martinez, 1976; Martinez and Meyer, 1976; Martinez, 1976).

In addition, ML staff has directed a contractual effort with Stanford Research Institute to establish relationships between ground-level photochemical oxidant (ozone) patterns, patterns of precursor emissions, and meteorological variables on all scales. The study is in support of an EPA review of oxidant control strategies. Of particular interest are (1) the role of intrusions of stratospheric ozone to ground-level, and (2) the role of the long-range transport of ozone and/or its photochemical precursors (NOx and hydrocarbons). Results to date indicate that while a strong _prima facie_ case can be made for long-range transport under favorable meteorological conditions, a definitive, quantitative relationship cannot be established, with state-of-the-art techniques, between ozone levels and precursor emissions far upstream. As to the strato-

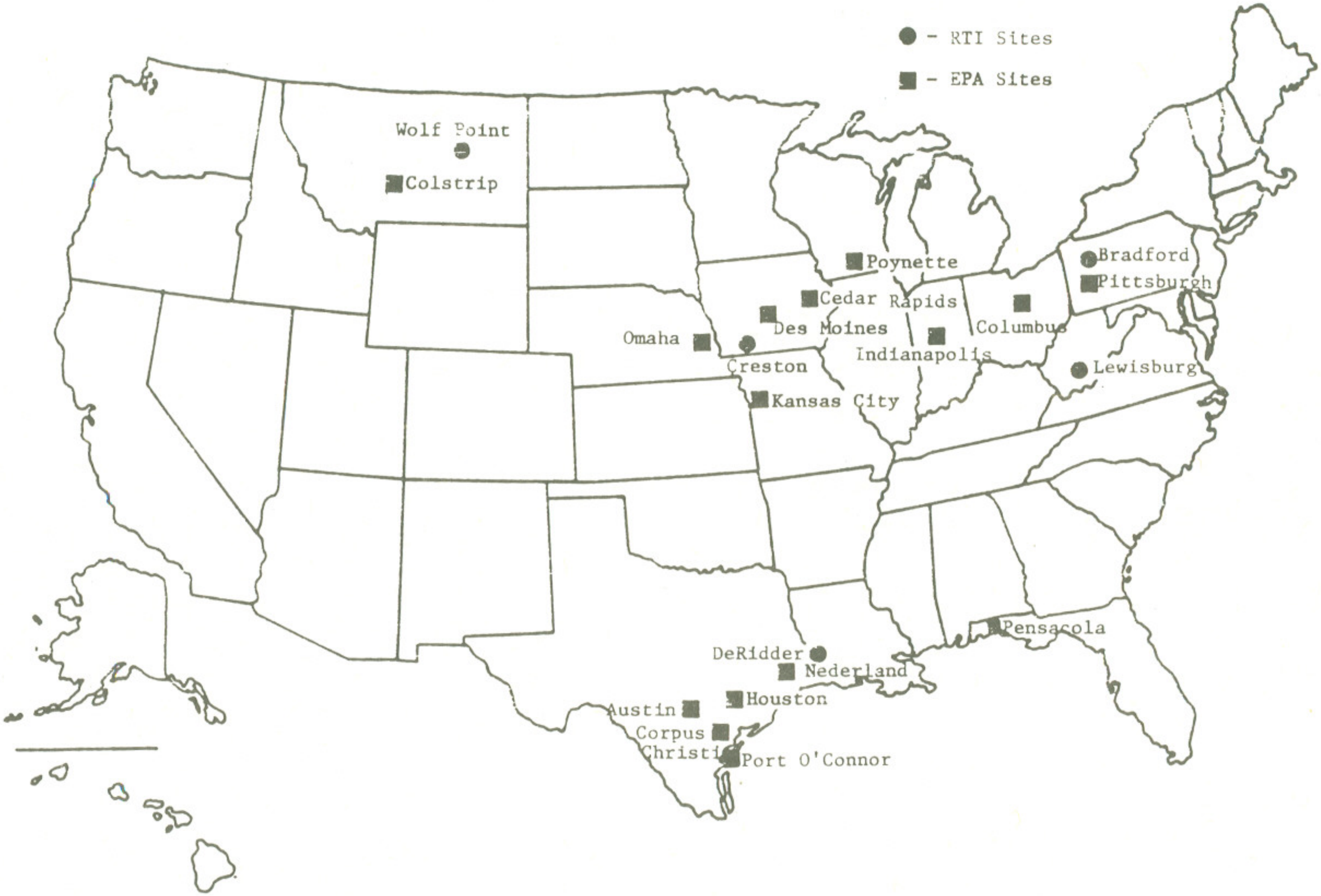


Figure 3. Site location for ground station network.

spheric aspect, the study has quantified, within a reasonable degree of uncertainty, the role of stratospheric ozone. It is seen that stratospheric intrusions alone can account for ground-level concentrations of ozone slightly in excess of the 0.08 ppm, 1-hour average, NAAQS. The study shows, however, that such occurrences are highly unusual. A final contractor's report on the study is expected in early 1977.

Table 1. Summary of Ozone Data Above NAAQS by Station

Station	Maximum Hourly Average Concentration ($\mu g/m^3$)	99th Percentile ($\mu g/m^3$)	Days Exceeding Standard (Number)	Days Exceeding Standard (%)	Hours Above Standard (Number)	Hours Above Standard (%)
Bradford, Pa.*	248	200	18	18.5	100	4.3
Lewisburg, W. Va.*	225	180	11	11.1	59	2.5
Creston, Iowa*	245	155	7	7.9	17	0.8
Wolf Point,	128	115	0	0.0	0	0.0

*Rural Stations [June 27-September 30, 1975].

2.1.4 Urban meteorological measurements

Research grant support to the University of Wyoming continued during FY-76 for studies of temporal and spatial variations of the St. Louis metropolitan atmosphere. Field programs were conducted in the St. Louis area during July-August 1975 and August 1976.

During July-August 1975, the University of Wyoming employed an airborne Doppler navigation system to measure meso-scale wind fields over the urban area. The effect of the urban heat island, surface friction, and local terrain features on the mixing layer airflow over the St. Louis metropolitan area were studied. Airborne temperature and wind measurements taken during summer days were used in this study. A downwind displacement of the elevated heat island and convergence induced by the elevated heat island were found when the elevated heat island was strong and the wind was light. When the elevated heat island was weak and the wind was strong, the frictional drag appeared to dominate over the thermally induced pressure perturbation, and the wind speed decreased over the city. Under both conditions, the terrain had only a minor effect on the urban airflow. There was also a good correlation between the thermal field and the generation of vorticity.

Study of the urban plume downwind of St. Louis was also conducted during the summer of 1975. On moderate wind days (7-8 meters per second), urban thermodynamic perturbations in the mixing layer were limited to regions 30-35 km (1.3 hours travel time) downwind of the metropolitan area. Any urban rainfall anomalies associated with these thermodynamic perturbations would be limited to this area. However, Aitken condensation nucleus plumes were detected out to four hours downwind of the metropolitan source region. Beyond that diffusion and coagulation decrease Aitken nucleus concentrations, with coagulation being most important. Forty-five percent reductions in visibility were consistently detected in regions 2.5-3.0 hours downwind of St. Louis. These locations did not coincide with those of maximum concentration of Aitken nuclei, suggesting that a certain portion of the aerosol spectrum, rather than the total concentration, is responsible for the visibility decreases. Such downwind reduction in Aitken nucleus concentrations and corresponding increase in cloud condensation nucleus concentrations suggest a particle size transformation to larger sizes, possibly through coagulation and/or photochemical effects, at travel times approximately 3 hours downwind from the urban complex.

Mesoscale anomalies of temperature and moisture have been documented in the urban environment and are being related to observed air mass modifications. The temperature and moisture anomalies are often related to specific urban land use features and provide critical components of the energy budget of the earth's surface and lower atmosphere.

During August 1976, the Department of Atmospheric Science conducted the final field study in the St. Louis metropolitan area. The objectives of this concluding field expedition were (1) to observe and analyze the flow structure and turbulence in the planetary boundary layer in the urban and rural atmospheres, (2) to relate the horizontal and vertical motions to energy sources, such as surface heating, as well as to fluxes of water vapor and temperature within and out of the urban plume, (3) to observe and analyze the individual radiation components of the urban and rural earth-atmosphere systems, (4) to interpret these components as they influence urban-rural climate, and (5) to predict the effect on the heat exchange and radiation budgets for other urban-rural areas.

2.1.5 Planetary boundary layer field studies

Extensive boundary layer field studies were conducted in the St. Louis metropolitan area. These studies should improve our understanding of the complex dynamic-thermodynamic-pollutant interactions in the urban/rural boundary layers. Field observations were made to obtain detailed information on the time and space variation of the temperature, wind, moisture, haze, and SO_2 fields, and the mixing height in an urban-rural complex with particular emphasis on the important morning and evening transition periods. These periods are characterized by rapid changes in the transport and diffusion capability of the boundary layer and the height and strength of the mixed layer.

The observational program was planned to obtain sufficient data to statistically examine the major parameters of the boundary layer for different meteorological conditions and seasonal variations. In this regard, intensive field studies of 4 to 6 weeks duration were conducted in 4 summer periods dating back to 1973 and 3 winter periods from 1974. A fall intensive field study was planned for October and November 1976.

In addition, measurements of the turbulent temperature, wind, and moisture fields for various land use types were obtained during the FY-76 summer program. From these measurements, turbulent energy fluxes will be determined as well as dispersion parameters. These measurements are essential for validation of recent parameterization models of mixing layer growth. In addition, the roughness length of a land use type, the space and time variations of the surface energy budget parameters in the city, and the variations in the dispersion parameters as a function of the meteorology of different land use types will be computed and analyzed.

Measurements were taken from a bell Model 47J2 helicopter instrumented with a SIGN X measurement system consisting of an SO_2 analyzer and scrubber, a bead thermistor, a pressure-altitude sensor, an EG and G Vapor Mate II dew-point hygrometer, and an MRI integrating nephelometer. The data were recorded on a Metrodata Logger at 2.5 samples/second as well as on a Hewlett-Packard dual-pen electrostatic strip chart recorder. A mobile van was similarly instrumented to provide surface based information.

Real time control of the field experiments was maintained from RAPS headquarters with radio communication to the helicopter and mobile van. In addition, radios were installed in a command car to allow flexibility in experiment coordination as well as in several other mobile units serving as maintenance vehicles. A typical mission could be described as lasting between 5 to 12 hours consisting of 3 to 5 helicopter flights of about 1.5 hours in duration. The flight path would be chosen along one of the major routes into St. Louis that would best coincide with the prevailing wind direction. Vertical profiles would then be obtained at up to 10 preselected sites along that route; the helicopter would spiral from the surface to a height of about 2000 feet msl obtaining data with a vertical resolution of about 1 meter. Special flights to greater heights were obtained when desired. The mobile van would traverse the city along the same preselected route concurrently to provide data on which to extrapolate the helicopter soundings to the surface. Temperature data from each sounding were radioed to the base station whereupon real time decisions regarding the mission were made, i.e., change of site, altitude, or termination of the mission. The scientist on duty would have at his disposal, on a real time basis, the van and helicopter data, the surface data from the 25 station RAMS network and the upper air data from the study station network to call on in making decisions regarding the fate or direction of that experiment.

Lidar was also used in these experiments. The EPA Mark VIII unit was employed up to the FY-76 winter study; the Mark IX of Stanford Research, Inc. participated in the FY-76 summer study. The Lidar data should yield very detailed time/height changes of the mixed layer.

On several occasions, special flights were made using an EPA helicopter to extend the basic boundary layer mission in time, space, and heights above the ceiling of the small helicopter. In addition during periods of rapid rise and final dissolution of the morning inversion, the Pennsylvania State University aerocommander aircraft was sometimes used to obtain the vertical structure of temperature through a deep layer extending to 10,000 feet above ground level.

A typical example of the profiles taken with the helicopter is shown in Figure 4. From these data, the rate of rise, the strength, and the duration of the low level inversion will be derived for different land use categories and for different seasons. Figure 5 shows an example for a single experiment.

In addition, numerical schemes are being devised to calculate the surface heat flux from selected data sets using an energy budget approach. The calculations incorporate the time and space variation of the inversion height as the upper limits of integration. Figure 5 shows the analyzed inversion base for one case study and illustrates the doming effect of the city. These budget estimates will be compared with the surface based turbulence/flux measurements and the aircraft measurements of the turbulent heat fluxes.

The measurements of the turbulence in the wind, temperature, and moisture fields will be used to provide information about the differences between the turbulence fluxes and scales of eddies associated with urban land-use types in contrast to the more familiar and prevalent rural or homogeneous terrain studies. In-depth studies are planned to point out these differences, to test inversion rise models as a function of land use, to increase our understanding of the mesoscale circulation due to the presence of the city, and to provide information on dispersion statistics/stability classification for different land use areas.

Five stations were selected from the St. Louis RAMS network and were instrumented to obtain data from which the components of the surface energy budget can be calculated. They are sites 105, 107, 109, 111 and 113.

Site 105 is considered to be the most representative of "urban" land use among the five sites. It is located in the south central section of St. Louis approximately 1 km west of the Mississippi River. Land surrounding the station is used for trucking, warehousing, and commercial operations. Buildings are predominantly two story structures. Special instrumentation at the site included a Gill UVW anemometer, a fast-response temperature system of in-house design, and a Lyman Alpha humidiometer, all located at the top of a 30-meter tower. Values from these systems were recorded every 1/2 second in the RAMS data acquisition system. A Swissteco net radiometer was extended two meters from the tower on a boom located about 29 meters above the surface. Output from this system was recorded on a Hewlett-Packard chart recorder. Operational periods for the instruments are given in Table 2 for all five sites.

Site 107 is located in the northwest section of St. Louis, approximately 6.4 km from the center of the city (the Arch). The area surrounding the site is occupied by older, single family and duplex two-to-three-story residential dwellings. Population density is high and the site is considered urban in

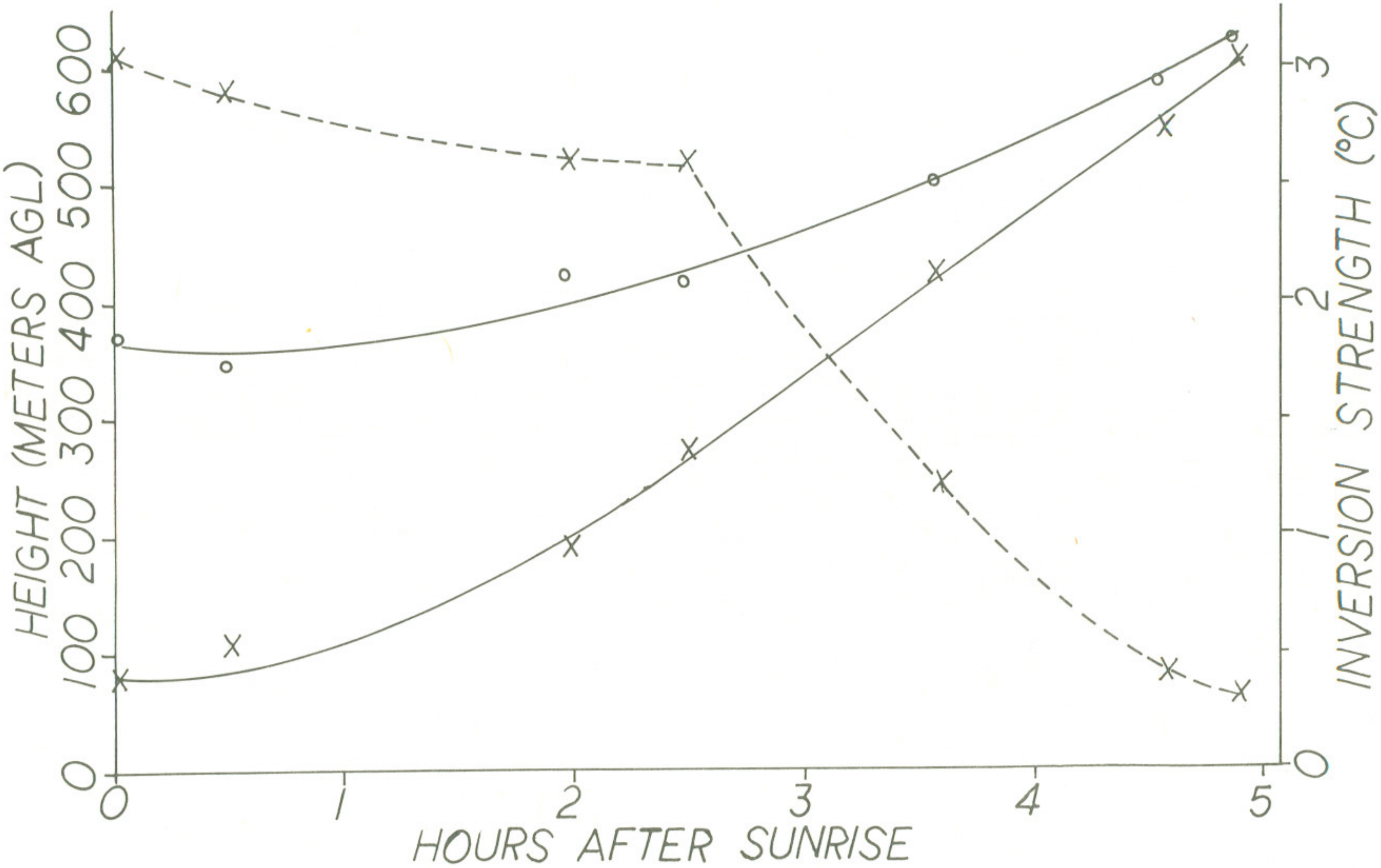


Figure 4. Temporal variation of the base (x-x-x), top (— —), and strength (x---x---x) of the nocturnal inversion over downtown St. Louis, MO, from data collected by helicopter soundings on July 17, 1975.

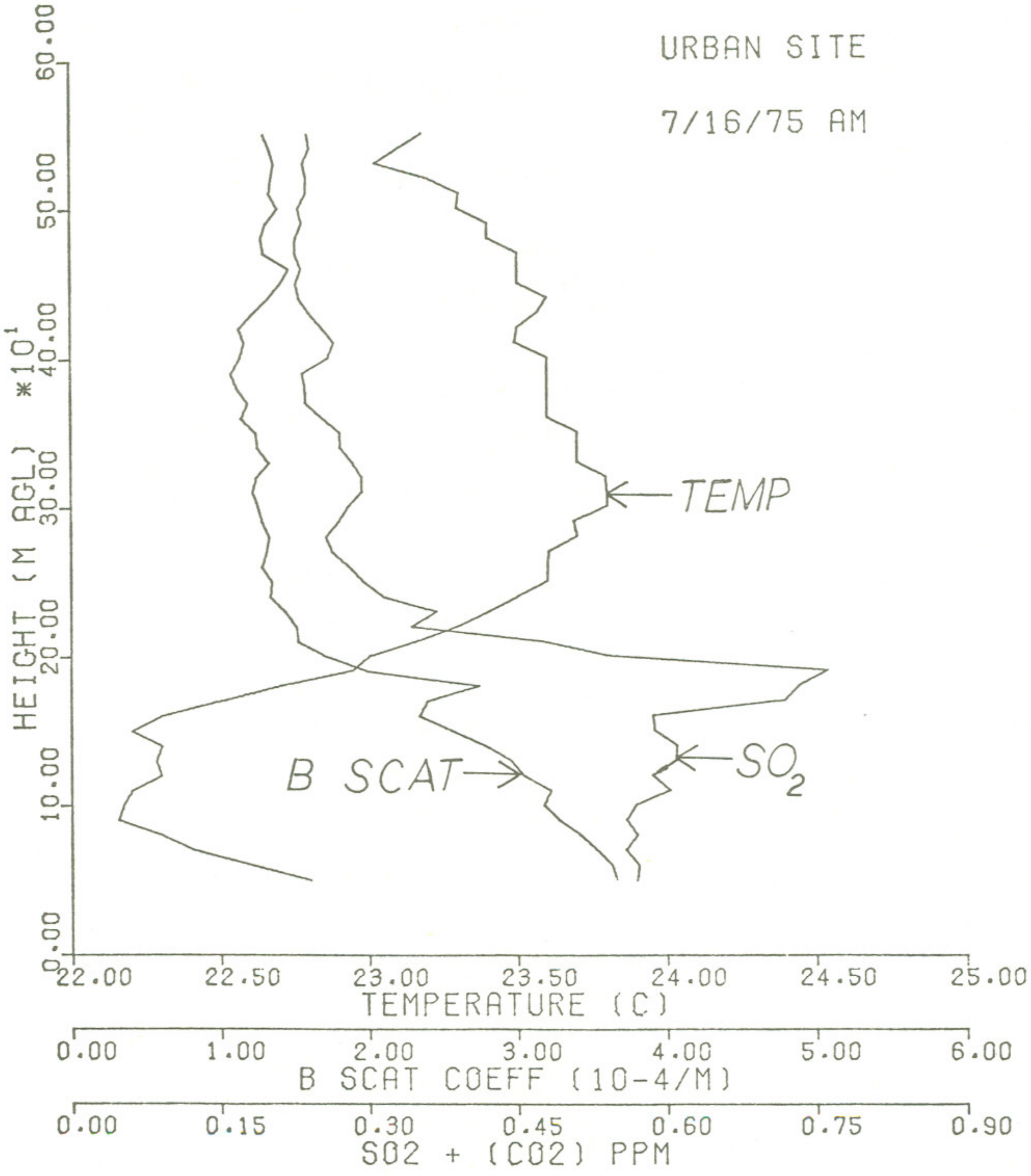


Figure 5. Profile of temperature, SO_2 and β-scatter coefficient from helicopter soundings in St. Louis at 0600 CST.

character. Special instrumentation at the station consisted of a Gill UVW anemometer and a fast-response temperature system exposed as described for station 105.

Site 111 is located in a residential community approximately 9 km southwest of the Arch. The land use in the vicinity of the station consists of high-density single-family dwellings. Special instrumentation consisted of a Gill UVW anemometer and a fast-response temperature system exposed at the top of the 30-meter tower.

Table 2. Operational Dates of Special Tower Energy Budget Instrumentation, and Percent of Time Systems Were Operational During Specified Periods

Measurement	Station	Operational Dates	Percent
UVW	105	20 July - 31 Aug	100
	107	20 July - 31 Aug	95
	109	20 July - 31 Aug	98
	111	21 July - 13 Aug	88
	113	21 July - 30 Aug	90
Temperature	105	20 July - 31 Aug	98
	107	20 July - 31 Aug	98
	109	20 July - 31 Aug	98
	111	1 Aug - 13 Aug	92
Lyman Alpha	105	20 July - 7 Aug	*
	109	9 Aug - 13 Aug	*
Net Radiation	105	20 July - 31 Aug	95
	109	20 July - 31 Aug	95

*Lyman Alpha humidiometer was operated only intermittently

Site 113 is located in a predominantly high density single family residential area approximately 13 km northwest of the Arch. Special instrumentation at this site consisted of only a Gill UVW anemometer. The system was severely damaged by lightning on 31 July which terminated the special measurements at that site.

Site 109 is located in a rural agricultural area 9.5 km east of the Arch. Special instrumentation and instrument exposure for this site were the same as for site 105. There was only one Lyman Alpha humidiometer used in the study.

It was installed at site 105 on 29 July, moved to site 109 on 9 August and removed from the network on 13 August. The stations were visited for cleaning and calibration of the instruments about every other day.

In addition to these measurements, the National Center for Atmospheric Research (NCAR) Queen Air aircraft equipped with an inertial navigation system was flown over the St. Louis metropolitan by personnel from NCAR and the University of Wyoming to provide vertical profiles of temperature, moisture, and horizontal and vertical wind fields. Each flight consisted of several horizontal legs about 40 km in length between 150 m and 2000 m above the surface with the aircraft heading parallel to the wind and then followed by cross wind flights. Flights varied from 2 to almost 5 hours and were flown during morning and afternoon hours for a total of approximately 20 hours. From this data set, computations will be made of the variances of the temperature (T), moisture (q), two horizontal wind components (u and v), and the vertical wind component (w), as well as the various covariances between w and T,q,u,v to provide the vertical extension of the surface turbulence network. In addition, spectral analysis of the data will yield important information regarding the scales of the turbulence over St. Louis. Personnel from the University of Wyoming are responsible for the reduction and processing of the turbulence data and spectra. The dates and times of these missions are listed in Table 3.

Table 3. University of Wyoming and NCAR Turbulence Flights

Date	Time of Flight (CDT)	Duration
8/7/76	0841-1114	2h 33 m
8/8/76	1200-1600	4h 0 m
	1711-2014	3h 3 m
8/9/76	0758-1241	4h 43 m
	1346-1739	3h 53 m
8/10/76	1331-1800	4h 29 m
8/12/76	1256-1442	1h 46 m
8/13/76	1057-1320	2h 23 m

An urban area is characterized by a variety of different land use types. Each land use type has a unique energy budget and climate associated with it which is due in part to the varying thermal properties of the materials that are used in the construction of the urban fabric. A separate field experiment was designed to obtain data for an in-depth analysis program of the energy budget of several of the materials that characterize urban land use.

The energy budget is described by the following equation:

$$F_s^{\downarrow} + F_l^{\downarrow} - F_s^{\uparrow} - F_l^{\uparrow} - G - H - LE = 0$$

or

$$F_n - G - H - LE = 0$$

where F_n, the net radiation received at the surface is distributed to a ground heat flux or soil heat storage term, G, and to the atmosphere in the form of a sensible heat flux, H, and the latent heat flux, LE, if evaporation is active. The net radiation is the difference between the net solar, F, and the net longwave radiation F_l. A deserted air strip, Smartt Field, located 25 miles NW of the St. Louis Gateway Arch, served as the experiment site for the energy budget study. Subsurface thermistors to measure the ground temperature were set at various depths from the surface to 50 cm in and under a concrete slab, simulated asphalt surface, and grass-soil surface. From the temperature profiles, one cannot compute G. A CSIRO Swissteco net radiometer was mounted over each surface to measure the net radiation F_n. Thus, for a dry concrete and blacktop surface the sensible heat, H, is derived as the residual of the energy budget since the latent heat flux, LE, is zero. Also, the ratio of heat absorbed by the different surfaces to the net radiation will be calculated and studied. The energy budget of soil, however, requires either measurements of H or LE or both in order to fulfill the requirements of the energy balance equation (The Bowen ration, H/LE, would also suffice). In order to determine these quantities an experiment was designed to measure the turbulent wind, temperature, and moisture fluctuations over the soil. Measurements of wind and temperature were made using fast-response, high-precision sensors recorded digitally at 5 samples per second for one-hour intervals. Latent heat flux will be determined as the residual of the energy budget equation. In addition, in-house designed analog processors using the principle of the Fluxatron (Dyer, Hicks, and King, 1967) were employed to obtain real-time values of sensible heat flux. The measurements were made between July 18 and August 12, 1976. Altogether, 36 hours of digital fluctuation data were collected for later processing and analyses. The results will be compared with the analog processed flux information. A comparison between EPA and Argonne National Laboratory fluxatron and energy budget instruments were made and the results are being evaluated. Preliminary analyses show good agreement between the two systems.

Although the turbulence measurements were limited to the 1976 summer field experiment (and a similar one the previous winter), the subsurface and net radiation equipment is being maintained for at least one year of data collection through a contract effort. This will allow analyses of seasonal as well as daily and diurnal variations of several components of the energy budget of the three surfaces.

In addition to these measurements, certain days were selected during the 1976 summer activity for case studies involving the rise of the nocturnal inversion in the early morning hours as a function of the surface heat fluxes.

For these studies, the EPA instrumented helicopters obtained special vertical profiles of temperature over the Smartt Field area. These flights consisted of a series of vertical spirals every 10 minutes or so from the surface to 2000 feet msl between 0500 to about 1100 CDT. Those data are being reduced and corrected for time lag by EPA personnel and will be available for analysis later this fall. This inversion rise study conducted over a predominantly rural area will provide a comparison with the inversion rise experiment conducted concurrently in the urban area. Supplementary pibals were also taken. In addition, the RAPS helicopter was directed to provide temperature soundings at Smartt Field from the surface to 2000 feet msl at the beginning and end of every routine RAPS helicopter mission over St. Louis (Figure 6). This amounts to about 4 morning soundings per mission day for studies of the inversion rise. The subsurface and net radiation data are being reduced by a contractor. The fluxatron type heat flux data have been reduced and are not undergoing quality checks.

2.1.6 Measurement of dry deposition of fossil fuel plant effluents

Battelle-Pacific Northwest Laboratories, under an Environmental Protection Agency contract, conducted a feasibility study of the measurement of dry deposition using a prototype field data acquisition system based on a combination of flux relationships (Droppo et al., 1976). During system field tests, measurements were made of SO_2, O_3, NO_x, NO, and aerosols. The aerosol samples were analyzed for total sulfur and lead.

Meteorological and composition observations were made using a 17.1 meter tower. Temperature and three dimensional wind observations were made at 1.8, 7.8, and 17.1 meters, wind speed at 4.8 and 11.2 meters, and air sampling at 1.0, 6.1 and 15.2 meters. The air samples were analyzed for sulfur dioxide using a portable gas chromatograph developed by Analytical Instruments Development, Inc; for ozone using a chemiluminescent instrument from Bendix; and for NO/NO_x using a REM chemiluminescent detector. Instrument specifications are discussed by Droppo et al. (1976). Aerosol samples were collected on Nuclepore filters and analyzed in the laboratory using both energy dispersive X-ray fluorescence and conventional wavelength-type X-ray fluorescence techniques.

Field tests were conducted over a grass surface near the Centralia Steam Power Plant, Centralia, Washington. Twenty-four tests were conducted over a period of six days. Deposition velocities were computed for each valid field test for the gaseous pollutants. Valid sulfur and lead aerosol data were insufficient for deposition computations. The sulfur dioxide profiles gave reasonable estimates of the dry deposition values. They were comparable with those in the literature and varied from 0.10 to 2.38 cm/sec. Values for the O_3 deposition velocities were very small, close to zero. The results for NO varied over a wide range, about two orders of magnitude. The number of NO profiles was insufficient to reach a definitive conclusion; NO_x deposition velocities were very small.

The surface layer profile method examined in this study has been shown to have the capability of estimating dry removal rates of pollutants under field

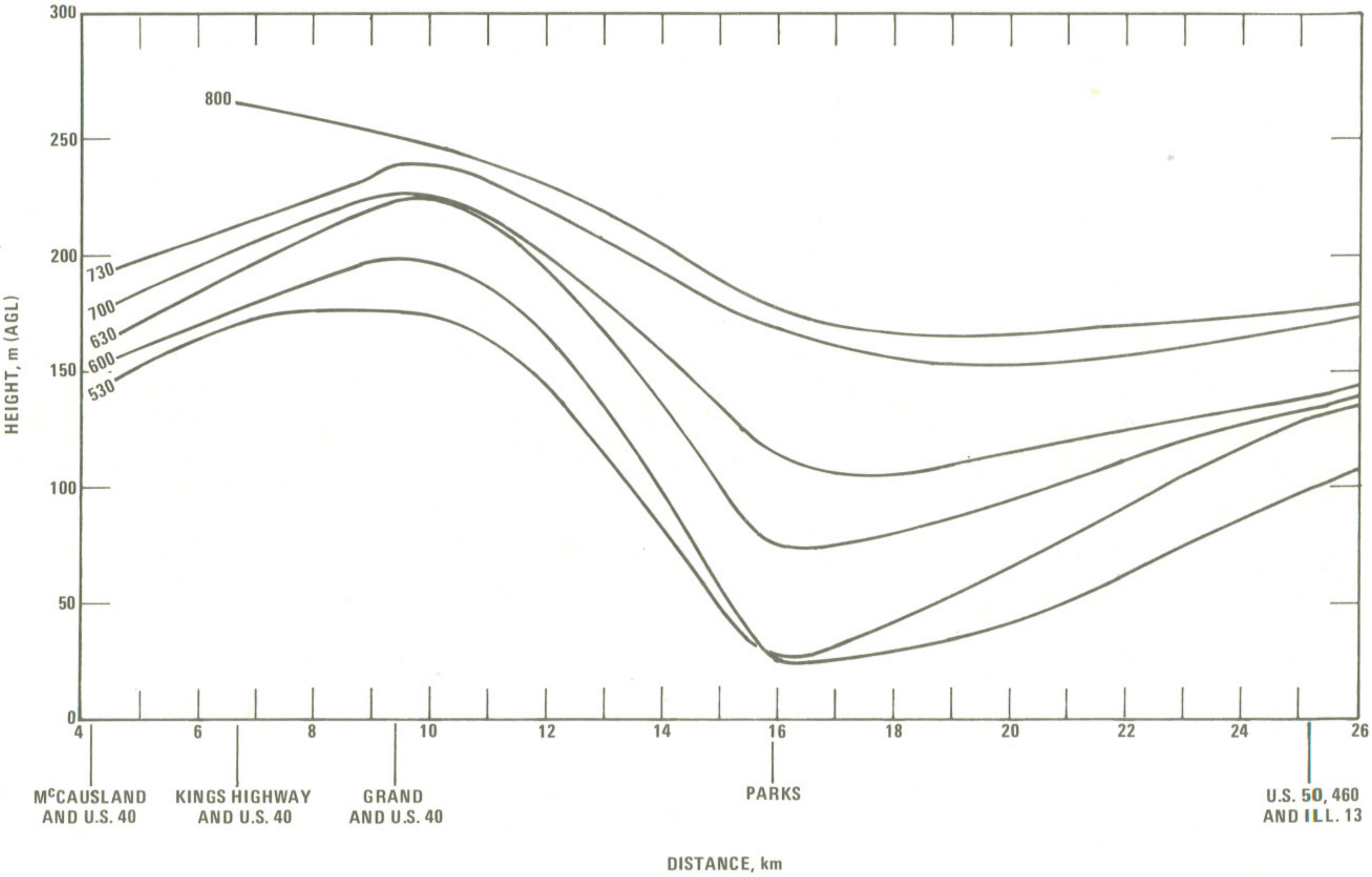


Figure 6. East-west variation of the base of the radiation inversion over St. Louis on July 29, 1975 for various times (CST).

conditions (Droppo et al., 1976).

2.2 Basic Studies - Theoretical

2.2.1 Diurnal variation of photolytic rate constants

The recent proliferation of photochemical air quality simulation models (PAQSM) has necessitated the development of a technique for the accurate and efficient calculation of photolytic rate constants for certain smog-related species. These PAQSMs are apt to be applied at a variety of locations and times of the year. Consequently, any objective method of providing photolytic rate constants for such models must incorporate both a spatial and temporal flexibility of operation. Typically the PAQSMs are used to simulate a period of less than twenty-four hours at a time within a specific region. The related inputs of photolytic rate constants thus must involve a pattern of diurnal variation.

The research and development program initiated by the Meteorology Laboratory, mentioned in the FY-75 NOAA Annual Report (Viebrock, 1976), resulted in an operative technique for calculating the rate constants (Demerjian and Schere, 1975, Peterson et al., 1976; and Schere and Demerjian, 1976). This technique is contained within a computer program which provides the necessary rate constant parameters for the chemical kinetic mechanisms utilized by the PAQSM. Given the latitude, longitude, and date for a specific location, the program will generate photolytic rate constants for various species over a preselected diurnal time range at a specified time interval. The photolytic species currently included in the program are NO_2, O_3 (three reactions), HONO, $HONO_2$, H_2CO (two reactions), CH_3CHO (two reactions), and H_2O_2.

The general expression for the photodissociation of species i in the lower atmosphere at solar zenith angle θ and altitude h may be expressed as

$$k^i(\theta,h) = \sum_{\lambda=290\text{nm}}^{800\text{nm}} J(\lambda,\theta,h) \cdot \sigma^i(\lambda) \cdot \emptyset^i(\lambda)$$

where $k^i(\theta,h)$ = photolytic rate constant (sec^{-1}) for species i at solar zenith angle θ and altitude h,

$J(\lambda,\theta,h)$ = radiation intensity (photons $cm^{-2}sec^{-1}$) averaged over wavelength interval Δλ centered about λ at solar zenith angle θ and altitude h,

$\sigma^i(\lambda)$ = absorption cross sections (cm^2) for species i averaged over wavelength interval Δλ centered about λ,

and $\emptyset^i(\lambda)$ = primary quantum yield of species i averaged over wavelength interval Δλ centered about λ.

The current version of the rate constant computer program does not permit a variation in altitude of $J(\lambda,\theta)$. The level used is that of a near-surface layer, representing an average for approximately the first tens of meters or so above ground. The $J(\lambda,\theta)$ values incorporated into the computations are those recently calculated by Peterson (1976). Sources of the values used for $\sigma^i(\lambda)$ and $\emptyset^i(\lambda)$ are noted in the forthcoming report on this study by Schere and Demerjian (1976).

Photolytic rate constants for all of the previously named species are computed using equation (1) as the theoretical framework. A User's Guide to program operation, included in the report by Schere and Demerjian (1976), describes the simple method of specifying location, date, and time-period of interest. As an example of the results obtainable from the program, Figure 7 incorporates the computed diurnal range of rate constants for the photodissociation of NO_2 in Los Angeles (34.1°N, 118.3°W) at three different times of the year. The lower values reflected in the December curve are a result of the larger zenith angles present throughout the day at this time of the year. Not all of the photolytic species absorb solar radiation in the same wavelength band. Those which absorb in a narrower range of wavelengths than NO_2, toward the shorter end of the spectrum, tend to display a greater seasonal variation than that shown by the curves in Figure 7 for NO_2.

Validation of the theoretically-computed photolytic rate constants for NO_2 was attempted using measured values of that quantity obtained by a device that provides its continuous in-situ measurement. It was operated at Research Triangle Park, NC, by the Research Triangle Institute over a period of several days in late April 1975. In order to compare the values obtained by measurement with those calculated by the program, which are applicable only to clear-sky conditions, the latter values had to be adjusted to reflect attenuation of radiation by clouds. It was decided to scale the program-generated values by the percentage departure of ultraviolet radiation measurements, taken simultaneously at RTP, from their expected values during cloudless sky conditions. The resulting values of the photolytic rate constant might then be more justly compared with the observed ones. Figure 8 depicts this comparison for April 23, 1975, one of the four days studied. The oscillatory nature of the scaled rate constant curve and the observations gives an indication of the partly-cloudy conditions on that day. They are generally in quite close agreement. The other days studied include one with clear skies and one with a total overcast. Here again the scaling technique brings the program-generated values to a good approximation of the measurements.

In summary, the technique described here of the automated calculation of photolytic rate constants as inputs for PAQSM is a viable methodology for those simulation days during which clear-sky conditions exist. On days with clouds it is suggested that the program be used along with a parameterization of the effects of the clouds.

2.2.2 Numerical solution of the conservation-of-species equation

Accurate and efficient numerical procedures for solving the partial differential equations describing the transport, diffusion, and transformation processes occurring in polluted atmospheres are of major importance to the development of air quality simulation models. In order to test standard

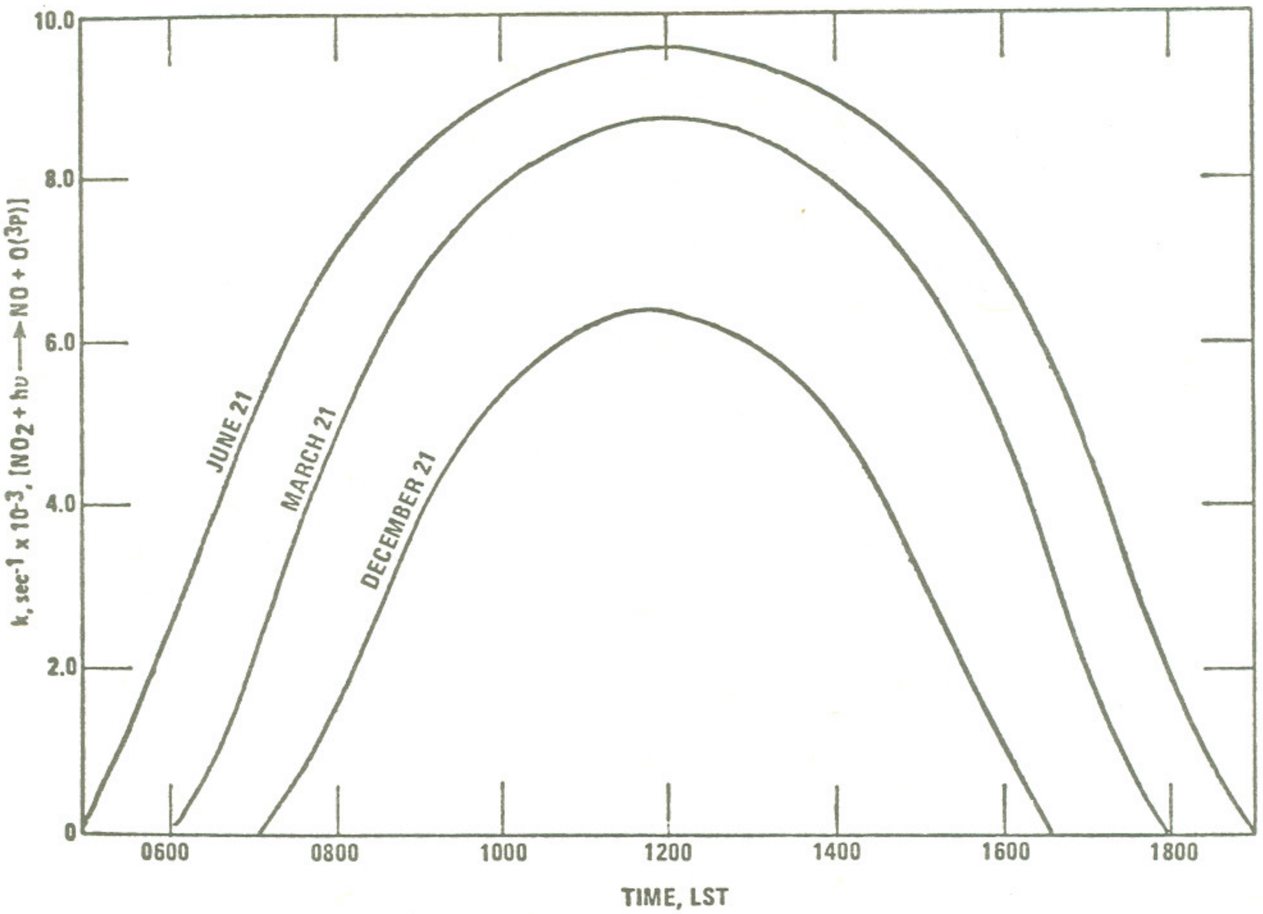


Figure 7. Diurnal variation of the photolytic rate constant for the formation of $O(^3P)$ *from* NO_2 *in Los Angeles (34.1°N, 118.3°W) for three times of the year.*

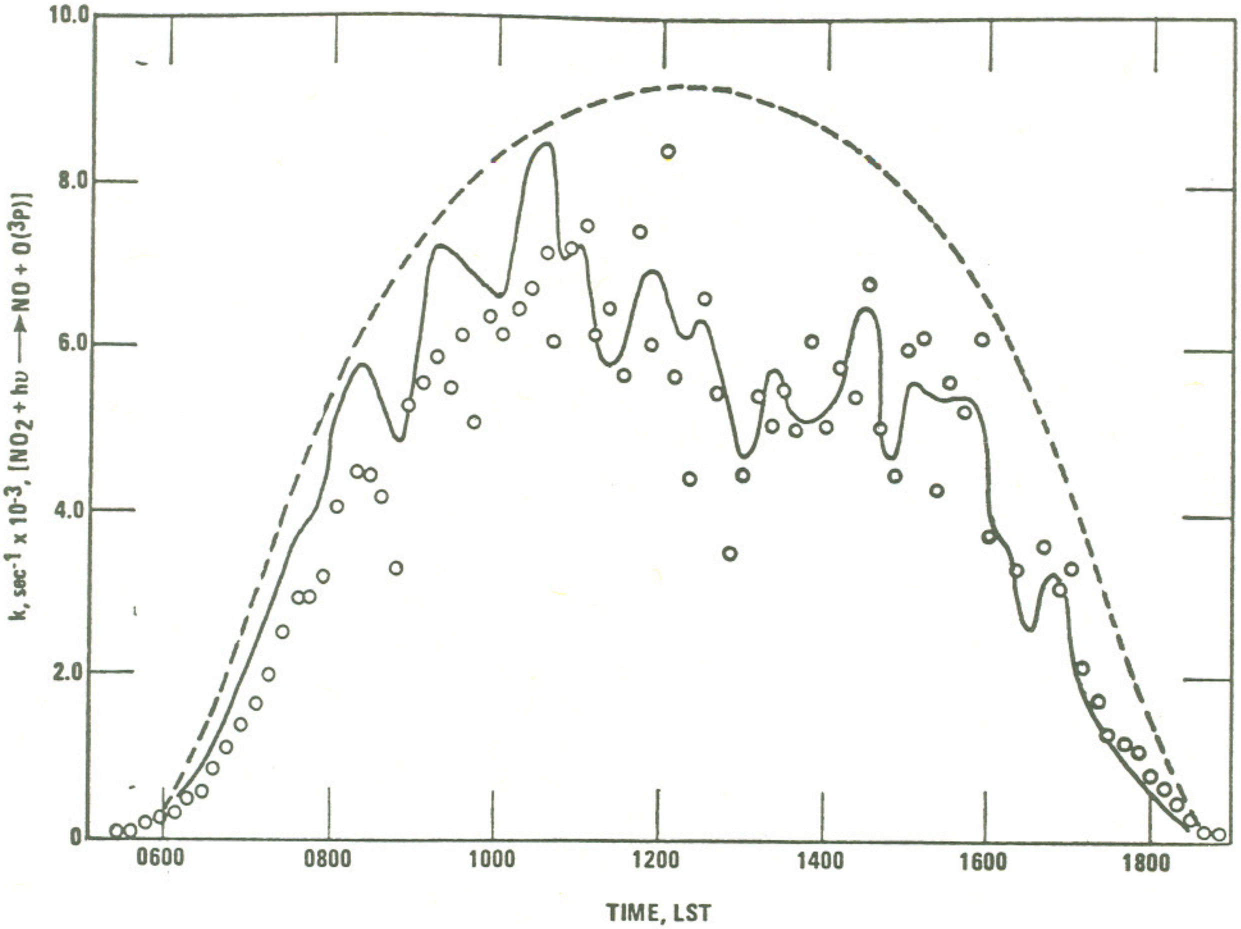


Figure 8. Comparison of the experimental (circles), theoretical (dashed line), and U.V.-scaled theoretical (solid line) diurnal variation of the photolytic rate constant for the photolysis of NO_2 near Raleigh, NC (35.8°N, 78.6°W) on April 23, 1975.

numerical techniques and a new method, the advection and reaction kinetics of two chemical systems are examined in a one dimensional model. The first chemical kinetic system

$$A \xrightarrow{k_1} B \tag{2}$$

$$B \xrightarrow{k_2} A \tag{3}$$

$$B \xrightarrow{k_3} C \tag{4}$$

yields the following differential equations

$$\frac{\partial A}{\partial t} + \nabla \cdot A\vec{V} = -k_1 A + k_2 B \tag{5}$$

$$\frac{\partial B}{\partial t} + \nabla \cdot B\vec{V} = k_1 A - (k_2 + k_3) B \tag{6}$$

$$\frac{\partial C}{\partial t} + \nabla \cdot C\vec{V} = k_3 B \tag{7}$$

where k_1, k_2, k_3 are chemical reaction rate constants. The second chemical system considered is

$$A \xrightarrow{k_1} B + C \tag{8}$$

$$B + C \xrightarrow{k_2} A \tag{9}$$

$$C + 2A \xrightarrow{k_3} 2D \tag{10}$$

which yields the following non-linear system of partial differential equations:

$$\frac{\partial A}{\partial t} + \nabla \cdot A\vec{V} = -k_1 A + k_2 BC - 2k_3 CA^2, \tag{11}$$

$$\frac{\partial B}{\partial t} + \nabla \cdot B\vec{V} = k_1 A - k_2 BC, \tag{12}$$

$$\frac{\partial C}{\partial t} + \nabla \cdot C\vec{V} = k_1 A - k_2 BC - k_3 CA^2, \tag{13}$$

$$\frac{\partial D}{\partial t} + \nabla \cdot D\vec{V} = 2k_3 CA^2. \tag{14}$$

It should be noted that the A^2 term in (11) makes this equation non-linear and, therefore, standard analysis techniques cannot be applied to this system of equations.

In this study the solutions of these two chemical systems were compared for an implicit calculation and a modified explicit calculation. The modified explicit method separates the advection and chemistry into disjoint operations allowing advection time steps much larger than numerical stability would allow if done simultaneously with the chemistry.

This study showed the following for the two chemical systems studied:

(1) For linear systems, implicit schemes are as accurate as the modified explicit schemes and much faster; therefore, they are superior.

(2) However, this is not true for non-linear systems where the implicit scheme is not conservative while the modified explicit is conservative.

(3) We have found that van Leer's method suffers from the shortcoming that the velocity must not change signs in any dimension (one-dimensional convergence). For many meteorological problems convergence is expected on any one axis and, therefore, use of van Leer's method is restricted.

(4) Linear chemistry could handle negative values without becoming unstable but this was not true of the non-linear chemistry. A more detailed description of this work is available in Eskridge and Demerjian (1976).

2.2.3 A model of dry deposition

Surface removal by dry deposition is potentially an important sink mechanism for gaseous pollutants. Measurements have been made to determine the removal rate, especially of SO_2, on various surfaces (Whelpdale and Shaw, 1974; Owens and Powell, 1974; Shepherd, 1974). Removal capacity is usually expressed in terms of deposition velocity, the vertical flux divided by the concentration at a reference level. Establishing a representative value of deposition velocity would allow long range transport models to predict the removal rate from the calculation of a surface layer concentration (Bolin and Persson, 1975).

Recently a mathematical model was developed by Shreffler (1976) to describe the transfer of gaseous pollutants to a vegetational surface. The model was shown to be consistent with wind tunnel measurements taken over an artificial grass-like surface. This model is now being extended to treat natural surfaces, forests, and grasslands, and is directed principally at establishing the maximum possible deposition velocity, e.g., that of a highly soluble gas, such as SO_2, which is lost to a water surface, either on the vegetation or after passing through fully open stomata to the interior of the leaves. Some preliminary results of the model are presented below.

A leaf area density (L.A.D.) profile representing a deciduous forest canopy with a sparse grass undergrowth is adapted from Rauner (1976, p. 245) and is given in Figure 9. For this study, this is the standard forest canopy; the standard grass canopy will be five times as dense as the sparse grass in Figure 9. These canopies have leaf area indices (L.A.I.s) (including the area of both sides of the leaf), of 6.6 and 5.0, respectively. The forest canopy is typical of both coniferous and deciduous forests where L.A.I.s generally range from 1 to 10 (Jarvis et al., 1976, p. 188; Rauner, 1976, p. 242). Predicted deposition velocities would decrease about 20 percent if a canopy with uniform L.A.D., but the same L.A.I., were substituted for the forest canopy.

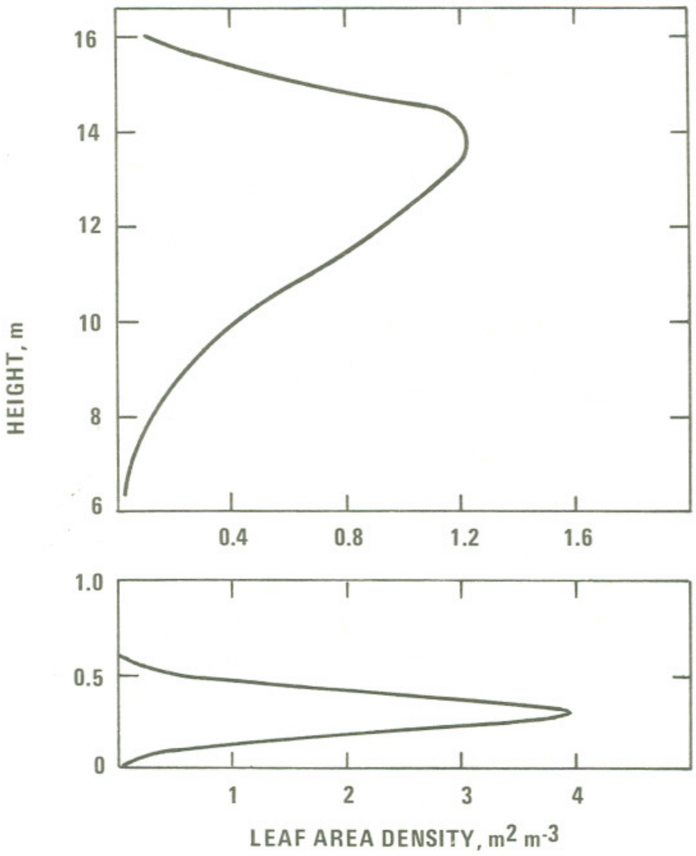


Figure 9. Leaf area density, both sides of the leaf, for a deciduous canopy.

Following the notation in the original presentation of the model (Shreffler, 1976), the expression for interfacial flux is altered to allow inclusion of physiological (stomatal) resistance to uptake by vegetation. Defining the stomatal resistance as r_s and the aerodynamic resistance for a thin sublayer on each leaf as r_a, it follows that

$$I(z) = \frac{c(z) - c(0)}{r_a(1 + r_s/r_a)} \tag{15}$$

where $r_a = 1/B(z)$ (Shreffler, 1976).

The mass conservation equation is then

$$F(h) - \int_z^h fD(z)I(z)dz = K(z)c'(z) \tag{16}$$

where the factor f will be varied to show the effect of changing the L.A.I.s of the standard canopies. It will also be used to qualitatively indicate the effects of changing the assumptions for r_a and r_s.

Some results of the model are given in Figures 10 and 11. The deposition velocities are predicted under the assumption that $c(0) = 0$ and $r_s = 0$, i.e., that the entire surface of each leaf is a perfect sink for the pollutant. The molecular diffusivity of SO_2 is assumed in calculating r_a, and the reference level is 20m. Figure 10, under the stated assumptions, shows a nearly linear dependence of v_d on $u*$ for the forest, grass, and flat surfaces. Figure 11 is strictly applicable only when $c(0) = 0$, $r_s = 0$, $u* = 40$ cm s^{-1}, and f is interpreted as a multiplicative factor for the leaf area densities of the standard canopies, but may also be used to obtain a fairly accurate description of model predictions under different assumptions on u_* and r_s.

Figure 11 may be assumed approximately correct for other u_* merely by using Figure 10 to make a proportional adjustment of the scale for v_d. Referring to (15) and (16), if r_s and r_a are about equal, then $f \neq 0.5$ would be a proper choice in Figure 11. In fact, it can be shown that, for a typical case of fully open stomata r_s/r_d changes such that f goes about 0.6 to 0.35 as u_* goes from 20 cm s^{-1} to 80 cm s^{-1} (Penman and Schofield, 1951). The assumption that gaseous uptake occurs within the leaf adds a further constraint. In many species, stomata are virtually all located on one side of the leaf, consequently halving the effective L.A.I.

By way of example, suppose a forest canopy has an L.A.I. of 10, the pollutant is SO_2 for which the interior of the leaf is a perfect sink and the exterior cuticle is very resistant to uptake, stomata are located on one side of the leaf, and $u_* = 20$ cm s^{-1}. One finds $f \simeq (1.5)(0.6)(0.5) = 0.45$, and, using Figures 10 and 11, that $v_d \simeq 0.8$ cm s^{-1}. The important point to see is that, even under assumptions which tend to maximize deposition while remaining realistic, one is forced to the left side of Figure 11, where the distinction between forest and grasslands is lost and predicted deposition velocities do

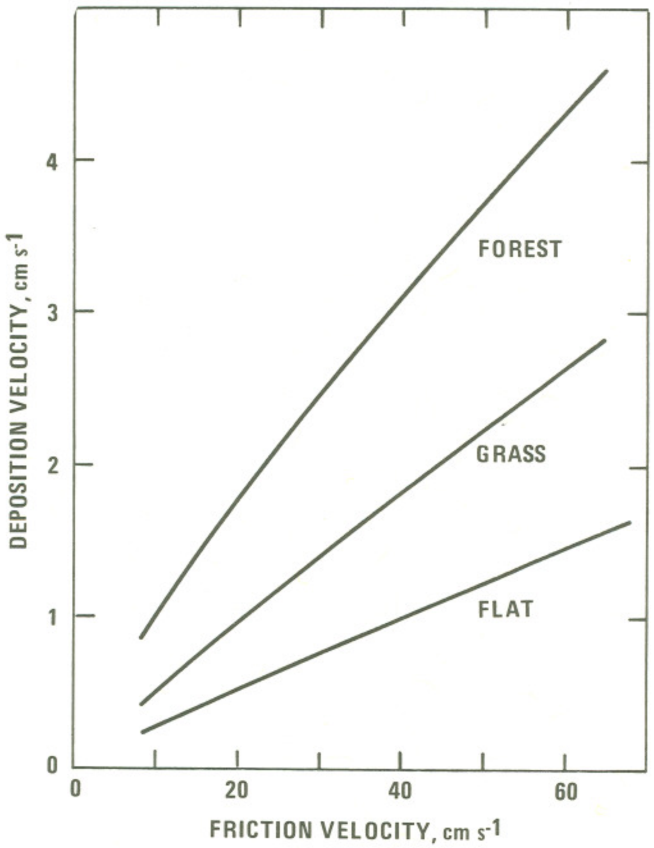


Figure 10. Deposition velocity as a function of friction velocity over forest, grass, and flat surfaces, assuming that each surface is a perfect sink for the gaseous pollutant.

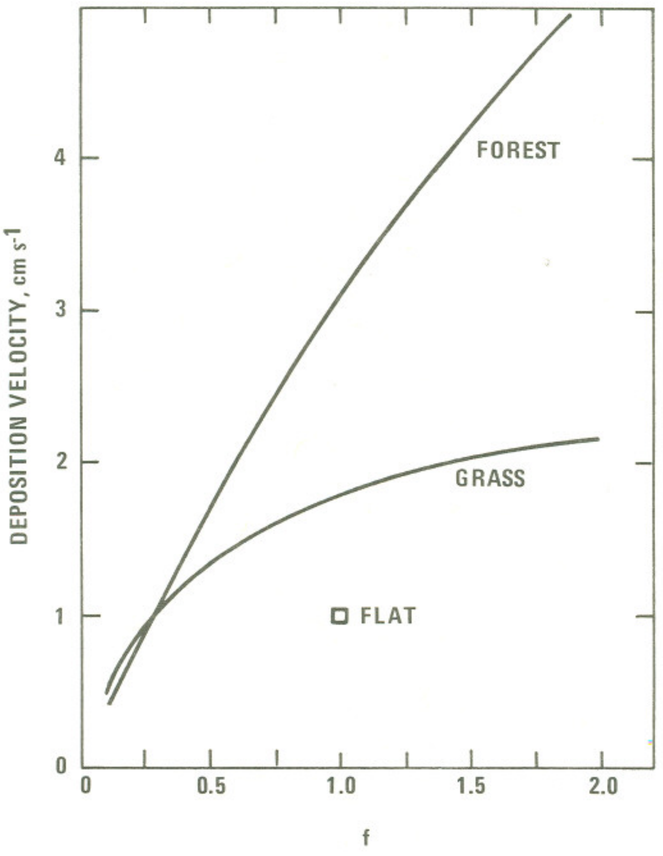


Figure 11. Deposition velocity as a function of a multiplicative factor for the L.A.I.s of the forest and grass canopies, assuming a perfect sink surface and $u_* = 40$ cm sec^{-1}.

not differ greatly from those over a flat, perfect sink, surface.

From these preliminary results, the following conclusions (given the same u_*) are derived.

(1) Assuming perfect sink surfaces, deposition velocity will increase less than 50 percent as fast as Leaf Area Index, and, for typical forest canopies will never exceed 3 to 4 times that over a flat surface. Ideally, this situation may be interpreted as SO_2 deposition on a canopy completely overlain with a water film compared with deposition on the ocean.

(2) Considering a dry canopy, where the pollutant gas is lost to the interior of the leaf after passing through open stomata, it is unlikely that the deposition velocity of SO_2 will exceed that over a flat water surface.

Work is continuing to make the results of this model easily applicable to long-range transport models.

2.2.4 Second order closure models of turbulence

The Meteorology Laboratory has a continuing developmental effort in modeling turbulent flows by the most realistic, yet practical methods. During this fiscal year, a substantial portion of the work was done under contract with Aeronautical Research Associates of Princeton, New Jersey (ARAP). One part of the effort was the development of a two-dimensional unsteady model of planetary boundary layer flow and dispersion of a passive contaminant. The model solves time-dependent partial differential equations for the turbulent kinetic energy (per unit mass), the vertical and lateral velocity component variances, the temperature variance, the shearing stresses, the turbulence heat fluxes, the turbulent length scale, mean wind field, mean temperature field, mean concentration field for a passive scalar contaminant, flux and variance of the contaminant, and contaminant-temperature covariance. This model can predict contaminant dispersion under a variety of thermal stratifications, which may change with time, and is set in an x-z (downwind-vertical) plane, but also calculates the turbulent quantities in the y-z (crosswind-vertical) plane. Major results of this work have been reported by Lewellen and Teske (1976), who show two asymptotic solutions. First, in the case of stationary, homogeneous velocity fluctuations with no temperature fluctuations, and the scale of a contaminant plume being the same as the scale of the ambient or background turbulence the solution is a Gaussian plume. Second, for the same conditions except that the plume scale is much smaller than the ambient turbulent scale, the solution has a wave-like form which Lewellen and Teske (1976) interpret as plume meander in the large eddies of the ambient field. From these two solutions, they argue that a plume initially meanders in the ambient wind field; then as the plume spreads the wave like motion (meander) is damped out and the plume becomes completely diffusion dominated. Other results concern the strong non-Gaussian behavior of plumes in stable Ekman-like flow geometries. Later work of ARAP includes the modeling of a buoyant plume entering the atmosphere. Teske and Lewellen (1976) discuss a buoyant plume entering a neutral atmosphere, its rise rate, and the conditions under which bifurcation occurs. The rise rates are quite comparable with the recent results of Briggs (1975). Bifurcation seems to occur with zero or very low ambient turbulence levels, since the experiments reported show that a plume emitted into an atmosphere with zero background turbulence, then subjected to an ambient turbulence with a scale equal to the plume scale, shows bifurcation followed by collapse to a single plume. Entrainment effects are enhanced with higher background turbulence levels; that is, the plume will rise less in higher ambient turbulence levels since the enhanced entrainment causes rapid dilution and reduced buoyancy. Extension of this work into the unstable is straight forward. The stable case presents certain difficulties concerning internal waves. The developmental work on this method is also concerned with reducing the computational load both in computer time and memory space.

The in-house effort in this area is concentrating on "minimum closure techniques", namely how simple a model adequately describes the characteristics of turbulence. A surface layer model has been developed which uses a horizontally homogeneous stationary assumption, certain closure forms from Zeman (1975) and a wall supression effect. The turbulent transport of turbulent quantities is ignored. Under these assumptions, a simple algebraic model results (Binkowski, 1976b). This model can give values for the root mean square turbulent velocity components which compare quite favorably with available data. Similarly the scaled standard deviation of the turbulent temperature fluctuation compares favorably with the data. Details of this model and a comparison with data taken by the Air Force Cambridge Research Laboratory (AFCRL) under nearly ideal conditions in Kansas and Minnesota will be published in a forthcoming paper. Comparison with the RAPS data is planned.

2.2.5 Boundary layer radiative transfer model

In order to accurately calculate the temperature field at night, a high quality long wave (infrared) radiative transfer model is necessary. Starting with the method of Rodgers and Walshaw (1966), a model was developed using the transmission function of Malkmus (1967) (Rodgers, 1968). By using this transmission function and by assuming a linear variation of the Planck function with absorber amount for thin layers, a significant simplification of the vertical quadratures for the upward and downward fluxes is possible. The simplification arises because the Malkmus transmission function is analytically integrable using absorber amount as the variable of integration. Thus, analytic integrations are obtained for relatively thin layers, then summed to obtain the vertical quadratures. Details of this approximation are given by Binkowski (1976a). The model has 12 unequally spaced intervals covering the radiation longer than 4 μm. Two intervals are used for the 8 to 13 μm window. The band parameters were calculated from the AFCRL line data of McClatchey et al. (1973). The window was treated by the method of Lee (1973). Preliminary results of Binkowski (1976a) indicate that the model is quite accurate as well as quite efficient. Four clear sky and clean air cases were selected from the data presented by Gille and Kuhn (1973). Each of these cases had three simultaneous measurements of the upward, downward, and net long wave radiation. The mean of the calculated fluxes was indistinguishable from the mean of the observed fluxes at the 5% level of confidence using a student's test for significance. The mean of the case-by-case differences between calculated and measured are significant at the 5% level. These differences are of the same order of magnitude as the differences among the three instrumental measurements which contributed to the mean of the observations, and further, the differences between this model's results and Ellingson's 100-interval-model results reported in Gille and Kuhn (1973) are the same. Consequently, Binkowski (1976a) concluded that the model was quite accurate and, because of the relatively small number of intervals and the simple vertical quadratures, also quite efficient.

Further work on this model will emphasize the inclusion of aerosol and cloud effects in the simplest possible way, starting with these effects in the 8 to 13 μm window.

2.2.6 Modeling of radiation in the planetary boundary layer

Grant support of Purdue University continued during the fiscal year to model the interaction between radiatively participating air pollutants and both solar and long wave radiation. During the past year the work focused on a series of numerical simulations and sensitivity studies of radiative transfer in the planetary boundary layer (PBL) and the effects of pollutants on thermal structure and dispersion in the PBL.

Radiative transfer in a polluted urban PBL was studied using an unsteady two-dimensional dynamic model developed earlier by Viskanta et al. (1976). The diurnal nature of radiative transfer during summer conditions was simulated for the St. Louis, Missouri, metropolitan area (40 km in extent) and the effects of various parameters were investigated.

Based on the results of the particular numerical experiments conducted and the sensitivity studies performed, it was concluded that:

(1) Air pollution has the potential of playing an important role in the radiative regime of the urban area and the energetics of the PBL.

(2) The radiatively participating pollutant aerosols in the city lead to a decrease of absorption of solar radiation by the ground and an increase in absorption of solar radiation in the earth-PBL system. Hence, there should be net warming effects. However, it is not possible to draw general conclusions on the effects of the pollutant aerosols on the surface and PBL temperatures without qualifying the conclusions with statements about the meteorological conditions, urban and air pollutant emission parameters, radiative characteristics of aerosols and of the ground, size of urban area, concentration and distribution of aerosols, latitude, local time, and time in the season.

(3) Gaseous absorbers in the atmospheric window from 8 to 13 μm can contribute markedly to the radiative transfer in the thermal (long wave)

part of the spectrum. The net effect of gaseous pollutants in the city under clear sky conditions is to increase the absorption of thermal radiation by the surface and to cool the earth-PBL system.

The effects of elevated pollutant layers on the mixed layer growth were also studied during the year and the results were reported in Venkatram and Viskanta (1976).

In this analysis the radiative transfer was predicted using a two-flux approximation, and the turbulent diffusivities were estimated using the kinetic energy of a turbulence model. The effects of elevated pollutant layer height were investigated, and numerical simulations with radiatively nonparticipating, participating, solar (shortwave) participating only and thermal (longwave) participating only pollutants were performed for stable atmospheric conditions during the summer.

Based on the numerical simulations performed and the results obtained, it was concluded that:

(1) Elevated layers of pollutants played a significant role in modifying mixed layer growth. Solar heating led to the formation of sharp inversions which hindered the vertical expansion of the mixed layer. Cooling aloft, induced by gaseous pollutants, helped the growth of the mixed layer.

(2) The height of the elevated layer was an important factor in determining the final height of the mixed layer. When the pollutant layer was placed at 300 m the mixed layer was able to penetrate the stable layer created by solar heating. However, when the pollutant layer was located at 600 m, the inversion strength became large enough to prevent the mixed layer from penetrating the inversion.

(3) Elevated pollutant layers had a significant effect on pollutant dispersal as they affected the growth of the mixed layer. Dispersion was enhanced when the mixed layer height was large. On the other hand, a small mixed layer thickness was conducive to the build-up of pollutants near the surface.

(4) In most of the simulations, aerosols decreased the effective albedo of the earth-PBL layer system at small zenith angles, and increased it at large zenith angles. Thus aerosols had a warming influence in the hours around noon, and a net cooling effect around sunset and sunrise.

2.2.7 Objective interpolation of pollutant concentration fields

A small air pollution research grant was supported at the School of Urban and Public Affairs, Carnegie-Mellon University, Pittsburgh, PA, devoted to the application of numerical optimization techniques in air quality modeling. The specific problem studied was that of objective interpolation, i.e., one that does not involve personal or subjective judgment, of the air quality distribution over a region in terms of sparse measurement data obtained at a quite limited number of air quality monitoring stations. The empirical information provided by the measurements is incorporated with information on atmospheric dispersion functions of the kind commonly used in source-oriented air quality models, to provide improved estimates of the entire concentration field over an extended region. The method involves the use of interpolation functions that are computed using numerical optimization techniques based on the method of least squares. Because of the large number of different "weather" states that affect the atmospheric dispersion of pollution, considerable computation is required, although the bulk of this can be done in advance, so that the final interpolation from the measured values requires only very simple calculation. Thus the proposed method has the potential for application on a real-time basis. In addition to the mathematical formulation of the problem, this preliminary study included numerical experiments to illustrate the technique based on the use of a current multiple-source air quality model. Two reports have been published discussing this work in detail (Gribik et al., 1976; Gustafson et al., 1976).

2.2.8 Select research group in air pollution meteorology

A major research grant was established in 1972 as a five-year program under sponsorship of the Environmental Protection Agency. It entered its fourth year of support to Pennsylvania State University in October 1975. Its basic intent is to establish a center of excellence in the atmospheric transport and dispersion aspects of air quality modeling. During fiscal year 1976 the research was conducted under five separate but interrelated programs:

(1) Numerical modeling of the atmosphere on the mesoscale (Busch et al., 1976; Anthes, 1976a, 1976b; Keyser and Anthes, 1976a, 1976b; Anthes and Seaman, 1976; Warner, 1976).

(2) Development of improved atmospheric boundary layer models (Blackadar, 1976).

(3) Development of 2nd-order closure techniques for dynamic models of atmospheric turbulent transport (Lumley, 1975a, 1975b; Tennekes, 1976a, 1976b; Zeman, 1975; Zeman and Tennekes, 1975, 1976; Tennekes and Zeman, 1976; Zeman and Lumley, 1976a, 1976b, 1976c).

(4) Natural removal processes for airborne pollutants (Rasmussen et al., 1975; Kabel, 1976a, 1976b; Brtko and Kabel, 1976).

(5) Development of indirect and airborne measurement systems for atmospheric and pollutant parameters (Schere and Thomson, 1975; Pena et al., 1975; Thomson, 1975; Reagan et al., 1976; Thomson and Scheib, 1976; Thomson et al., 1976).

Comprehensive documentation of the research on these topics includes the references shown above and annual progress reports. Two progress reports are awaiting publication by EPA: the third annual progress report in two volumes covering the period October 1974 to September 1975 and the fourth annual progress report covering the period October 1975 to September 1976.

2.3 Mathematical Air Quality Simulation Modeling

2.3.1 Roadway model

A finite-difference model of the transport, diffusion, and chemical reaction of emission from automobiles is being developed using GM test data from the fall 1975 experiment. This model differs from other models in that it uses flux profile methodology to determine eddy diffusion coefficients and is designed to include complex chemical reactions.

A system of conservation of species equations of the form

$$\frac{\partial c_i}{\partial t} + \nabla \cdot \vec{v} c_i = \nabla K \nabla c_i + \text{Sources} + \text{Sinks} \qquad (17)$$

are solved numerically in the x-z plane in a 185m by 30m region (21 by 10 grid) with $x \simeq 9.$m and $z \simeq 3.$m.

Unfortunately, since the GM highway measurement system was two-dimensional (instrument towers sited in the x-y plane) a three dimensional model could not be verified, therefore, only a two-dimensional model was considered. The x axis is horizontal and normal to the road, and the z axis pointed vertically.

This model, as most others, does not attempt to predict the wind field, but uses observations to produce a wind field which is used to transport pollutant species.

The numerical technique used to solve for advection is the method of fractional steps, which reduces a multi-dimensional calculation into two or three one-dimensional calculations. The scheme uses the flux correction method, SHASTA, of Boris and Book (1973) which is conservative and positive. This scheme was used in anticipation of eventually adding nonlinear chemistry, which requires positive concentrations to ensure numerical stability.

The model at present has two options with respect to pollutants. The model can be executed in a nonreactive pollutant mode or in a reactive mode. The reaction sequence currently considers only the interaction between H_2SO_4 and NH_3.

$$2NH_3 + H_2SO_4 \xrightarrow{k_1} (NH_4)_2SO_4$$

which yields

$$\frac{\partial(H2SO4)}{\partial t} + \nabla\cdot\vec{v}(H_2SO_4) = -k_1(NH_3)(H_2SO_4) + \text{Emission} + \text{Diffusion} \quad (18)$$

$$\frac{\partial(NH3)}{\partial t} + \nabla\cdot\vec{v}(NH_3) = -2k_1(NH_3)(H_2SO_4) + \text{Diffusion} \quad (19)$$

Expansion of the reaction sequence to be considered by the model is reasonably simple.

One of the fundamental problems of highway models is the correct delineation of the dispersion of pollutants due to turbulence. This model assumes that a type of basic state of unperturbed atmosphere exists upon which deviations due to mechanical turbulence of the car is superimposed.

The validity of this approach will be tested by comparing the prediction of the model with fifteen days of SF_6 tracer experiments performed at the GM Milford proving grounds.

2.3.2 Photochemical Box Model (PBM)

Early in the fiscal year a development program was initiated to consider simplified approaches to photochemical air quality simulation modeling and to evaluate their potential for application in urban areas. The model would represent an intermediate approach, until the more complex modeling techniques under development are completed and evaluated. The initial emphasis of the program was to implement simplified techniques for simulating the processes of atmospheric transport and dispersion, while considering in more detail the chemical transformation processes of atmospheric pollutants. This approach is one of several being considered as a possible alternative to the current regulation technique used for determining the amount of organic emission control needed to provide for attainment of the national photochemical oxidant standard.

The development of the urban scale photochemical box model has occurred in three phases.

In phase one a lumped chemical kinetic mechanism was developed and evaluated utilizing an extensive set of smog chamber data gathered at the Bureau of Mines (Dimitriades, 1970).

Phase two involved developing the basic box modeling algorithm and incorporating the lumped chemical kinetic mechanisms, an algorithm for generating the diurnal variation of photolytic rate constants used in the mechanism, and a methodology for treating emissions in the model.

Phase three which is still underway involves verifying and evaluating the developed model using the St. Louis RAPS data base.

2.3.3 Long range transport model

Recent field programs have demonstrated that air pollution extends far beyond the boundaries of major urban source complexes. Measurements of ozone, $SO_4^=$ and related precursors in rural areas has indicated the need to understand the physical and chemical processes associated with pollutant transport over long distances. In light of these recent findings, a mesoscale air pollution simulation model is being developed to simulate pollutant transport, dispersion, transformation, and disposition over an area from the Rocky Mountains to the Atlantic Ocean and from the Canadian border to the Gulf Coast (Figure 12). The model solves a set of conservation-of-species equations on a 35 by 30 by 10 grid using meteorological parameters generated by a boundary layer model being developed at the Technique Development Laboratory, NOAA. As a minimum expectation the model should predict pollutant transport from major source complexes and establish trends and proportionate concentrations of ambient pollutant species. An optimistic expectation would be accurate model predictions of the absolute concentrations of primary and secondary pollutant species. In the final analysis accurate model prediction will depend on emission inventory accuracy, knowledge of the chemistry of multi-day simulations and the parameterization of deposition, and accuracy of predicted diffusion and wind fields.

The model solves a set of conservation species equation of the form

$$\frac{\partial c_i}{\partial t} + \nabla \cdot c_i \vec{v} = \frac{\partial}{\partial z} K_z \frac{\partial c_i}{\partial z} + E_i(x,y,z,t) + R_i(c_1,c_2,\ldots,c_n), \quad i = 1,2,\ldots,n \qquad (20)$$

where

n = number of pollutant species

c_i = mean concentration of pollutant species i

x,y,z = Cartesian coordinates

$\vec{v}$ = three dimensional velocity

K_z = vertical turbulent eddy diffusivity

E_i = rate of injection (or removal) of species i by a volume source or sink

R_i = rate of production (or consumption) of species i through chemical reactions

This system of equations is solved by use of the method of fractional steps. Advection is computed in the x,y, and z directions using a flux corrected upstream numerical method which is conservative and positive. Diffusion is calculated using an implicit scheme, and chemical reactions are calculated using an ordinary differential equation solver not yet chosen.

The long-range transport model requires air pollution emissions data for a large portion of the United States and southern Canada. These data include both point and area source emission rates for particulates, SO_2, NO_x, HC, and CO, as well as the location of these sources and various stack parameters.

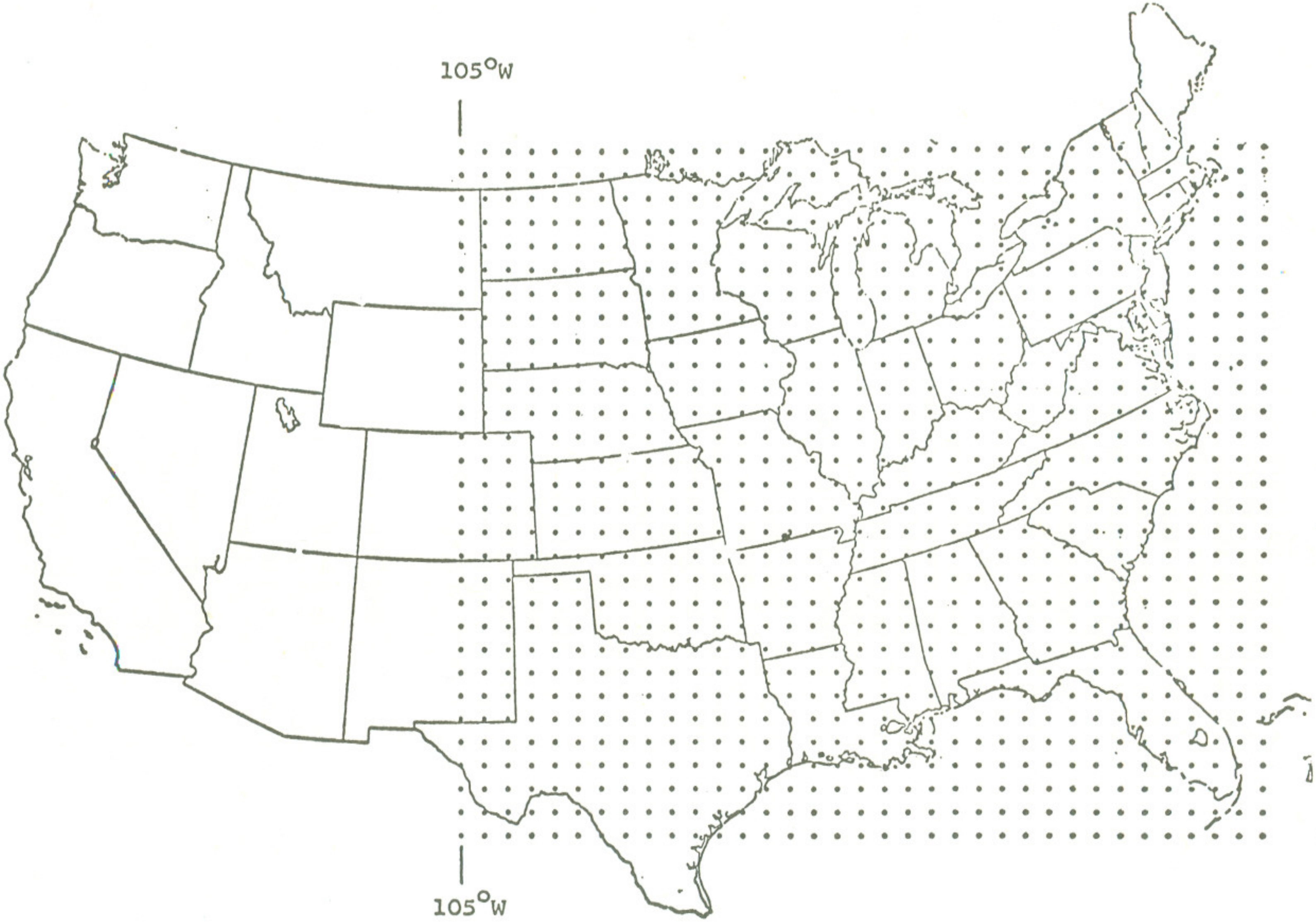


Figure 12. The horizontal grid used in the long-range transport model. The distance between grid points is approximately 95 km.

The emissions data for the United States were obtained from the EPA National Emissions Data System (NEDS), which contains all of the necessary parameters. The NEDS contains both estimated and calculated emission rates for the five pollutants. Area source emission rates in most states and point source emission rates in half of the states were estimated by either the state governments or private contractors who established their own emission factors. Large discrepancies occur in the estimated emission rates. Later the emission rates were calculated by the EPA using the data collected by the state governments or contractors. The estimated emission rates will be used in the model as it is developed; calculated emission rates will be used after the development has been completed.

The emission rates for Ontario, Canada were obtained through the ministry of the environment. The Ontario inventory included all of the parameters required. However, emission rates from sources across all portions of Ontario were not estimated. The area to the north and northeast of Lake Huron was not included in the inventory received. This area is sparsely populated with the exception of the cities of Sudbury and North Bay.

An emission inventory from Manitoba and Saskatchewan was received from Environment Canada. The emission rates for the point sources were listed for the major industrial centers, but no stack parameters were given. Also, no specific locations were listed for the point sources. The total area source emission rates were estimated by the Canadian Government for the portions of the two provinces included in the grid area. These area source emission rates were apportioned to grid squares according to population distribution.

The remaining emission rates were apportioned to grid squares according to the source locations. Ten maps depicting area and point source emission rates for the five pollutants were created. Numerical schemes to be used by the model have been tested. A simple chemical reaction system for the transformation of SO_2 to $SO_4^=$ is being incorporated into the model and will be tested using the estimated NEDS emissions.

2.3.4 Advection and diffusion model for St. Louis

The transport of puffs of inert gaseous contaminants across the St. Louis area is modeled by a numerical method. A trajectory approach was chosen, since trajectories 1) yield a better spatial resolution of a plume than a grid point model, and 2) adapt easier to changing wind fields than a Gaussian model.

The trajectories of the puffs are analyzed from two-dimensional fields of streamfunction values. If the two-dimensional divergence across St. Louis is negligible, trajectories of puffs will approximate closely streamlines, or lines of equal streamfunction values.

The streamfunction fields are calculated by Equation 21 from objectively-analyzed fields of u and v components of the wind.

$$\frac{\partial^2\psi}{x^2} + \frac{\partial^2\psi}{\partial y^2} = \frac{\partial v}{\partial x} + \frac{\partial u}{\partial y} \tag{21}$$

The wind fields are analyzed on a 40 x 40 grid (Figure 13) with a grid spacing of 1 km, while the streamfunction fields are calculated on a 20 x 20 grid with identical grid spacing. After each time step (100 seconds) the latter grid can be moved across the former grid in order to keep the puffs near the center of the streamfunction analysis where accuracy is greatest.

Wind fields are generated by the objective analysis procedure developed by Jalickee and Rasmussen (1973). Wind data, which were averaged over 15-minute intervals, were obtained from the RAPS data base.

From a point of origin, a puff is transported along a line of constant streamfunction value at a rate equal to the interpolated wind speed for periods of 100 seconds. At the end of each time step, the concentration of the puff is determined by

$$\overline{c}(x,y,z) = \frac{Q}{8(\pi Kt)^{3/2}}, \tag{22}$$

where Q is the initial generation of contaminant (gm), K is the diffusion coefficient (m^2sec^{-1}), and t is the time after release (sec). Values of 10 and 100 m^2sec^{-1} were chosen for K during generally stable and unstable conditions, respectively.

As a means of model verification, data from a tracer study performed by California Institute of Technology through EPA sponsorship were compared with the results of the model. The results are detailed by Clark and Eskridge (1976).

Figures 14 and 15 depict comparisons of the results of the model with the data of the tracer study. The dots represent the positions of the puffs at the end of 15 minute periods. The point of origin of the puffs was at Webster College (WC in figures) and the elongated symbols above highway #270 represent the width of the tracer plume as it crossed the highway.

The results illustrated here show that the model was successful in defining the location of the tracer plume 20 km downwind from the source. The model correctly shifted the contaminant eastward 4-5 km along the highway in a period of an hour. Also the calculated concentrations of the tracer were at least 50% of the maximum measured concentrations along the highway segments.

2.3.5 Prognostic air quality simulation model

The Center for Environment and Man (CEM) has developed an urban meteorological-pollutant model and used it to predict the CO concentration in Los Angeles (Pandolfo and Jacobs, 1973). Improvements in the model were made during the fiscal year. The CEM model predicts the wind, temperature, moisture and non-

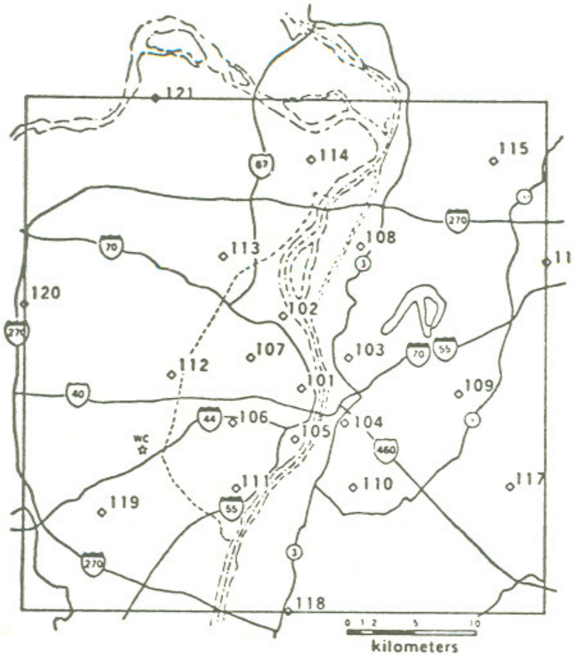


Figure 13. The boundary of the 40 x 40 grid and the RAPS network for St. Louis, MO.

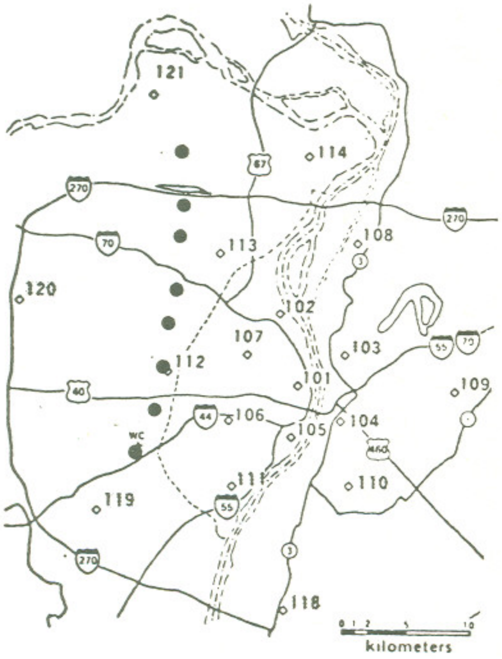


Figure 14. Trajectory of puff released at WC at 11:45 p.m., August 12.

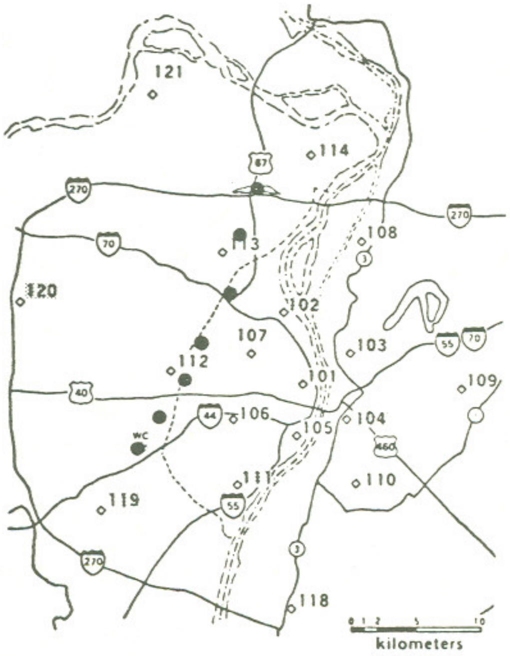


Figure 15. Trajectory of puff released at WC at 12:30 a.m., August 13.

reactive pollutant fields in the planetary boundary layer. Basically, a highly parameterized 3-D numerical and physically consistent hydrodynamic-pollution code is developed from the primitive equations. The important flux divergences are parameterized using the eddy diffusivity approach and the surface energy budget is incorporated to predict the surface temperature and energy fluxes. Non-reactive pollutants are coupled with radiation processes which in turn affects the temperature fields. Atwater (1971) discusses this important relationship.

The Pandolfo and Jacobs (1973) study used a coarse 8 mile grid for both the meteorology and the CO distribution. The temporal and spatial variations of temperature, wind, and moisture were simulated with encouraging realism. Nappo (1974) found the CO predictions to be fairly realistic but suggested that a 2-mile horizontal grid resolution should improve the model performance. This refinement was accomplished under an EPA contract and reported in Pandolfo et al. (1976). Figure 16, reproduced here from that report compares the space and time correlation statistics generated by this study and others used in the Nappo analyses. The new statistical quantities were generated by running the coarse grid model with improved meteorology (solid circle) and also with the refined grid (solid square). The results show that making fuller use of the inherent meteorological capabilities of the model significantly increases the spatial and temporal accuracy of the CO predictions. These features were exploited by combining model-generated vertical profiles of temperature with observed surface temperatures to obtain a better initial temperature field, and allowing radiatively active pollutants to affect the predicted temperatures. However, increasing the degree of detail of the source emission inventory did not in this case significantly increase the sensitivity and accuracy of the pollutant concentration forecast. Pandolfo, et al. (1976) attribute this to the inherent degree of approximation attached to their horizontal advection (upwind differencing) calculation scheme. They also note that the detail of the vertical diffusion calculation is not very significant in determining a model's accuracy. This conclustion was reached by varying only the grid resolution in the vertical. In summary, this study demonstrated:

(1) The pollutant forecasts were among the most accurate in terms of the Nappo $\overline{R(t)}^{s}$ and $\overline{r(s)}^{t}$ statistical quantities.

(2) The pollutant forecasts were about average accuracy in terms of the Nappo $\overline{R(s)}^{t}$, $\overline{\sigma(s)}^{t}$ and $\overline{\sigma(t)}^{s}$ statistical quantities.

(3) The meteorological predictions yielded by the model are well suited for input to any pollutant prediction model requiring such inputs.

2.3.6 Continued research and development of a photochemical air quality simulation model

Systems Applications, Inc. was awarded a contract in FY-76 to complete the final phase of development of the photochemical airshed model initiated in FY-75. The work emphasizes the incorporation of the theoretical sub-models and

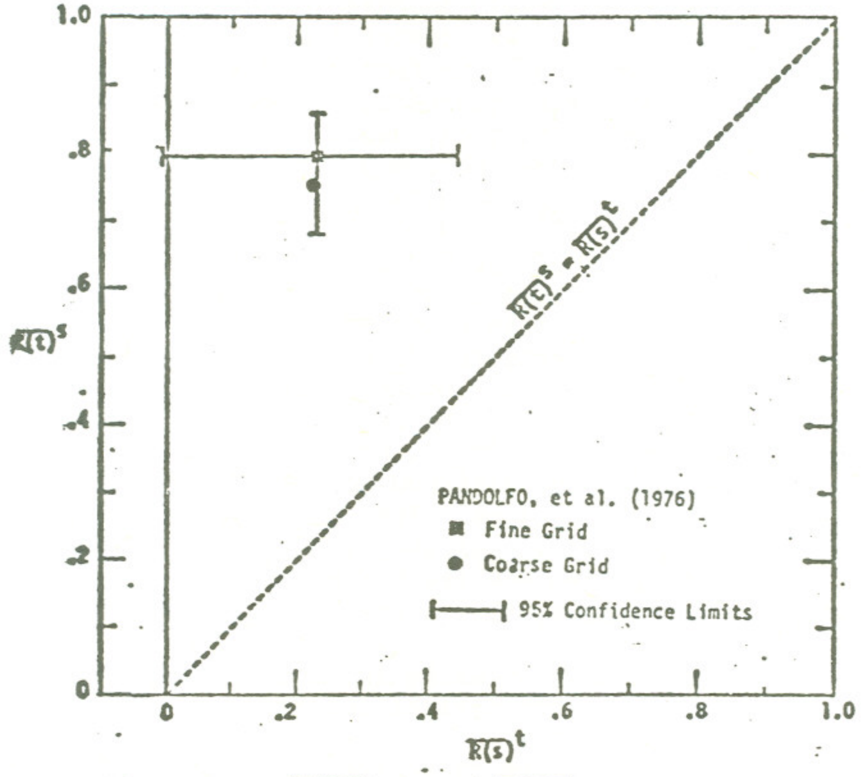


Figure 16. $\overline{R(t)}^s$ *versus* $\overline{R(s)}^t$ *average result for each model tested.*

refinements considered in FY-75 into a finalized operational version of the model. The contract work, to be completed in March 1977, will report in detail on the following major areas.

(1) Aerosol Modeling - A simplified model of the dynamics of photochemical aerosols has been developed which can be incorporated in or coupled to a photochemical air quality simulation model. The aerosol model takes into consideration the emissions of particles with diameters of 0.01 μm to 1.0 μm and their growth in this size range by the formation of secondary aerosol. The formation of very small particles by homogeneous nucleation and their subsequent growth is treated as a boundary condition on the particle size distribution function at a diameter of 0.01 μm. Although coagulation is not included in the model, methods were studied for obtaining solutions to the coagulation equation with computational efficiency.

(2) Microscale Modeling - Development work in this area has considered the derivation of wind shear and diffusivity profiles; parameterization of the effects on chemical reactions of sub-grid-scale variations in the mean concentration; implementation of a closure scheme for turbulent concentration fluctuations; and resolution of concentration variations in the vicinity of point and line sources.

(3) Numerical Refinements - An evaluation of several numerical techniques in terms of accuracy and computing efficiency has been made for application to photochemical air quality simulation modeling. The SHASTA algorithm (Boris and Book, 1973) has been selected over the techniques of Price et al. (1966) and Egan and Mahoney (1972) and incorporated into the airshed model.

(4) Surface Sinks - A review of the conceptual models and available data concerning surface sinks of ambient pollutants has been performed for the purpose of evaluating their importance in air quality simulation models. Sinks of SO_2, NO, NO_2, and O_3 have been incorporated into the air quality model to determine the significance of these loss mechanisms on the predicted pollutant concentrations. The deposition velocity, a mass transfer coefficient, has been used to calculate the rate at which a pollutant is removed from the air column. Recent techniques which relate rate of deposition to physical properties of the surface (such as roughness length) and meteorological variables are being evaluated for possible inclusion into the model.

(5) Chemical Refinements - A new generalized photochemical mechanism developed under separate contract with EPA will be incorporated into the air quality simulation model. The mechanism is based on a new concept which distributes hydrocarbon composition as a function of the carbon bonding structure of the compound. Updating of rate constants and the inclusion of temperature effects on chemical reaction rate constants are also under study.

(6) Meteorological Refinements - Techniques developed and implemented for the treatment of meteorological variables utilized by the photochemical airshed model include: improved methods for analyzing winds aloft; refined diffusivity relationships; refined methods for estimating the location and elevation of the inversion; and the spatial and temporal variations in UV radiation.

2.3.7 Tall Stacks and Sulfate Prediction Modeling

ML meteorologists continued to be involved with the evaluation of tall stacks for achieving acceptable levels of air quality and providing requested assistance to EPA in its discussions to define a tall stack policy. The policy was announced in the Federal Register (Environmental Protection Agency, 1976a), in the form of a stack height increase guideline which concluded that "so long as stack height is not used in lieu of emission reduction, the Agency encourages tall stacks as a means of further minimizing the effects of emissions on ground level concentrations."

Additional efforts by Battelle Pacific Northwest Laboratories, under contract, to provide a definitive scientific assessment of the utility of tall stacks to obtain acceptable air quality, led to a report on tall stacks and the atmospheric environmental (Environmental Protection Agency, 1976b). Critical circumstances relating to air quality are listed as:

(1) plume trapping during low wind-speed conditions;

(2) inversion breakup fumigation;

(3) fumigation from on-shore flows;

(4) return-flow conditions; and

(5) interaction with complex terrain.

The exceptions to general adequacy of field data for model evaluations are given as stagnation conditions, onshore flows, and regions of complex terrain.

The second phase of the contractual effort consisted of a literature review of SO_2 oxidation in plumes (Environmental Protection Agency, 1976c). Plume measurements of SO_2 oxidation rates are cited which range from 0 to 55 percent per hour.

The third and final phase is to result in a user-oriented computerized model that provides estimates of concentrations and removal rates in airborne, multicomponent, reactive plumes. The computer program is complete except that changes are currently being made in the input and output segments. The program is labeled "Source-Transport-Receptor Analysis Model" (STRAM) and consists of three major routines. First, a trajectory routine calculates trajectories of plume increments over a regional scale using historical gridded wind data; a dispersion routine then calculates dispersion parameters, wet and dry removal, and transformation of pollutant mass by non-linear chemical processes, and finally a sampling routine interpolates plume concentrations to specified locations. The fundamental basis for STRAM is an integral material balance over a finite volume element of plume. Dispersion is through the bivariate-normal (Gaussian) concept.

2.3.8 Model improvement studies

ML meteorologists are routinely involved in applying dispersion models to a wide variety of point sources. Results of these applications are frequently used in making decisions on the amount of air pollution control required for individual plants and on the adequacy of proposed air pollution control regulations. One of the most frequently used models is the Single Source (CRSTER) Model, derived from the MX24SP model (Turner and Novak, 1976).

Last year's Annual Report (Viebrock, 1976) described source validation studies which were performed on this model. This year GCA/Technology Division, under contract to EPA, continued the study of the time-concentration relationships begun as part of the validation study and tested certain potential improvements to this model. This study, which is still underway, consists of three parts:

(1) Further analysis of time concentration relationships (Mills, 1975),

(2) Testing and evaluation of improvements to the Single Source (CRSTER) Model (Mills and Stern, 1975), and

(3) Further analysis of modeling results for possible model improvements.

Part 1 is an extension of earlier analyses of ratios of one-hour peak to three-hour mean concentrations, and of ratios of one-hour peak to 24-hour mean concentrations. In the earlier studies, the distributions of these ratios were determined from monitoring data around four different power plants. The current study considers the effect, on these peak to mean ratios, of selectively using only the ratios where the peak concentrations are above certain cut off concentration values. In each case, the distribution from this restricted data set, relative to the distribution of the total set of peak to mean ratios, shows that the restricted set is more nearly log-normal, there is less scatter about the geometric mean, and there is little or no change in the geometric mean of the peak to mean ratios.

Part 2 is a study of the effect on model accuracy of the use of four different sets of dispersion coefficients (σ_y and σ_z). The Gifford-Briggs dispersion curves, the F.B. Smith curves, and the Smith-Singer curves are being compared with the present use of the Pasquill-Gifford curves (Turner, 1970). Preliminary results indicate that none of the former sets of dispersion curves show any significant improvement over the Pasquill-Gifford curves. This is particularly surprising since two of the plants have stacks of about 250 meters.

Work progressing (Part 3) includes a comparison of model accuracy stratified by stability class, wind speed, and mixing height. The stratification of each parameter is being done separately. Comparisons are also being made of the effects on model accuracy of using local weather service winds versus local plant winds, and the effect of using monthly average emissions versus hourly emissions.

A second model improvement study now in progress involves an Argonne National Laboratories agreement for the modification of the climatological dispersion model (CDM) for use in air pollution control regulation development. The purpose of this project is to modify CDM to produce point and area source culpability lists, calibration routines, and incorporate an averaging-time statistical package.

2.3.9 Model modifications

Three algorithms, RAM, PAL, and MX24SP, all based on the Gaussian plume model have undergone modification prior to the final preparation of user's guides and placement on the Users Network for the Applied Modeling of Air Pollution (UNAMAP).

> RAM is a Gaussian-plume multiple-source air quality algorithm which estimates concentrations of stable pollutants from urban point and area sources. Hourly meteorological data and Briggs' plume rise formula are used. Hourly concentrations and averages over a number of hours can be estimated. The model uses the Pasquill-Gifford dispersion equations with dispersion parameters valid for urban areas. Concentrations from area sources are determined using the narrow plume hypothesis, that is, sources directly upwind are considered representative of area source emissions affecting the receptor. Special features of the model include determination of receptor locations downwind of significant sources and determination of locations of uniformly spaced receptors to ensure good area coverage with a minimum number of receptors.

Although RAM was intended for application to urban areas for time periods of several hours to several days, potential users have suggested several other uses: 1) a version of the algorithm with open country dispersion parameters so that proposed multi-source industrial sources in a basically rural environment could be evaluated, and 2) a version of the algorithm with most of the options deleted that would make calculations for urban sources at fixed urban receptors for a long period of record, for example, a one year period. Calculated concentrations would be recorded on magnetic tape so that frequency distributions could be determined for each receptor.

Because of these projected uses of the RAM algorithm, four versions of RAM have resulted. The basic RAM, including options to help locate maximum concentrations downwind of significant sources and to insure good area coverage, exists in two versions, one having dispersion parameter values appropriate for urban areas and the other having dispersion parameters values appropriate for rural areas. These versions are named RAM and RAMR, the latter R standing for rural.

Two other versions of RAM, which estimate concentration frequencies by application over a one year period of record, are RAMF and RAMFR. The F stands for frequency and the last R for rural.

At the end of FY 76, the computer codes were being finalized and explanatory comment statements added. A user's guide will be written in FY 77 incorporating information on all four versions.

PAL is an algorithm for point, area, and line sources. This short term Gaussian algorithm estimates concentrations of stable pollutants from point area, and line sources. Computations from area sources include effects of the edge of the source. This requires considerable computer time. The model is not intended for application to entire urban areas but for smaller scale analysis of such sources as shopping centers, airports, and single plants. Hourly concentrations are estimated and average concentrations from 1 hour to 24 hours can be obtained.

Major modifications to PAL were the development of three subroutines which allow for the acceptance of three new source types. These are (1) curved path sources, (2) slant or special line sources, and (3) special curved path sources. The curved path formed by a flow of vehicles is approximated by an arc of a circle determined from three points on the curved path. In the past, curved path sources were modeled using a number of straight lines to approximate the curve. This routine now allows estimation of concentrations in one computation. The special line source subroutine incorporates changes of emission rates, such as a vehicle under-going a constant acceleration, as well as allowing for the line source to be sloped relative to the ground. It is anticipated that the greatest application will be for estimating concentrations downwind of a line source formed by aircraft takeoff and approach paths. The special curved path source subroutine is much like the curved path source subroutine except that (1) the special path source subroutine models one lane at a time and (2) the special curved path source subroutine allows for validation of emissions like the slant line source subroutine. The special line and curved path source subroutines used together should be very helpful in modeling aircraft approach and climb-out patterns.

MX24SP is a Gaussian-plume algorithm which estimates the maximum 24-hour concentration of stable pollutants that occurs during a year resulting from emissions from a single plant having one or more stacks. Estimates of hourly concentrations are made at 180 receptors (5 distances by 36 azimuths) using meteorological data for one year. Concentrations are averaged, midnight to midnight, each day. The annual concentration at each receptor, the maximum 24-hour concentration at each receptor, as well as the maximum 24-hour concentration of all receptors are included as outputs.

The MX24SP algorithm is applied by using a preprocessor which operates on the meteorological data, calculating stability class, and randomizing the four vectors (wind direction ± 180 degrees) within each 10° sector. At the time of the inception of the algorithm, an IBM computer was used. Because of the form of the card images of the meteorological data received from the National Climatic Center, it was convenient to use the programming language PL-1 (a IBM programming language) for the preprocessor. Later, when a UNIVAC computer replaced the previous computer, another group translated the preprocessor program COBOL. At one point, when attempting to preprocess data for a run of this algorithm difficulties were encountered with the COBOL preprocessor program. These were later determined to be the fault of the COBOL compiles. In order not to delay the project and also to provide the preprocessor in a commonly used language, the preprocessor was programmed in FORTRAN.

2.3.10 General modeling studies

Two general modeling studies were carried out as student summer projects during the fiscal year.

The first was a modeling study to examine the detection of air quality standard violations near a single plant using various sampling station networks. In this study hourly SO_2 concentrations were estimated for a one year period at locations on a polar coordinate receptor grid. MX24SP, a Gaussian type single-source dispersion algorithm described in section 2.3.9, was used. Plant parameters for an actual coal-fired power plant with two stacks were used, including hour-by-hour emissions from each stack based on power production. Surface meteorological data and mixing height, determined by using upper air data from a nearby location considered representative of the plant site, were used for the same year as the emission data.

Using these estimated concentrations, time series of concentrations for the 180 receptors were determined for two averaging times: three hours and 24 hours. Various sampling network configurations that included from 5 to 20 sampling stations were selected. Using the primary 24-hour and the secondary 3-hour sulfur dioxide air quality standards for comparison, the two time series were analyzed to see how many periods violated these standards and what proportions of these periods were detected as a violation by the various sampling networks.

Godfrey et al. (1976) showed that of 139 days calculated to have violations of the 24-hour air quality standard, 59 days of violations could be detected using a five station sampling network, 83 days could be detected with a ten station network, and 109 days with a twenty-station network. Of 521 three-hour periods calculated to have violation of the three-hour air quality standard, 167 periods could be detected using five stations, 233 periods could be detected using ten stations, and 326 periods could be detected with twenty stations. Thus for the plant examined, a twenty station sampling network detected 78% of the 24-hour violations and 63% of the three-hour violations.

In addition to the above, 12-and 18-station sampling networks, with stations all at one distance and distributed uniformly in azimuth, were tested and compared with the other networks selected by considering the number of violations at each calculation point. For this example, the uniformly distributed networks detected approximately the same percentage of violations as did selected networks having the same number of stations.

The second study dealt with the types of days associated with maximum 24-hour SO_2 concentrations near single plants (Turner et al., 1976). Although atmospheric dispersion models are available to compute concentrations from single plants, there has been little guidance as to the type of meteorological conditions that are associated with once-a-year maximum 24-h concentrations. Model calculations of SO_2 concentrations using worst-day meteorological conditions are frequently desired to provide comparisons with existing air quality standards. Although the study is limited in scope, it provides some indications of the type of meteorological conditions that occur on days when 24-hour concentrations are the highest.

In a previous study, 24-hour SO_2 concentrations were calculated for the ambient air in the vicinity of 27 power plants; the calculations were made for each day of 1964. From these data, the meteorological conditions that prevailed on the day having the highest calculated SO_2 concentration for each of the 27 power plants were tabulated. Thus, the meteorological conditions existing on 27 days were identified with maximum annual calculated SO_2 concentrations.

Five power plants, which represent typical but different sizes, were selected from the 27 sources. In addition, emission data from other power plants were examined to estimate diurnal variations of emissions. Twenty-four hour SO_2 concentrations for the 27 meteorologically different days were then calculated for two cases: emissions that remained constant throughout the 24-hour period, and emissions that varied hour by hour. For each combination of plant size and emissions (constant or variable), the 27 meteorologically different days were ordered according to the calculated maximum SO_2 concentration for each day.

The study indicates that different meteorological conditions prevail when maximum SO_2 concentrations occur for each of the five power plant sizes. For the largest plant size, the meteorology was characterized by light winds and strongly unstable conditions for several hours with the wind from nearly the same direction. For smaller plants, the meteorology was characterized by slightly higher winds from nearly the same direction for 7-8 hours under moderately unstable conditions.

2.3.11 Averaging-time model modifications

A single air quality data analysis system is needed for interrelating air pollutant effects, air quality standards, air quality monitoring, diffisuion calculations, source-reduction calculations, and emission standards. A two-parameter averaging-time mathematical model has been developed to meet the need for such a single system (Larsen, 1971, 1973, and 1974). The model makes three basic assumptions: (1) pollutant concentrations are lognormally distributed for all averaging times; (2) median concentrations are proportional to averaging time raised to an exponent; and (3) maximum concentrations are approximately inversely proportional to averaging time raised to an exponent.

Urban air pollutant concentration data usually fit this two-parameter model quite well. Concentrations measured near isolated point sources often do not fit the model, though. A three-parameter model has been developed to fit these data (Larsen, 1976). The first two parameters (the geometric mean and the standard geometric deviation for any averaging time) are the same. The third parameter is an increment (either positive or negative) that can be added to each measured concentration so that the adjusted data will more nearly fit a lognormal distribution.

As an example, the three-parameter model has been applied to the problem of relating ambient air quality data to the national ambient air quality standards to determine the degree of emission reduction needed to achieve the standards. The ambient standards for sulfur dioxide relate to the annual arithmetic mean and the second highest three-hour and 24-hour concentrations measured in a calendar year. This type of information, in conjunction with diffusion calculations, can then be used both to characterize the ambient data and to calculate the degree of emission reduction needed to achieve the ambient standards.

As part of the effort to develop a single air quality analysis system, a plant leaf injury mathematical model has been developed (Larsen and Heck, 1976). The model makes two basic assumptions: (1) a constant percentage of leaf surface is injured by an air pollutant concentration that is inversely proportional to exposure duration raised to an exponent and (2) for a given exposure duration, the percent leaf injury as a function of pollutant concentration tends to fit a lognormal frequency distribution. Measured ambient air quality data can be compared with model results to determine the degree of pollutant concentration reduction needed to prevent leaf injury.

2.3.12 Holzworth Model of Meteorological Potential for Urban Air Pollution

Holzworth (1972) suggested a simple air quality model that may be used for semi-quantitative analysis of the large-scale features of the meteorological potential for urban air pollution. For a hypothetical, constant, unit-value of the ground-level area-source emission rate for the entire city, the model estimates the pollutant concentration averaged over the along-wind center line. This is done as a function of the size of the city and the meteorological conditions of mixing depth (H) and wind speed (U). Utilizing climatological data for H and U for the contiguous United States, the model has been used to analyze the urban air pollution potential for the United States. In a recent consideration (Calder, 1976) of the model motivated by the possibility of its application to a different geographical area, the need for a basic correction to the model formulation has come to light. The usefulness of the model concept is in no way diminished and the correction of the earlier published figures should be straightforward. Two simple non-dimensional approximation formulae have been suggested in place of previous tabulations based on evalaution of rather awkward formulae. If U = average pollution concentration over the along-wind center line of city, Q = uniform strength of urban area-source emissions (i.e., in $gm^{-2}sec^{-1}$), H = mixing depth, U = average wind speed in mixing layer, S = city size in direction of wind, then we have the approximate relations

$$\frac{\chi U}{Q} = 58 \text{ for } S < 80H$$

$$\frac{\chi U}{Q} = 47 + \frac{S}{2H} \text{ for } S > 80H$$

Thus even under bad conditions for pollution, e.g., H = 125m and S = 100km, $\chi U/Q = 447$, which is roughly 8 times the "universal" valid (irrespective of city size and mixing depth) that corresponds to effectively unbounded mixing. For given wind speed and pollution emission rate, this factor defines the total range of the potential for urban pollution as reflected by variation of mixing depth and city size. To compare levels of average pollution concentration it is, of course, still necessary to consider the variations of Q and the wind speed U.

2.3.13 Residence Time and Long Distance Transport

Since April 1975, Colorado State University, under a grant, has been studying the residence time of anthropogenic pollutants and long range transport. A major part of this work has been to develop a trajectory model suitable for tracking pollutants downstream of large industrial complexes. The basic model assumptions are discussed below.

First, the general track of pollutants in the mixing layer is determined by the mean wind field in the layer. In practice the pollution movement can be tracked by a step-by-step trajectory analysis, in which mean wind speed and direction in the mixing layer are estimated from available sounding data and are applied for a period of several hours. From these time-dependent mean wind fields, the trajectory can be obtained.

Second, the horizontal dispersion of pollutants is caused by horizontal turbulence and by mean wind shear. However, for long-range transport, the mean wind shear is by far the dominant cause for the dispersion of pollutants. In the transport mode, the horizontal dispersion of pollutants is determined by the quantity, σV_h, which is the product of the standard deviation of wind velocities in the mixing layer and the travel time. The computer program for trajectory analyses which was provided by NOAA's Air Resource Laboratories (Hefter et al., 1975) has been modified for our purpose. This program is capable of calculating, for a chosen layer, "forward" and "backward" trajectories across the North American continent. A wind dispersion model as well as the method of determining the mixing layer height is included in this computer program.

Further, the formula for horizontal dispersion is based on the assumption that the wind-shear structure throughout the mixing layer along the trajectory is persistent at least for the period of the time-step of the trajectory segment. In order to examine the validity of this assumption, the persistency index of σv_h along a trajectory was calculated. The index defined as the ratio of the averaged value of the absolute difference of σv_h along a time-step to the average value of σv_h along a trajectory. The small value of this index means that the assumption is valid. The calculations of this persistency index were conducted for different timesteps along many different trajectories which originate from different locations in the eastern United States.

The data used were from the NASA-sponsored Atmospheric Variability Experiments (AVE) II. The mean values of the persistency index for all trajectories increased slightly with increasing time step, Δt, from 0.3 for $\Delta t = 3$ hours to 0.4 for $\Delta t = 12$ hours. It was concluded that the method of calculating the horizontal dispersion of pollutants seems valid for practical use.

A parameter which adequately characterizes the fate of pollutants over long time and space scales is the residence time in the atmosphere. This parameter, so far, has been given inadequate attention. Assuming that precipitation and deposition are the main mechanisms of pollutant removal, the regional residence time of pollutants was calculated. This residence time is based on the climatological mixing layer height and hourly precipitation data. The residence time T is defined as

$$T = \frac{1}{k} = \frac{1}{k_d + k_p}$$

where T is the residence time, k the total decay rate of pollutants, k_d the decay rate due to deposition, and k_p the decay rate due to precipitation. Furthermore,

$$k_d = v_d/H = 1/t_d$$

$$k_p = 1/t_p$$

where v_d is the deposition velocity, H the mixing layer height, t_d the expected residence time due to dry deposition, and t_p the expected residence time due to precipitation.

The climatological mixing layer height H calculated by Holzworth (1972) is used for the calculation of k_d. For the calculations of k_p, the method developed by Rodhe and Grandell (1972) is applied by analyzing the hourly precipitation data of 1974. The year is divided into the cold season (January-April, and November and December) and the warm season (May-October), and the residence times T for the two seasons are calculated for the region of the United States east of W105 degree longitude.

The results of this research can be summarized as follows:

(1) The residence time is longer in the warm season than in the cold

season over the whole region studied. This is due to shorter dry periods in the cold season than in the warm season, and due to the shallower depth of the mixing layer in the cold season than in the warm season.

(2) Short residence times characterize the region surrounding the Great Lakes and the northeastern part of the United States .

(3) Long regional residence times are found in the western parts of the studied area, where the mixing layer height is large, and the precipitation frequency is small.

2.3.14 Analysis of GM test data

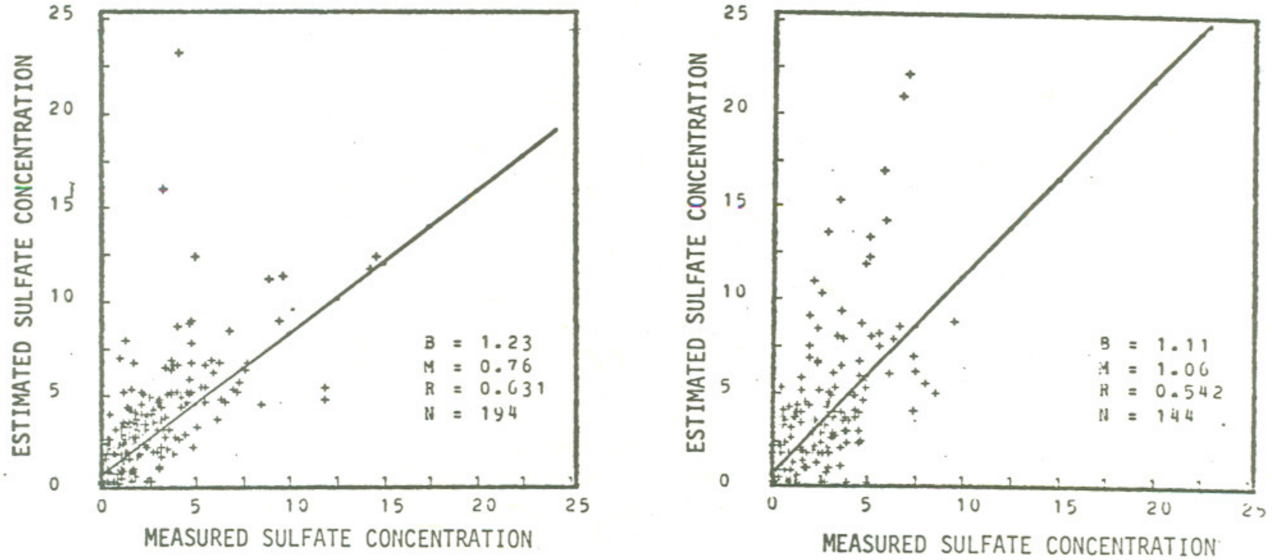
Because of considerable interest in sulfate emissions from catalyst equipped vehicles, an experiment was initiated to measure roadside sulfate exposures from a fleet of catalyst equipped vehicles. A major purpose of this experiment was to gather data on the physical and chemical properties of aerosols emitted by automobiles equipped with catalytic converters under simulated freeway conditions.

The sulfate dispersion experiment was a joint study between General Motors (GM) and the Environmental Protection Agency. The experiment was performed at GM's Milford Proving Ground. The test track used for the experiment was a narrow oval with 5 km straightways. A fleet of about 400 vehicles was driven on the 10 km test track during the morning hours on 16 days in October. Air quaility measurements were made for half-hour periods. Meteorological parameters were also measured and averaged over half-hour periods. Sulfate emissions from the automobiles were determined by dynamometer tests on a sample of the vehicles.

A test track provides advantages in a dispersion study, because traffic volume and vehicle speeds can be determined accurately. The automobiles in this study were all catalyst equipped. Also, this experiment included the use of a tracer, sulfur hexafluoride, which was measured at the same receptors as the sulfate. This enabled checks of dispersion independent of the vehicle emission and without high background interferences. One short-coming of this data set is its limited size. Thirty hours of data do not provide enough information to see the interrelationship of two or more variables to concentration.

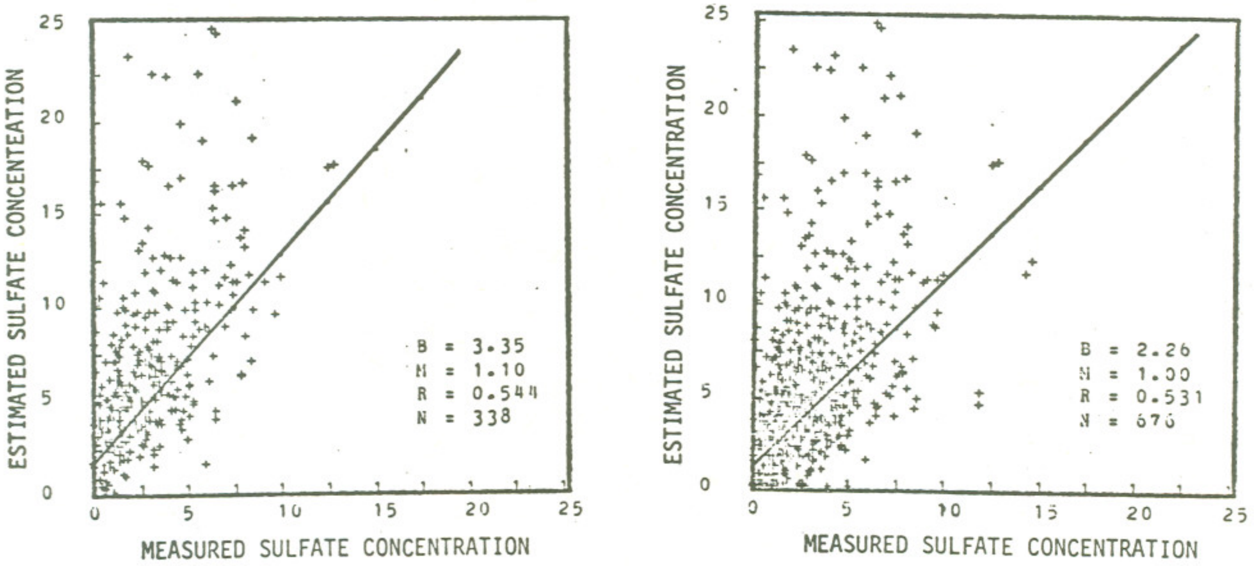
Figure 17 shows the measured sulfate concentration versus estimated sulfate concentrations for various wind conditions. Estimates were made from the HIWAY Model. The results shown here are highlights of the preliminary analysis of the data.

The preliminary analysis of the sulfate and SF_6 data showed that the model performed best for unstable atmospheric conditions or when the winds were near perpendicular to the test track. The model overestimated concentrations to the greatest extent during stable conditions or when the winds were near paral-



PERPENDICULAR WIND CASE

OBLIQUE WIND CASE



PARALLEL WIND CASE

ALL SULFATE DATA

Figure 17. Measured sulfate concentrations versus estimated sulfate concentrations ($\mu g/m^3$). B, M, R, N are the intercept, slope, correlation coefficient, and number of data points respectively.

lel to the test track. It is suspected that the low frequency meander of the wind, unaccounted for in the Pasquill-Gifford sigma-y curves, is the cause of the overprediction during parallel wind conditions. When the high frequency meteorological data are received, the wind fluctuation statistics can be determined to test this hypothesis. When the complete data set is received, further analysis should prove to be very helpful and should make possible modification of the model to improve performance.

2.3.15 Model development and adaptation using RAPS data

The development and refinement of air quality simulation models have proceeded at a reasonable pace over the past several years, but with little or no validation of these models due to the lack of an adequate data base against which to test the models. A major objective of the St. Louis Regional Air Pollution Study (RAPS) is to provide the necessary meteorological, air quality, and emissions data for extensive model verification studies. Prior to verification, models selected for testing must be adapted for the St. Louis Region and the RAPS data base. Since model verification requires numerous computer runs, optimization of model codes for computational efficiency must also be considered. Three models are in the process of being adapted for the St. Louis area.

Late in FY-76 a contract was initiated with Systems Applications, Inc. to adapt and optimize for computational efficiency the second generation photochemical airshed model developed under contract with the Environmental Protection Agency. The basic model will have its computer code restructured and streamlined to take advantage of operational and/or price structure peculiarities of individual host computers. In addition, an improved user's manual will be written incorporating all new program codes developed in the past year.

The adaptation of the model for the St. Louis Region for use with the Regional Air Pollution Study Data Base will be completed early in May. Systems Applications, Inc. will make two test runs using the St. Louis RAPS data base. The model will then be turned over to EPA personnel, who will carry out the verification study.

Under an Interagency Agreement the air quality models LIRAQ-1 (SO_2) and LIRAQ-2 (photochemical) are being adapted for use with the data base provided by the Regional Air Pollution Study (RAPS). These models were developed at the Lawrence Livermore Laboratory and have been previously applied to the San Francisco Bay Area. In order to gain access to the LIRAQ Model, it is being transferred to the Lawrence Berkeley Laboratory under this agreement. This transfer involves major coding changes because of computer differences; the effort covers all of FY-76 and is due to be completed February 1, 1977.

LIRAQ is an Eulerian grid model having a minumum horizontal resolution of 1 km but only one level in the vertical. Wind and pollutant concentration profiles are assigned from empirical power law approximations. Simulations are dependent on prescribed meteorology (wind speed and direction, atmospheric transmissivity, and mixing depth) and source emissions. A unique feature of

LIRAQ is its ability to generate a mass consistent wind field which has minimum deviation, in a least square sense, from the observed field. This feature is of great importance in areas of complex terrain and may also be useful for RAPS.

2.3.16 Model verification using RAPS data

Eight or more numerical, urban-scale air quality models will be tested for predictive accuracy using the data from the Regional Air Pollution Study (RAPS). These models represent state-of-the-art approaches which cover a broad spectrum of computational complexity. Most of the models are of an Eulerian type, consistent with the data derived from RAPS. The SO_2 models currently include a box model, RAM (Gaussian plume), LIRAQ-1 (single level grid with mass-consistent wind field), and IBM (multi-level grid). The photochemical models include a box model, LIRAQ-2 (single level grid with mass-consistent wind field), and SAI (multi-level grid).

This will be the first study in which a number of models are tested side-by-side against the same data base. It is hoped that comparisons of observations with model predictions will provide answers to the following questions.

(1) How well do models predict pollutant levels at a particular point in time and space?

(2) Do complex air quality models, using large amounts of computer resources, offer a significantly better predictive capability than simpler, less costly models?

It is also belived that insights will be gained which identify problem areas in existing approaches and lead to model improvements.

This study has been delayed during FY-76 due to lack of a complete emissions inventory for St. Louis. The inventory is expected in Spring 1977, at which time production runs of the SO_2 models will begin. In anticipation of receiving an emissions inventory, a running strategy has been developed. The data tape formats have been structured and modifications have begun on the models so they can accept and best utilize the RAPS data.

2.4 Physical Modeling

2.4.1 Facility, systems and equipment

The Fluid Modeling Facility (FMF) provides a laboratory for in-house study of atmospheric dispersion using laboratory simulation techniques. Two wind tunnels and a water channel/towing tank are used to model the dispersion of emissions released near buildings or from sources over complex terrain for both neutral and stably-stratified atmospheres. The Fluid Modeling Facility is located in Research Triangle Park, NC.

The new water channel/towing tank and its associated filling system to produce stratified density layers, constructed by Aerolab Supply Company of Laurel, Maryland, were completed in December 1975. Most of the remainder of FY-76 was used to instrument, test, and evaluate the new facility.

In addition to the developmental work performed on the water channel/towing tank, serious efforts were directed towards increasing the accuracy of measurement of velocity components, turbulence, and Reynolds stress with hot-film anemometers.

Four major research projects were undertaken during FY-76. Two of the studies dealt with dispersion from sources near buildings, another was a continuation of the work begun in FY-75 on near-highway dispersion of automobile exhaust and the fourth is a study of evaporation rates from grass-like surfaces.

The FMF meteorological wind tunnel (MWT) is an open-return tunnel with a test section 3.7 m wide, 2.1 m high, and 18.3 m long. Neutral atmospheric boundary layer flows are developed in the test section with vortex generators and surface roughness elements (Counihan, 1969). The test section air speed can be varied from 0.5 to 10.0 m/sec. A remote controlled instrument carriage positions velocity or concentration sensors anywhere in the test section.

The EPA Air Pollution Training Institute houses its wind instrument calibration and demonstration wind tunnel in the FMF. This tunnel is available for use by the FMF except for times it is required for EPA training courses. The tunnel is 1 m wide, 1 m high, 3 m long and is useful for special projects and small scale studies.

The new water channel/towing tank (WCTT) is, as its name implies, a dual function facility (Figure 18). In the water channel mode of operation, velocities of up to one m/sec can be obtained in the 2.4 m wide, 1.2 m deep, 25 m long test section. Models are either fixed to the floor, as in a wind tunnel, or suspended from a platform into the moving water to model neutral atmospheric conditions. The towing tank mode of operation is achieved by blocking the ends of the test section with gates and filling it with layers of salt water. The density of each layer is controlled by mixing variable proportions of saturated salt water and fresh water with an adjustable mixing valve. Stably-stratified atmospheres are modeled by this density stratification. Models are mounted on a platform, suspended from a variable speed (0.1 to 0.5 m/sec) towing carriage, and towed through the still fluid. Multiple channel velocity and concentration probes are used to maximize the data obtained per run.

A Digital Equipment Corporation PDP 11/40 minicomputer, located within the FMF, is used to digitize, linearize, process, and store all laboratory data. The system was greatly expanded during FY-76 and now includes 3 magnetic tape drives, 3 disk drives, an 80K memory bank, a 16 channel analog-to digital converter, a refresh-graphics terminal, and an electrostatic printer/plotter. The new operating system, RSX-11D, is a multi-task, multi-user system.

Fluid velocities are measured with constant temperature hot-film anemometers. Thermo-Systems, Inc. model 1054A and 1053B anemometers are used with

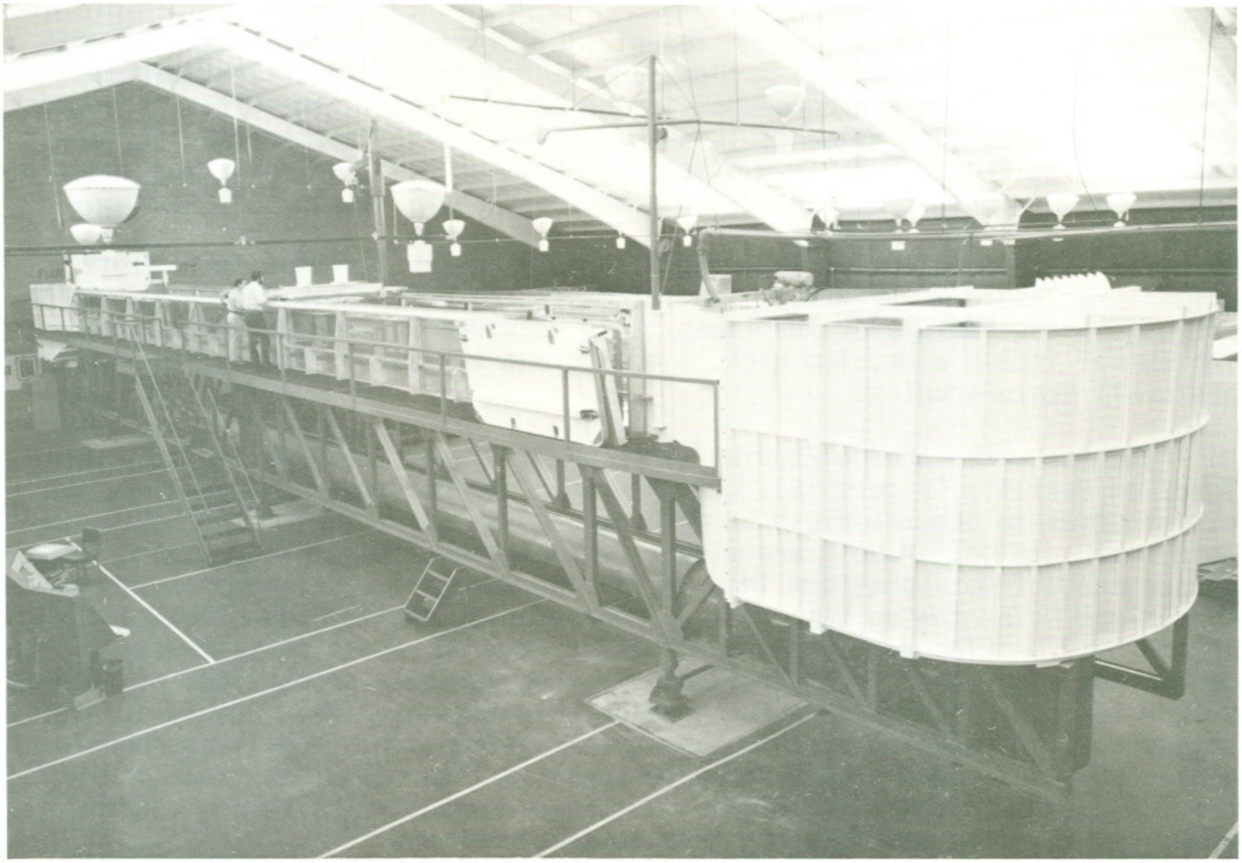


Figure 18. The Fluid Modeling Facility's water channel/towing tank.

a variety of probes (e.g. models 1210 and 1230). Special protective coatings are applied to the probes intended for use in salt water. The signals from multiple channels are processed in the minicomputer to yield real-time results of velocity, turbulence intensity, and Reynolds stress. The raw data are also stored on magnetic tape for later analysis of such things as turbulence spectra.

Hydrocarbon tracers are used for quantitative measurement of concentration in the wind tunnel studies. Beckman model 400 hydrocarbon analyzers (flame ionization detectors) give reliable determinations of the percentage of tracer (butane, methane, etc.) in samples drawn from various positions in the dispersion field. The analyzers are connected to the minicomputer for real-time feedback of results.

Concentration measurements in the WC/TT are made by using dye (food coloring) as a tracer and collecting samples with a vacuum system. The samples are drawn into small glass jars and the amount of dye in each sample is then determined with a Bausch and Lomb spectrophotometer (Spectronic 20).

Fully equipped machine, woodworking, and electronic shops accomodate in-house construction and repair of models and electronic instrumentation.

2.4.2 Complex terrain studies

A wind tunnel study conducted in the Fluid Modeling Facility (Huber et al., 1976) vividly portrayed augmented dispersion of pollutants in the lee of a ridge. A limited review of the literature reveals that similar effects have been noted in field studies. An attempt is being made to account for these potential adverse influences on air quality concentrations measured at ground level. Based upon physical modeling, the following approximation was derived for σ_z', the dispersion coefficient which represents the augmented, hourly vertical standard deviation of concentrations at right angles to the plume axis:

$$\sigma_z' = [\sigma_z^2 + (0.7R)^2]^{1/2}$$

where subscript z refers to the vertical coordinate, σ_z is the Pasquill-Gifford dispersion coefficient, and R is the ridge height in meters.

The σ_z' is used only when the source lies in the lee of a ridge, and no further than 10R from the ridge crest; only when wind speed u exceeds 3 ms^{-1}; and only when the effective plume height, H, is less than 1.5R. H is defined by $3DW(u+h_s)$ where D is internal stack diameter, W is stack gas exit velocity, u is wind speed at stack height, and h_s is physical stack height. At $u > 3$ ms^{-1}, the turbulent wake due to the ridge is considered to be fully developed, and the above evaluation appropriate as a first approximation of the effects of the ridge. However, when $u > (2/3)W$, $H=h_s$ is used. Evaluation of this approach will proceed as appropriate field data become available. No generalized expression for an augmented horizontal dispersion coefficient, σ_y', has yet been derived.

2.4.3 Roof-top emissions

Pollutants released at the roof level of buildings are nearly certain to be trapped in the aerodynamic cavity of highly turbulent flow that forms in the lee of the building. Once trapped in this cavity, the pollutants are drawn to ground level where human exposure is of concern. A basic study was performed in the MWT to determine the downwind concentration field of a neutrally buoyant, low-momentum effluent released from the center of the roof of an isolated building (Thompson and Lombardi, 1977). Four rectangular building shapes were studied with a cubical building used for the most extensive measurements. Vortex generating fins and floor roughness elements were used to create a boundary layer flow in the wind tunnel test section.

Vertical, crosswind, and downwind profiles of concentration were determined by emitting a low percentage of tracer in the effluent from the model source, drawing samples downwind, and analyzing them for tracer content. The measured concentrations, C, were non-dimensionalized with respect to the building height, H, the wind speed at that height, U_H, and the emission rate, Q, to give $\chi = CU_H H^2/Q$. The non-dimensional concentrations at ground level under the plume centerline as a function of downwind distance for four experimental cases are shown in Figure 19. It was observed that for a cubical building, changing the approach wind direction from perpendicular to a building face to 45° to a building face increased the maximum ground level concentration by a factor of six.

2.4.4 Building effects on short stack effluents

A study was performed in the MWT to investigate the effects of a squat building on the dispersion of the effluents from a short stack located nearby (Huber et al., 1977). The building, block-shaped with its width twice its height and breadth, was oriented with the broad face perpendicular to the approach wind and the stack was located midway along the downwind face. The model was placed in a boundary layer created in the wind tunnel test section with cortex generating fins and floor roughness. Several combinations of stack height, stack diameter, effluent momentum and effluent buoyancy were examined. Both smoke visualization and effluent tracer techniques were used to examine the characteristics of the building cavity and plume entrainment. To determine the influence of the building on dispersion, each case was repeated with the building removed. Building influences were observed for stacks up to twice the height of the building; the primary influence was a vertical oscillation of the building cavity size and shape which greatly increased the vertical mixing.

Based on the results of this study, a numerical model was developed which predicts the concentrations for this type of situation (Huber and Snyder, 1976). A formula for an enhanced vertical dispersion coefficient, to account for the increased vertical mixing, is used to adapt the well-known point source Gaussian plume formula.

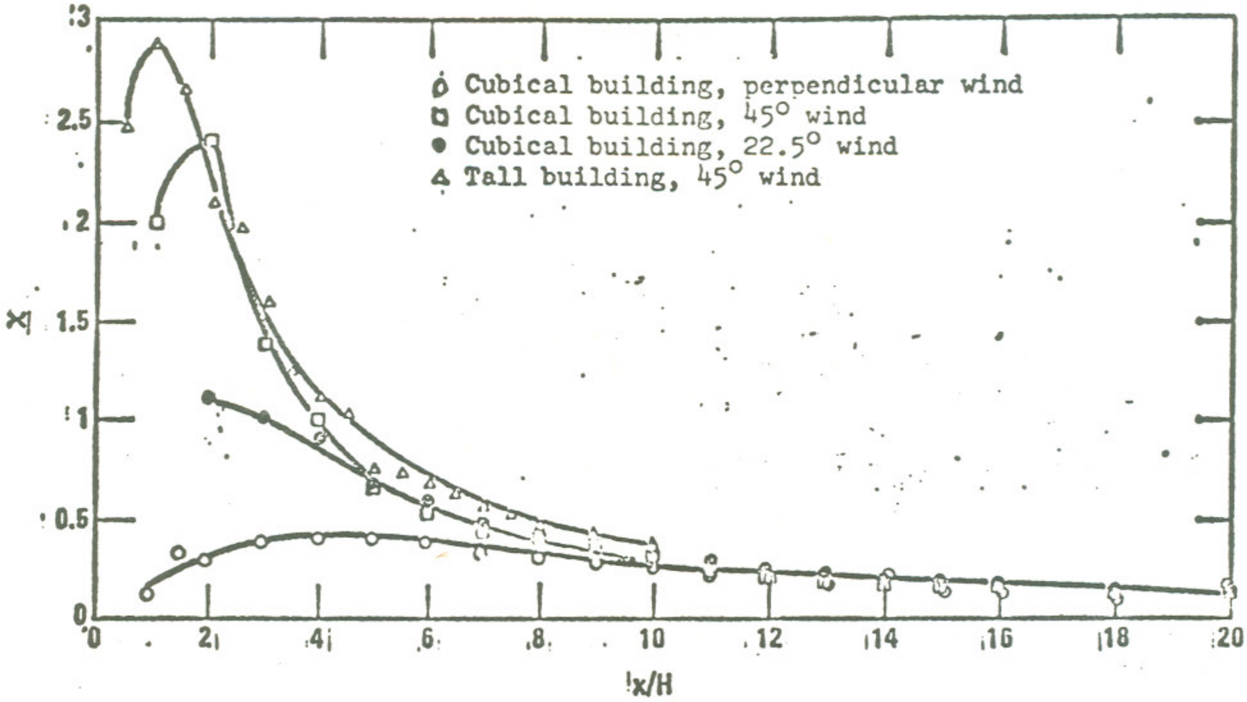


Figure 19. Non-dimensional ground-level concentrations, χ *under plume centerline as function of downwind distance, x. Values are shown for a cubical building with wind directions perpendicular and at 45° and 22.5° to the upwind building face, and for a taller building (one with its height twice the other dimensions) with a 45° wind direction. H is building height.*

2.4.5 Canopy flow experiment

A study was begun to investigate the characteristics of turbulent flow within and above a grass-like canopy. The objective of this experiment is to supply important parameters to a numerical model for transfer of gaseous pollutants to natural surfaces.

Steel pans, capable of holding liquid, were constructed and installed on the floor of the Air Pollution Training Institute wind tunnel. An array of several thousand upright aluminum strips, 0.6 cm wide, were fastened to a Plexiglass base to form the grass-like canopy. By adjusting this base vertically in the pan, the height of the blades above the liquid surface could be varied from 0 to 10 cm.

Mean velocity, turbulence intensity and Reynolds stress profiles were measured with an X-configuration hot-film anemometer for different combinations of wind speed and blade height. Figure 20 shows the mean velocity profiles over the canopy for three different blade heights. As this experiment continues into FY-77, the pans will be filled with isopropyl alcohol. Direct measurements of evaporation rates coupled with profiles of alcohol vapor concentration between and above the blades will supply information on turbulent transfer efficiecty within a canopy.

2.4.6 Near-highway dispersion of automobile exhaust

This study was a continuation of the work begun in FY-75 that involved the construction of a 1/32 scale model that utilized moving vehicles as pollutant sources. The model vehicles were affixed to a chain that extends around sprockets at either side of the MWT test section. The chain is driven by an electric motor with a variable speed arrangement.

During FY-76 the model was modified to increase the tracer emission rate, and hence produce more reliable sampling levels. A rotating manifold was mounted to the ceiling of the wind tunnel test section with a supply tube connected to each of two vehicles. A measured rate of tracer was fed to the manifold to define the emission rate from the vehicles. Vertical, lateral, and longitudinal concentration profiles were determined for a case where the highway was oriented perpendicular to the wind.

2.4.7 Equipment development and evaluation

Hot-film anemometers have proved to be valuable for the measurement of fluctuating velocities in air and water. In addition, the small size of the probes make them quite applicable to the types of measurements required in fluid modeling studies. Since the rate of heat loss from the heated probe, used to compute the fluid velocity, is dependent upon the difference in temperature between the probe and the ambient fluid, changes in ambient temperatures must be compensated for. Another difficulty encountered with hot-film anemometry has been obtaining good calibrations of individual probes, especially cross-wire configuration probes.

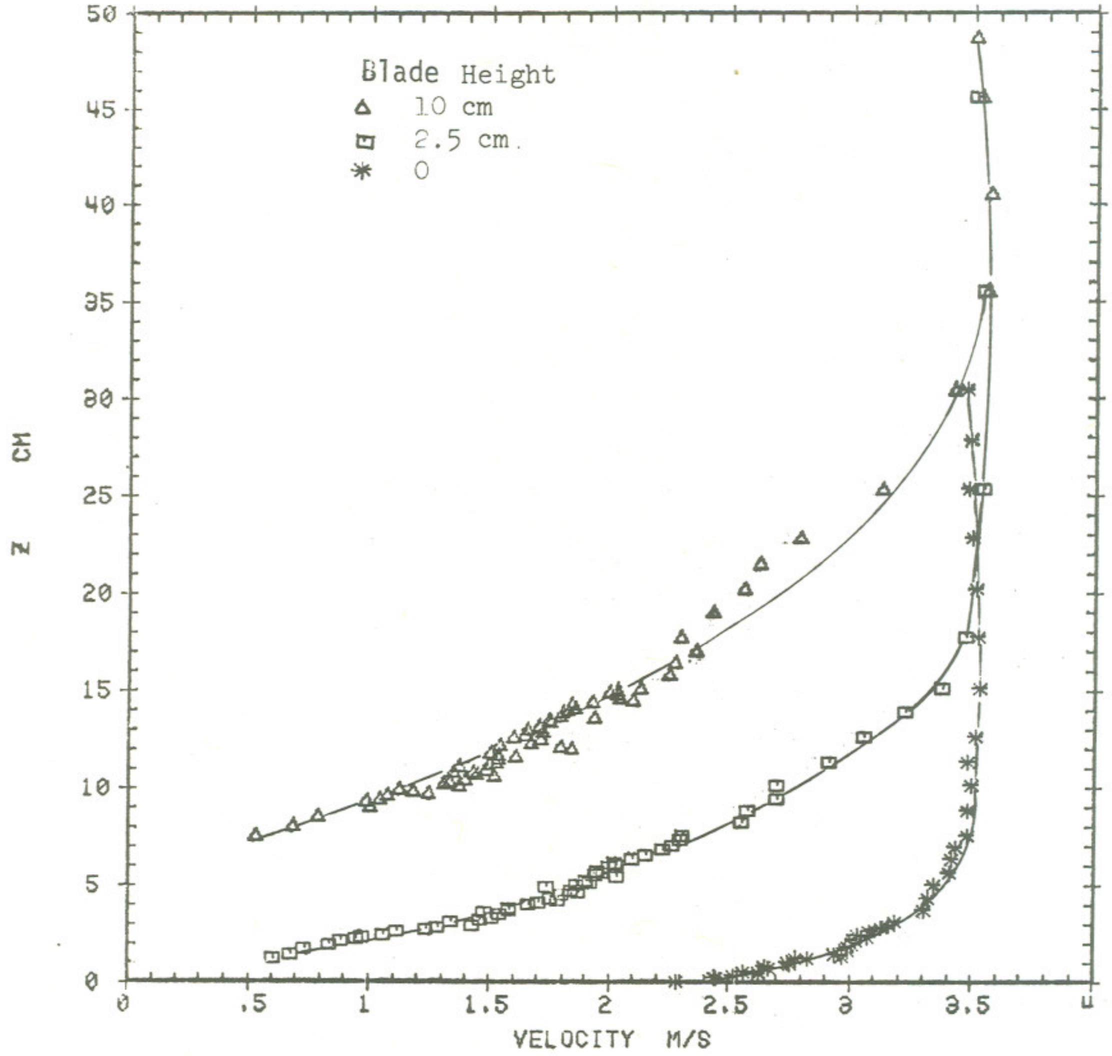


Figure 20. Mean velocity profiles over simulated grass-covered surfaces.

Once a probe has been calibrated, it is used for measurements throughout the day. Temperature variations within the laboratory were found to be affecting measurements, with morning to afternoon temperature differences producing errors in indicated velocity as large as 10 percent. A literature search did not turn up a suitable or well-accepted technique for making temperature corrections. Thus, a systematic study of the temperature dependence of the anemometer output was made to determine a correction technique to apply to the existing computer software used in processing the anemometer signal. A temperature-controlled calibration chamber was constructed and used to experimentally determine the appropriate temperature dependence. A temperature correction technique was based on this dependence and implemented into the existing software.

Two hot films arranged in a cross configuration with the elements at right angles to each other and at 45° to the mean flow are used in a probe to measure two components of a fluctuating velocity as well as their cross-correlation or Reynolds stress. To gain faith in the accuracy of this type of probe and the computer program that was prepared in-house to analyze its output, an experiment was conducted. A pipe flow apparatus was constructed to reproduce a turbulent shear flow for which several investigators have reported profiles of turbulent velocities and Reynolds stress. The profiles obtained in this investigation agreed quite well with the published results to indicate that the techniques used by the Fluid Modeling Facility are satisfactory.

To quantitatively determine concentrations produced by sources modeled in the water channel/towing tank, a tracer technique had to be developed. There were many to choose from, including dye, temperature, radioactive materials, and chemical properties such as pH. Because of its detectibility over a wide range of dilutions and its negligible interaction with other materials present in the water (NaCl, chlorine, etc.), dye or food coloring was chosen. This is also a safe material to handle, rather inexpensive and easy to remove from the water with bleach. Dye is easily mixed with salt water and alcohol to produce effluents of desired densities.

A system of collecting multiple samples from various sampling ports on the model and drawing them into separate bottles for subsequent analysis was constructed (Figure 21). The concentration of dye in each sample is determined by measuring light transmission characteristics with a spectrophotometer.

2.4.8 Other Fluid Modeling Facility activities

Dr. Gary Briggs, NOAA Atmospheric Turbulence and Diffusion Laboratory, joined the staff of the Fluid Modeling Facility in September 1976, for a period of approximately 20 months. He will work in close cooperation with the staff on numerous projects, including plume rise in stratified atmospheres, building effects on effluents from short stacks, and possibly multiple plume interactions.

A grant for "Basic Studies of Boundary Layer Flow and Diffusion Over Small Scale Topography" was awarded to the Department of Geosciences, North

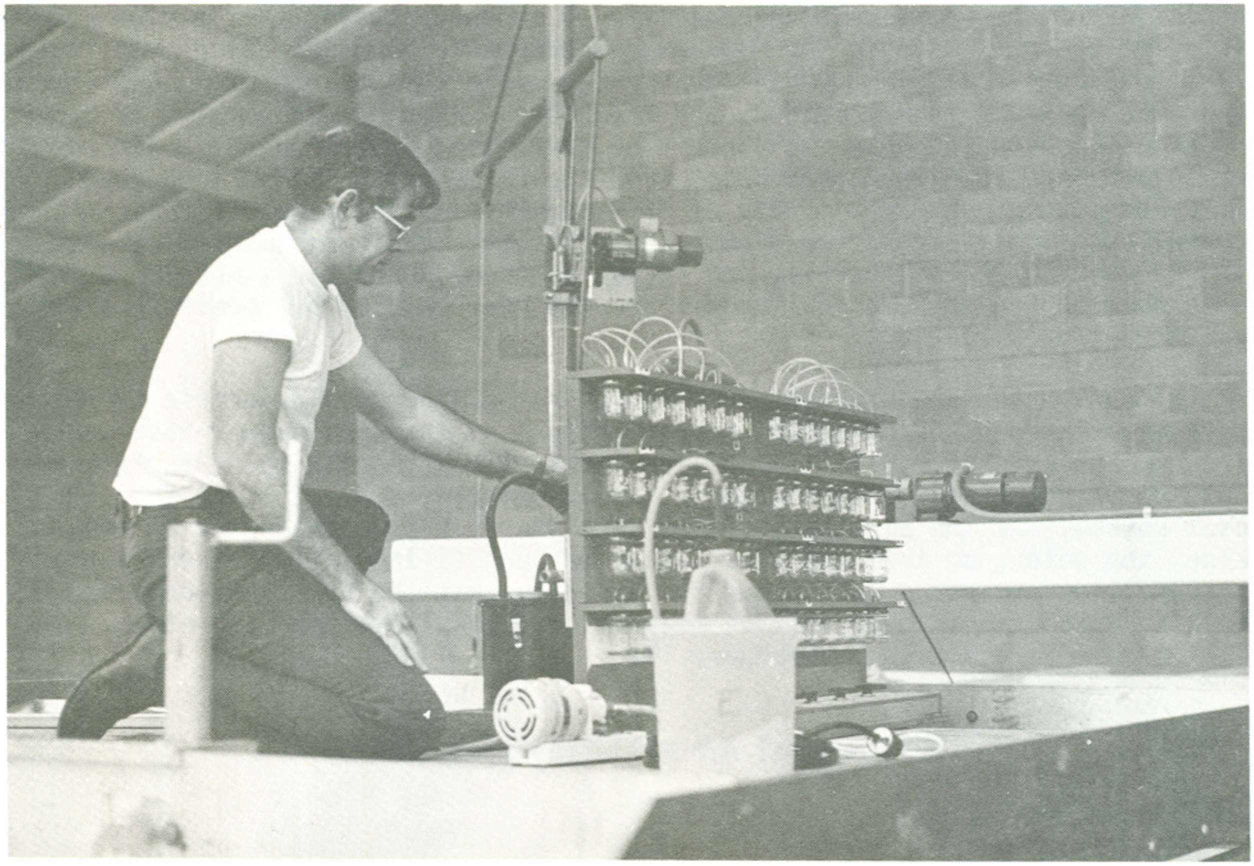


Figure 21. Sample collection system for dye tracer analysis technique for water channel/towing tank.

Carolina State University. Under this grant, a graduate student will use the facilities of the Fluid Modeling Facility to conduct studies of the flow and diffusion of pollutants in the simulated atmospheric boundary layer over complex topography (hills and buildings). Also under this grant, Dr. J.C.R. Hunt, Department of Applied Mathematics and Theoretical Physics, University of Cambridge, will join the university staff as a visiting professor for a six month period and work in close cooperation with the FMF staff in conducting model diffusion studies in the vicinity of two- and three-dimensional objects in neutral and stably-stratified flows. Coincidently, the experimental results will be used to extend, verify, and refine existing theoretical models as well as to develop new mathematical models for the more complex but commonly encountered flow situations.

A grant with the University of Houston to develop a colorimetric technique for the measurement of pollutant concentrations in the wind tunnel has received a four month extension. This technique involves coating the model surface with a pH sensitive gelatin film. Ammonia gas is emitted as a pollutant from the model source. As the ammonia diffuses into the film it changes the pH and, hence, the color, so that the final color pattern is indicative of the surface concentration pattern. Tests thus far indicate that the film developed provides a reproducible, quantitative measure of ground level concentration. The final report is expected in February 1977.

2.5 Regional Air Pollution Study (RAPS)

2.5.1 Introduction

In 1972 a major program was initiated in the St. Louis metropolitan area, the Regional Air Pollution Study (RAPS). The prime purpose of the program is the collection of a complete, accurate, verified data base in an urban area for use in the development, modification, and evaluation of air quality simulation models. During FY-75 the St. Louis observational network became fully operational. Operations continued through FY-76 under the direction and sponsorship of the ESRL and will cease in March 1977.

Operation of the field observation network and support for a variety of field studies was provided by the Air Monitoring Center of the Rockwell International Corporation under contract to EPA. Supervision of the program was done by NOAA personnel assigned to St. Louis.

2.5.2 Regional Air Monitoring System (RAMS)

The basic component of the RAPS field program is the Regional Air Monitoring System (RAMS). RAMS consists of a 25-station aerometric network tied to a central computer facility by telephone lines. All stations are equipped to measure ozone, oxides of nitrogen, carbon monoxide, methane and total hydrocarbons, total gaseous sulfur, aerosol light scattering coefficient, temperature, dew point, wind direction, and wind speed. At selected stations, sulfur chromatographs are used to measure sulfur dioxide and hydrogen sulfide in addition to total gaseous sulfur, and at other stations vertical temperature differences between 5 and 30 meters height is measured. Atmospheric pressure is measured at seven stations, and direct and diffuse solar radiation, as well as infrared sky radiation is measured at six stations.

A central computer controls operation of the stations. Commands are telemetered to the stations for operation of calibration systems to determine instrument zero and span responses, and once each minute stations are polled for acquisition of data. In addition to instrumental readings, a number of status check values are also telemetered back to the central computer. These status checks furnish information on operation of the instruments and systems, e.g., whether the flames are burning in the detectors of certain instruments, whether gas pressures are within proper limits, and whether temperatures in portions of the calibration system are within limits. Each station is equipped with a mini-computer which has local control of the station equipment and data acquisition system. All data that are normally transmitted each minute to the central computer are also stored locally on magnetic tape. Thus, if there is a telecommunication failure, due to problems with the central computer, with the telecommunications interfaces, or in the telephone lines, data can be retrieved by pickup of the station tapes.

Previously, major emphasis had been on the RAMS fabrication, installation, and operation. In FY-76 added emphasis was given to quality assurance, both in system operation and data processing. Preventive maintenance is performed regularly for the instruments and supporting equipment, and procedures were set up enabling corrective maintenance personnel to be notified of problems in a timely manner. Instrument calibrations are performed at regular intervals, and audits of the gaseous pollutant analyzers are also regularly carried out.

Considerable effort was put into developing criteria for validation of data, and developing the software to perform the validation. The objective of the validation steps is to maximize the quantity of high quality data. Questionable data are retained, but are flagged by cause, e.g., zero or span drift exceeding limits. Such questionable data would ordinarily not be retrievable as part of a routine request for data, but can be obtained if desired.

While the present data validation procedures are adequate to detect most questionable or erroneous data, there are some values that pass through the screening procedures that are highly questionable. It is expected that final procedures will be settled early in FY-77, with final archiving of RAMS data.

After the RAPS contractor had developed adequate internal quality assurance procedures, a separate contract was placed with an independent company to perform audits of the station instruments. Field audits were performed in June and September, 1976, with two more audits scheduled for the first half of FY-77. Results of these first two audits were quite satisfactory, indicating that even though the paths by which audit values are traced back to reference standards differ considerably, there were no serious differences between results obtained.

2.5.3 Upper Air Sounding Network

The Upper Air Sounding Network is made up of four fixed sites: one site near the urban center of St. Louis; a rural site in rolling terrain southwest of the urban area; a rural site in flat farmland southeast of the urban area; and a site on the grounds of an airport to the northeast. The latter two sites are in Illinois, whereas the first two are in Missouri.

Only the two Missouri sites were operated routinely. Operation consisted of five-day-a-week, Monday through Friday release of sounding balloons. Radiosonde releases were scheduled at 6-hour intervals, with the hours of release being seasonally adjusted so that the first radiosonde each day was released about an hour before sunrise. Pilot balloon soundings were made each hour except for those scheduled for radiosondes. Thus, for each site, 121 soundings were scheduled each week: 20 radiosondes, and 101 pilot balloon releases.

Major field exercises were carried out in July and August of both 1975 and 1976. During these periods of intensive activity the two Illinois sites were also used, with all four sites on a seven-day-a-week, around the clock schedule. A lesser field exercise was carried out in February and March, 1976, during which only the two Missouri sites were used, but on a seven-days-a-week schedule.

In spite of some problems with equipment and supplies, very few scheduled soundings were not successfully completed. About two percent of scheduled pilot balloon soundings were not completed, with virtually all missing observations associated with weather difficulties. Less than one percent of the scheduled radiosonde releases were not completed.

The quality control activities that were begun during the previous year were continued. All equipment is inspected and checked at regular intervals, and quality assurance personnel follow up on their observer training program by unscheduled visits to the sounding sites to ensure that proper procedures are used by site personnel. The recorded data are reviewed by quality assurance personnel to detect questionable recorded values, and possible errors in radiosonde computations. The data are then sent to North Carolina where computer calculations are used to work up the soundings and prepare output listings in convenient formats.

2.5.4 Other field support activities

In addition to operation of the RAMS and Upper Air Sounding Network, the contractor provided support for various short-period and continuing studies. Pilot balloon operators and teams were provided for both local and extended area studies of plumes from individual large sources as well as from the St. Louis urban area. The support was provided during the Summer 1975, Winter 1976, and Summer 1976 field intensive periods, as well as to Da Vinci II and III flights in June and July, 1976. Interim data from these sounding operations were provided to the various principal investigators who needed such data for operational decisions on a quick-response basis, but final release of data is made only after such data are put through the same quality control procedures as are used for Upper Air Sounding Network data.

Use was made of a small helicopter instrumented to obtain boundary layer profiles across the urban area during all periods. These flights were made in conjunction with instrumented surface vehicles which mapped the surface air properties. Measurements were made to determine surface heat and momentum fluxes, using both fluxatrons and the 3-dimensional propeller anemometers mounted on the towers at selected RAMS sites.

Numerous activities of a continuing nature were also performed. An installation of an array of surface and subsurface temperature measurements, together with near-surface atmospheric measurements was operated over and beside an abandoned runway at a local airport in a program to quantify the terms in the surface energy-balance equation. Operation of the WPL acoustic sounder installed at the urban Upper Air Sounding site, and analyses of the resultant data were also performed. Collection of total suspended particulate data by means of Hi-volume samplers, and laboratory analysis of the exposed filters was a continuing program. Also, operation of a network of dichotomous samplers was provided by the Atmospheric Instrumentation Branch, Environmental Sciences Research Laboratory, EPA. The dichotomous samplers are designed to divide the sampled aerosol into two size fractions by virtual impaction, with collection of the two fractions on small filters. The separation diameter is about two microns. The filters are mounted on holders which are inserted into 35-mm slide cases, 36 filters per case. The filters are sequentially inserted into the samplers at pre-set, fixed time intervals. After exposure, the filters are sent to the Lawrence Berkeley Laboratory, where through an Interagency Agreement with ERDA, they are analyzed by X-ray fluorescence for as many as 20 elements in addition to total mass.

A project to perform comparison audits of gaseous pollutant analyzers was also carried out. A Winnebago van was equipped with analyzers and calibration equipment to serve as a mobile calibration facility. It was first used extensively during the Summer 1975 Field Exercise, during which all analyzers used by experimenters were scheduled to be audited at least twice. These audits were performed with analyzers in place in the helicopter, plane, van, trailer, etc. in which they were mounted for use. Similar audits were also performed during the Winter and Summer 1976 Field Exercises. During the remainder of the time, the van was used to perform several checks on analyzers installed in the Illinois EPA, St. Louis City, and St. Louis County monitoring stations, as well as supplementary checks at a few of the RAMS stations.

Collection of whole air samples with subsequent analysis by gas chromatography was another task performed routinely. The samples were collected at a variety of sites selected on the basis of expected pollutant levels and constituents, and returned to the central facility where they were analyzed for $C_1 - C_{10}$ hydrocarbons. This more detailed characterization of ambient hydrocarbons is necessary because the importance of a particular species in photochemical reactions is highly dependent on its molecular structure. The scheduling of sample collection was based primarily on the well known diurnal cycle of vehicular emissions, with 2- or 3-hour samples collected most frequently during the morning traffic peaks and a lesser number of samples collected during the pre-dawn minimum, during the mid-day traffic plateau, and during the evening peak. Some problems were discovered with the Teflon bags used to collect the samples, and thus studies were also performed to assess the apparent out-gassing of hydrocarbons from the bags for a matrix of exposure conditions, as well as to determine the diffusion rates of various species through the bags when stored in the laboratory. These studies led to some revision of sampling and analysis schedules and procedures to minimize contamination and loss errors. Another limited study performed was to sample continuously for a period of a month at the site of the former Continuous Air Monitoring Program (CAMP) station in downtown St. Louis. This station was one of the early installations of the CAMP, a program begun in the 1960's to collect data on gaseous pollutant levels nationally, using standard sampling procedures. Concern had been expressed that the RAMS data showed average values of primary vehicular pollutants, carbon monoxide and hydrocarbons, significantly lower than the older CAMP data did. The sampling conducted under this limited study clearly indicated that the main cause of the differences was site location. The CAMP site is on the edge of a parking lot adjacent to a major street, whereas the siting criteria for the RAMS stations preclude locations strongly affected by local sources.

The central computer facility was used for various field data reduction runs. A quick look at reduced data, even if in raw, unedited form, is highly desirable to detect errors or malfunctions in analyzers and data acquisition systems. Data tapes primarily from airborne platforms were examined during all Field Exercise periods. Complete data reduction runs were performed on these tapes post-operationally. In addition, the central computer was used for reduction of data from the surface energy balance study, and for logging and editing data from the total suspended particulate measurements and from the gas chromatography laboratory operation. Lidar data from the van obtained in conjunction with the urban boundary layer studies were also reduced on the central computer.

A study to determine the role of ambient pollutant levels on materials was conducted beginning in October 1974 by the RAPS contractor for the EPA. Exposure racks were constructed and installed on the roofs of nine of the RAMS stations. Material specimens are mounted on the racks, with some facing upward, some downward, and some vertically. The specimens are of various metal surfaces -- stainless steel, galvanized steel, silver, stressed and unstressed aluminum -- painted surfaces of various types and colors of paint, and stretched nylon mesh. Some specimens will remain exposed for the duration of the RAMS operations, while others have been removed and replaced at a set of intervals. The specimens removed are analyzed for damage assessment by various means. The nylon mesh, for instance, is examined to see how many, and what size holes have developed, whereas the metal and paint surfaces are analyzed for weight changes, and by chemical and physical examination.

2.5.5 Emission inventory

A major part of the emission inventory work was carried out by the RAPS contractor. The many forms of input data and estimates, together with the need for better spatial and temporal resolutions of the emissions, require a comprehensive emission inventory data handling system. Development of the required system was started in the spring of 1974, but frequent modifications have been required to incorporate the changes in methodologies used in the many components making up the total inventory.

A further difficulty has been the operation of the computer facility in North Carolina on which the inventory system is to function, with serious slippage from originally planned schedules because of computer and/or peripheral equipment malfunctions. The overall result has been that utilization of the complete data handling system is not expected to be possible until the Spring of 1977.

In spite of these difficulties, most work on the components going into the emission inventory is completed or continuing. Collection of monitoring data from large point sources from which an accurate temporal allocation of emissions can be derived was begun in October 1974 and continued throughout the present Fiscal Year. Some records from one of the St. Louis utilities are not as complete as desired because of a strike in the summer of 1975. A few companies have cut back on the detail in the information they have provided, but nevertheless, most information originally sought is still forthcoming.

A number of individual sources were tested by sampling from the stacks that emit the effluent, in order to obtain updated St. Louis area information on emission factors. Emission factors are multiplier values used in conjunction with rate and process information to obtain emission estimates. For example, emission rates of SO_2 from combustion sources are calculated as directly proportional to the product of fuel combustion rate times percentage of sulfur in the fuel. Emission rates of oxides of nitrogen from stationary sources, on the other hand, are functions of the type of fuel, burner and furnace design, and level of unit operation as a percentage of design capacity, among other parameters. The source tests performed indicated that published emission factors for SO_2 were very good. Measured factors for CO and hydrocarbons, as well as for fine particulate concentrations, were generally lower than published values. The decreases in these factors in the last few years are consistent with the recent emphasis on good combustion practices as a means of fuel economy, i.e., sending unburned fuel up a stack wastes money. The measured factors for oxides of nitrogen averaged well below the previously estimated emission factors, with one exception. However, the range of emission factors measured were within the range of values previously measured to obtain the estimated factors for the type of sources tested.

In addition to measurements to obtain emission factors, measurements were also made to determine the proportion of sulfur emitted as SO_3 or sulfate, rather than SO_2. The portion of sulfur in the higher oxidation state averaged about 1.5%, in line with previous measurements and estimates considering the fuels used in the St. Louis area.

Previously published estimates and measurements of the size distribution of aerosols emitted by the various categories of sources were used to derive crude estimates of size distributions of particulate emission for the St. Louis region. Similar work was performed to estimate emissions of non-criteria pollutants (substances for which an air quality standard has not been set), mostly metals such as lead, mercury, and arsenic. Because the reliability of the particle size and non-criteria pollutant inventories is low, only annual estimates were made. In most cases, however, temporal allocation paralleling fuel use by source category is possible. Work is underway to estimate emissions from miscellaneous smaller sources, such as power lawn mowers and construction equipment. Emissions from these sources will be allocated spatially to the RAPS area source grid, but the temporal allocation will be very crude, e.g., for power mowers, daylight hours during the frostfree season will all have uniform emission rates, with zero emissions during all other hours.

2.5.6 Special RAPS studies

Many other investigators utilized the data base and facilities available from the RAPS program during the Field Exercise periods. Instrumented large helicopters from the EPA Environmental Monitoring and Support Laboratory, Las Vegas, provided support in the form of preselected flights to provide data in support of particular experiments. During the two summer Field Exercises, three helicopters were located at St. Louis, with two being used, while the third underwent scheduled maintenance checks. During the winter-1976 Field Exercise only two helicopters were located at St. Louis, with only one usually being airborne during flight missions.

The preselected flight paths were chosen so that for any given wind direction, aerometric soundings would be made over 6-8 RAMS stations in a roughly elliptical overall flight path. The paths were selected so that the soundings would provide data upwind of the urban area, as well as downwind of the principal source aggregation. About half the missions during the summer-1975 Field Exercise were of this kind, with a somewhat higher proportion during the other two periods.

Special flights supported many other field projects. During both summer Field Exercises, missions were flown when the weather appeared suitable to determine the location and intensity of the oxidant maximum downwind of the St. Louis area, as well as the downwind changes of NO and NO_2 preceding the oxidant peak. These missions usually extended 60-80 km downwind of the urban center.

Numerous missions were flown in support of plume characterization and pollutant transformation studies. The helicopters usually were used to obtain the near-source measurements, with fixed-wing aircraft measurements at greater distances. While primary emphasis in these plume measurements was on SO_2, sulfates, and aerosols in general, it was also important that other pollutants, especially ozone and oxides of nitrogen, be measured because of the many potential mechanisms associated with SO_2 oxidation and aerosol formation. These helicopters served a similar purpose during the flight of Da Vinci III, mapping the pollutant profiles in a plane normal to the wind in a Lagrangian framework tied to the manned balloon's position.

As part of the plume transformation studies, attempts were made to measure mass fluxes using the special pilot balloon soundings together with aircraft traverses at several altitudes and ground-based traverses to measure total overhead burdens of SO_2. In addition, another series of measurements was conducted to estimate uptake of SO_2 by surface vegetation. Samples were also collected on some of the aircraft flights by specially designed impactors to permit subsequent morphological examination of the collected aerosol.

The helicopters provided support for solar radiation studies, making special soundings over RAMS stations equipped with radiation sensors to obtain more complete data through the depth of the boundary layer. The helicopters during the summer 1975 Field Exercise made repeated flights above a RAMS site being used for a study of local pollutant variability, to provide a measure of temporal variability of concentrations as a function of height. They were used to collect syringe samples of SF_6 during a preliminary tracer study, to collect whole-air samples in Teflon bags for subsequent analyses at the gas chromatography laboratory, and to collect total aerosol samples for detailed analysis by another investigator.

The local pollutant variability studies were joint efforts by two investigators. One operated a tuneable diode laser as part of a van-mounted system to measure path-integrated pollutant burdens between the van and retroreflectors located generally 0.5 to 1 km from the van. The other used a combination of fixed and portable instruments carried on back packs to obtain end-point and moving path measurements.

Studies were performed at two of the RAMS sites to extensively measure atmospheric aerosol, with emphasis on the sulfur valence states, compound formation, and acidity of the aerosol. Evaluation of instrumental performance, as well as determining effects of filter material, sampling rates, and analytic procedures were all components of these studies.

During the 1975 summer Field Exercise, two other investigators conducted special boundary layer studies. One investigator made use of the National Center for Atmospheric Research (NCAR) aircraft to measure turbulent properties within the boundary layer over the area, together with trained teams from the Air Weather Service to obtain double-theodolite pilot balloon observations from which divergence may be calculated. The other investigator used an aircraft to make further measurements to describe the urban boundary layer in terms of temperature, moisture, and aerosol measurements, together with additional measurements of wind information from aircraft flight data and supplementary short-wave radiation measurements.

During the 1976 summer Field Exercise, a van-mounted Lidar system was operated by a contractor to obtain additional information on the boundary layer structure and its temporal and spatial changes. The Lidar system was also used to characterize the aerosol distributions within elevated plumes. The NCAR plane was used by a grantee to obtain further measurements of boundary layer turbulence statistics and of the influence of the urban area on these statistics and in the overall structure of the urban boundary layer.

Results of the many studies performed during the Field Exercise periods as well as data from the RAMS at year's end were at various stages of reduction, analysis, and verification. Results of primarily meteorological studies are reported more fully elsewhere in this report, and so only results of other studies already available are summarized below. While these studies were not direct ML efforts, they were supported by ML personnel in St. Louis and are included here for completeness.

The plume studies of SO_2 transformation have shown that the initial rate of conversion to sulfate proceeds at a rather slow rate of 1 to 2% per hour, with an increase to 5 to 6% per hour after a few hours travel. There is undoubtedly some temporal bias in these results, for usually measurements were begun early enough in the day that the plumes being measured were initially contained aloft within elevated stable layers, with only slow diffusion. As the plumes mixed with ambient air, the oxidant deficit in the plume, due presumably to NO emitted at the source, was replaced with an oxidant surplus relative to the ambient air.

Increased aerosol and particulate sulfate formation followed oxidant formation in time. The mechanism of sulfate formation cannot be determined from these measurements. The mixing of the plume which allows photochemical oxidant formation to proceed was generally attended by cumulus formation, meaning that air parcels were exposed to the liquid water in cloud droplets.

Because occurrences of very low transport winds lasting more than a few hours are rare in the St. Louis area, most emissions will be transported beyond the St. Louis Air Quality Control Region (AQCR) before there is significant formation of sulfate aerosol. Limited analyses made to date of the aerosol measurements from the Hi-volume samplers and from the dichotomous samplers indicate that particulate sulfate is predominantly from sources much more distant than these within the St. Louis AQCR. Both the spatial uniformity and the patterns of temporal changes indicate a lack of strong local influence. Rather extensive analyses that have been made of a few cases of higher sulfate concentrations as well as cursory examination of the synoptic situations associated with a number of other cases indicate the source region in such cases is the Eastern United States. There is typically a flat high pressure system to the east with rather light winds, implying air trajectories that were over the eastern part of the country for a minimum of four days before arriving in the St. Louis area. These cases are principally a summertime phenomenon, and the air is generally moist (dew points around 70°F) by the time it arrives in St. Louis, regardless of the air mass origin when it first started its slow drift over the eastern part of the country.

Studies of aerosol composition, with particular attention to the chemical forms of particulate sulfur, have not yielded results as definitive as had been desired. Nevertheless, there are strong indications that the sulfur is almost all in the form of sulfate, with at most a few percent sulfite. There is a deficit of metallic anions in the aerosol relative to the sulfate ions, which indicates that anions not detectable by elemental analysis, ammonium and hydrogen, are present. In other studies in which ambient aerosol is heated, the disappearance of aerosol is indicative of the presence of sulfuric acid and ammonium sulfate in varying proportions. Morphological examination of plume aerosols indicated that sulfuric acid, ammonium bisulfate, and ammonium sulfate aerosol were all present in different samples. The form of particulate sulfate cannot generally be determined from the routine Hi-volume and dichotomous sample measurements made at the RAMS stations, because of reactions that may occur in the sampling itself, or during the subsequent handling and transporting of samples prior to analysis. However, it is clear that the bulk of the particulate sulfur is found in the smaller size fraction from the dichotomous samples, with a typical percentage of 90% in that fraction. Limited comparison between total sulfur from the dichotomous samples, expressed as sulfate, and sulfate analyses of the Hi-volume samples show excellent agreement in measured concentrations.

Synoptic situations associated with higher background concentrations of ozone are somewhat like those associated with higher sulfate levels, but the variations of these two pollutants, discounting the strong diurnal variation of rural ozone concentrations, do not parallel each other too closely, indicating either that the sources of precursors are sufficiently different in detail, or that mechanisms of ozone and sulfate formation do not vary in parallel. Future work is planned to provide better understanding of conditions associated with higher concentrations both of background ozone and of sulfate.

Measurements and limited analysis made to assess the importance of St. Louis area sources on ozone concentrations show that while there is generally a suppression of ozone concentrations in the immediate areas of strong vehicular emissions, there is a downwind increase of ozone above regional background values associated principally with these same emissions. This downwind increase can only rarely be detected at the RAMS stations, because even when the wind direction may be from an appropriate sector, the ozone peak is generally at a greater distance than the most distant sites, roughly 40 km. Analyses of the total relationships between ozone, ozone precursors, and meteorological factors based on selected RAMS data are reported elsewhere in this report.

2.5.7 St. Louis land use inventory

A contract has been awarded to Environmental Quality Research, Inc. of Clayton, Missouri to prepare an inventory of land use patterns in the St. Louis area, using imagery from the LANDSAT satellite system. Using two grids, a regular array of 16 by 20 points 10 km on a side, and the RAPS Emissions grid, the contractor will produce a catalog of the fractional area of each grid cell (on each array) covered by each of the following categories:

water
marsh/swamp
grass cover
farmland
light density residential (with and without trees)
medium density residential and high rise
central business district
industry/railway
forest

After this inventory is prepared, it will be used with field data (already obtained) on heat fluxes over several of the land use categories to parameterize the surface heat flux for input for the meteorological sections of air quality models.

2.5.8 Objective analysis techniques

Control Data Corporation (Hovland et al., 1976) has developed an objective analysis program for the mesoscale gridding of hourly-averaged wind and temperature for the Regional Air Pollution Study in St. Louis, Missouri. The program is designed to produce an analysis on a horizontal, 21 by 21 grid with a 5 km grid spacing from a distribution of observations which is sparse near the boundaries of the grid and dense near the center. The grid is depicted in Figure 22.

An iterative scan procedure is used successively to correct an initial guess field until the analysis agrees reasonably well with observations. The mean square differences between the measured values at each station and the interpolated values from the analysis are calculated at the end of each iteration. The iterative process is terminated after the mean square differences approach zero.

The scan procedure was developed to approximate the field by first incorporating data from the widely-spaced outer stations and a large scan radius. This is successively followed by the addition of more observational data and reduction in scan radius. This procedure of simultaneously adding more data and shrinking the scan radius insures that the small-scale variability in areas of dense observations does not propagate into the surrounding areas where there are few data.

For the first iteration only the data observed at the four outermost stations are used. Data from eight more stations are used for iterations two and three and all data are used for iterations four and five. In addition, the scan radii used with each iteration are 20,15,7,4, and 1 grid units. The numbers of iteration when data from the stations are first used are given in Figure 22.

This objective analysis procedure was modified to generate analyses on a grid with greater spatial resolution (grid spacing of 1 km) and smaller total area (46 by 46). The procedure was used as a means of generating first-guess wind fields for a non-divergent wind analysis procedure, which is suitable for photochemical air pollution models.

A technical report will be written describing the modified version of the procedure, and the non-divergent wind analysis procedure. A sample of the output of the non-divergent wind analysis procedure for the 15-minute-averaged data centered around minute 7 of hour 7 CST of August 15, 1975, is illustrated by Figure 23. A listing of the computer programs and a user's guide will be included in the final report.

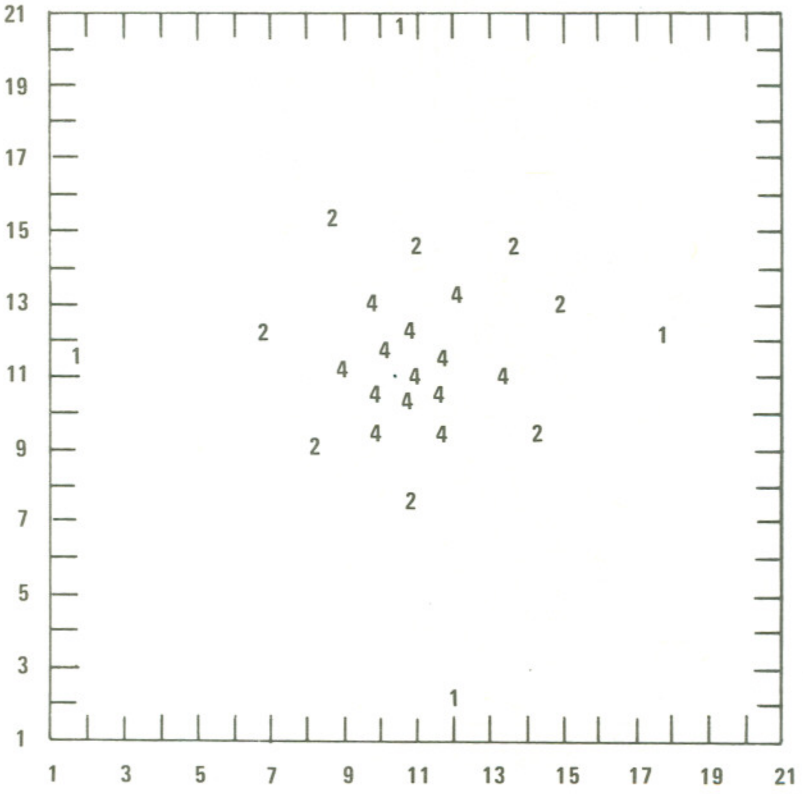


Figure 22. The boundary of the 21 x 21 grid used in the CDC objective analysis procedure and the RAPS data network configuration.

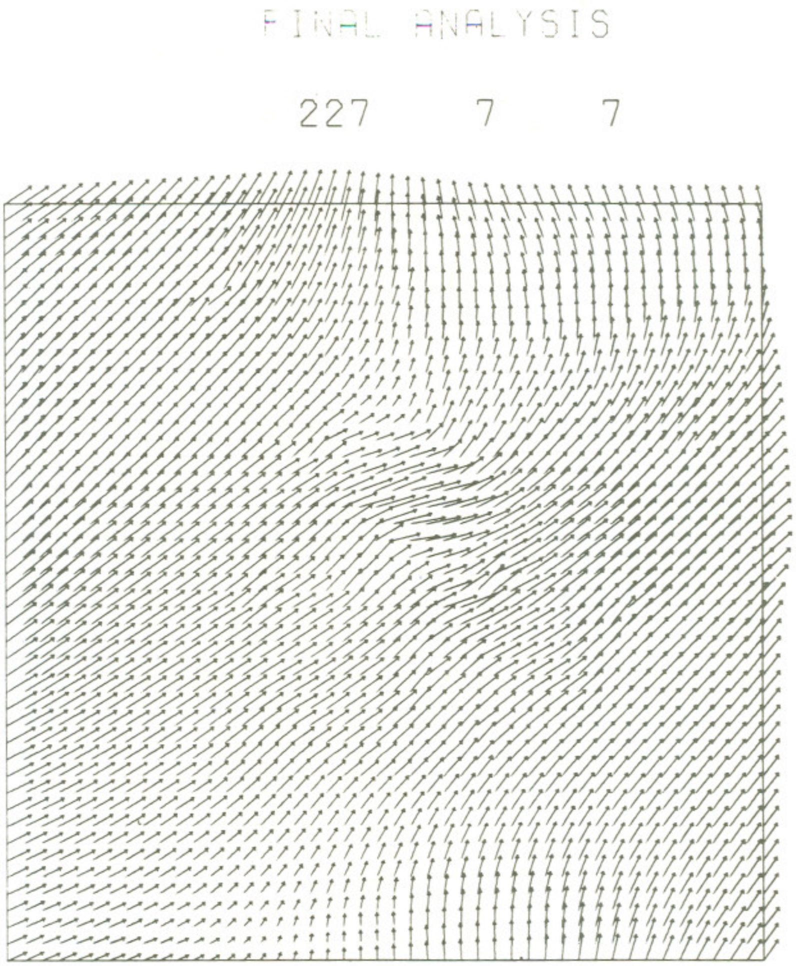


Figure 23. The analysis generated by the non-divergent wind analysis procedure for the 15-minute averaged data centered around minute 7 of hour 7 CST for August 15, 1975.

2.5.9 RAPS data management

The first two years of RAPS (1972-1974) were devoted principally to planning, contracting, site selection, facility construction, instrument selection, logistical support, preparatory research, and limited field programs. Data collection by the RAMS and the Upper Air Sounding Network began in late 1974.

RAMS is one of the most sophisticated air monitoring networks in operation. It was designed to provide a large body of valid ground level air monitoring data as the heart of the Regional Air Pollution Study. RAMS was formally accepted in March 1975 following results of a First Article Configuration Inspection (FACI) and two Systems Acceptance Tests (SAT).

The RAMS system can be logically divided into two parts -- the real-time, remote stations instrumentation (Table 4), data acquisition system hardware, and software; and the central facility which monitors and controls the RAMS data acquisition, telecommunications, and editing, validation and quality assurance analyses.

Several functions are performed in real-time under software direction at the central facility: The main function is the polling task in which data from the network are selectively retrieved and stored on magnetic tape in the central facility; the second major real-time function is to send messages to the remote stations for purposes of altering the instruments' status (e.g., initiate a calibration change, a range change, a change in averaging time, etc.).

Background programs use the St. Louis PDP-11/40 and are much more extensive than those required for polling. Because of the sheer volume of RAMS data (Table 5), the programs required to reduce, process, validate, and summarize the data must be exceptionally efficient, accurate, and yet flexible, in order to support personnel in operating, maintaining, and performing quality assurance and quality control for the network. It is in this processing, validation, quality assurance and quality control that the greatest changes and activities have taken place during the period of this report.

The most important background program for RAMS is a program called TAPEGEN: The purpose of TAPEGEN is to reduce and validate RAMS data.

As originally planned and placed in operation, TAPEGEN took data from the remote zero and span calibrations performed daily and updated all calibration files. Raw monitoring data from all network stations were read by TAPEGEN and converted to engineering units using updated calibration constants. "Validation" was performed using these calibration data and a variety of systems and instrument status words. TAPEGEN then computed all "validated" points for one-minute values from each of the network sources and wrote a second (Level II) tape for submission to RAPS Data Management in Research Triangle Park, North Carolina. On a separate pass, TAPEGEN used the "validated" one-minute averages and computed hourly averages for inclusion into a third file on the Level II tape.

Table 4. RAMS Station Instrumentation

		101	102	103(T)	104	105	106	107	108(S)	109	110(S)	111	112	113	114(S)	115(S)	116(S)	117(S)	118(S)	119(T)	120(T)	121(S)	122(G)	123(G)	124(G,T)	125(G,T)
O_3-Monitor Labs 8410		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
NO-NO_x Monitor Labs 8440		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
CO-CH_4-THC Beckman 6800		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
TS-SO_2-H_2S Tracor 270HA		x		x	x	x	x		x					x	x	x	x				x	x	x			
TS-Meloy SA 185			x					x		x	x	x	x					x	x	x				x	x	x
Visibility-MRI 1561		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Wind Speed-MRI 1022 S		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Wind Direction-MRI 1022 D		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Temperature-MRI 840-1		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Dew Point-Cambridge 880		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Temp. Gradient-MRI 840-2		x	x		x	x	x	x		x		x	x	x									x	x		
Barometer-Sostman 363		x								x			x										x	x	x	x
Solar Radiation (Eppley)	Pyranometer			x	x				x						x				x				x			
	Pyrheliometer			x											x				x				x			
	Pyrgeometer			x											x				x				x			
Turbulence-R.M. Young 27002						x		x		x		x		x												
Gas Bags-Xonics		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Hi-Vol, Sierra 305				x		x	x		x				x			x			x		x		x		x	
LBL Dichotomous Sampler				x		x	x		x				x			x			x		x		x		x	

T= 30 m tower; S = 10 m tower; G = Guyed Tower

Table 5. Maximum Potential Data - RAMS

Sampling Freq.	Measurement	Number of Stations	Data Capture Frequency	Volume of Data			
				Hourly	Daily	30 days	Annually
1/2 second	O_3	25	1 minute	1500	36,000	1,080,000	13,140,000
"	$NO-NO_x$	25	1 "	1500	36,000	1,080,000	13,140,000
"	NO_2 (calc.)	25	1 "	1500	36,000	1,080,000	13,140,000
"	CO (BECKMAN)[1]	25	1 "	1500	36,000	1,080,000	13,140,000
"	CH_4 (BECKMAN)	25	1 "	1500	36,000	1,080,000	13,140,000
"	TH_C (BECKMAN)	25	1 "	1500	36,000	1,080,000	13,140,000
"	TS (MELOY)	12	1 "	720	17,280	518,400	6,307,200
"	TS (TRACOR)[2]	13	1 "	1500	36,000	1,080,000	13,140,000
"	SO_2 (TRACOR)	13	1 "	1500	36,000	1,080,000	13,140,000
"	H_2S (TRACOR)	13	1 "	1500	36,000	1,080,000	13,140,000
"	WS	25	1 "	1500	36,000	1,080,000	13,140,000
"	WD	25	1 "	1500	36,000	1,080,000	13,140,000
"	T	25	1 "	1500	36,000	1,080,000	13,140,000
"	DP	25	1 "	1500	36,000	1,080,000	13,140,000
"	B_{scat}	25	1 "	1500	36,000	1,080,000	13,140,000
"	ΔT (GRADIENT)	12	1 "	720	17,280	518,400	6,307,200
"	P	7	1 "	420	10,080	302,400	3,679,200
	TSP-SUSP. PART.	5	1 day	-	5	150	1,825
	Global Solar Radiation: (PYRANOMETER)						
"	300-3000nm	6	1 minute	360	8,640	259,200	3,153,600
"	395-3000nm	6	1 "	360	8,640	259,200	3,153,600
"	695-3000nm	4	1 "	240	5,760	172,800	2,102,400
	Terrestrial Longwave Radiation: (PYRGEOMETER)						
	3,000-50,000nm	4	1 "	240	5,760	172,800	2,102,400
Ea. Channel: On-45 sec Off-15 sec	Direct Solar Radiation: (PYRHELIOMETER)						
	(1) 300-3000nm	4	1/9 "	27	648	19,440	236,520
	(2) 395-3000nm	4	1/9 "	27	648	19,440	236,520
	(3) 475-3000nm	4	1/9 "	27	648	19,440	236,520
	(4) 530-3000nm	4	1/9 "	27	648	19,440	236,520
	(5) 570-3000nm	4	1/9 "	27	648	19,440	236,520
	(6) 630-3000nm	4	1/9 "	27	648	19,440	236,520
	(7) 695-3000nm	4	1/9 "	27	648	19,440	236,520
	(8) 780-3000nm	4	1/9 "	27	648	19,440	236,520
	(9) Blank						
	Subtotal			24,276	582,624	17,478,720	212,657,760
	Turbulence:						
	U (along)	5	1/2 second	36,000	864,000	25,920,000	315,360,000
	V (across)	5	1/2 "	36,000	864,000	25,920,000	315,360,000
	W (vertical)	5	1/2 "	36,000	864,000	25,920,000	315,360,000
	Total			132,276	3,174,624	95,238,720	1,371,395,520

[1] 5 min. update inst. resp. time.

[2] 3:45 update inst. resp. time.

In early 1975 analyses and systems reviews by RAPS Data Management suggested that this level of "validation" was insufficient to serve the prime RAPS objective of refined model development and model validation. And it was evident that additional and substantial efforts would have to be devoted to an integral area of further systems documentation, data validation, quality control, and quality assurance activities on-site in St. Louis.

To further ensure the integrity of RAMS/RAPS data, two major efforts were initiated: First, an independent on-site audit of the RAMS network was ordered conducted for the purposes of establishing, estimating and documenting the precision, accuracy, completeness, and representativeness of the RAMS measurements (Research Triangle Institute, 1976b); second, rigorous systems data validation criteria were developed using physical, meteorological and air quality relationships, instrument capabilities and specifications, and within-station and across-network data comparisons, in addition to previously mentioned systems hardware status and calibrations information.

Based on experience with NASA, merging of these systems efforts resulted in one of the first award-fee contracts in EPA history: Under EPA Contract 68-02-2093, Rockwell International receives an "incentive" fee (award) based largely on data completeness, integrity, and quality assurance efforts to provide validated data for RAPS. The RAMS data validation procedures represent the first major attempt to incorporate both quality control feedback and near real-time analyses and systematic validation of data from any major air data bank in EPA, or in this country.

Under the original RAMS contract, "valid" data were simply defined as "digital representations of compound concentrations produced by properly calibrated instruments and recorded on magnetic tape".

The terms "valid" and "invalid" data are rigorously defined in the new contract and in subsequent revisions to the work plan. The term "data validation" connotes that complex air monitoring data can be clearly defined as either "good" or "bad" based on prescribed criteria; in most instances, however, such a clear dichotomy simply does not exist. For RAPS, the concept of "data validation" is to employ a scheme of "flagging" data that fail to meet established criteria. In all cases where such questionable data are "flagged" as "invalid", the original integrity of the data is preserved for possible later use by an investigator.

Under the old contract -- with the exception of systems status and calibration checks -- data submitted to RAPS Data Management, from St. Louis were presumed to be valid unless subsequent user analyses of that data indicated otherwise. Under the most optimum delivery and data processing schedules, data errors or systems problems were not likely to be diagnosed and reported back to St. Louis for corrective action within 10 days. resulting in some problems remaining unresolved for periods of 10-20 days, or more.

Under the new contract, all RAMS data are validated in near real-time on-site in St. Louis. Validation is based on model prototypes developed by RAPS

Data Management in North Carolina. Separate audits of the St. Louis validation models and software were conducted by RAPS Data Management using both control data and, finally, actual monitoring data prior to formal on-site implementation by Rockwell International Corporation. At the same time, an independent contract audit of both the Data Management and Rockwell validation models and criteria was performed by a team experienced in air quality instrumentation, quality assurance, and air quality data collection and analyses.

Using these audited data validation procedures under the award fee contract, the burden of producing maximum, systematic "valid" data from the RAMS network rests squarely with the contractor on-site and is reinforced by profit maximization/loss minimization incentives through the award fee for completeness, accuracy and quality of the RAMS data submitted to RAPS Data Management. Similarly, data flagged as "invalid" economically reinforce quality control, quality assurance and immediate corrective action on-site, minimizing future data losses and, at the same time, providing RAMS data collection audit trials and systems documentation.

Detailed documentation concerning RAMS system instrumentation, siting criteria, remote station and central facility data acquisition, calibrations, maintenance, quality assurance, and data validation protocols are available in the RAMS System Flow and Procedures Manual -- a required documentary report (Hern and Taterka, 1977).

It is interesting to note that when the entire prototype hardware/software data validation protocol was presented for peer review to the former EPA Air Pollution Chemistry and Physics Advisory Committee in November, 1975, considerable concern was expressed by some members that the majority of RAMS data might be invalidated on the basis of such a validation process. It was suggested by some that such validation acitivities are the exclusive province of the investigator, and not Data Management; others suggested far looser criteria. A second concern expressed by the committee was the amount of on-site computer processing time which would be required to fully implement the validation criteria. This second concern was prompted by the fact that during 1974-1975 original TAPEGEN processing necessitated 20-21 hours of central computer time to process one Level II RAMS tape per day -- and that process merely accounted for calibration, drift, and status checks, often resulting in data processing schedule delays for RAMS or for field investigators' data reduction, review and quality control during intensive expeditionary programs.

The apparent conflict between incorporating significantly greater numbers of status, quality control and data validation checks into RAMS and TAPEGEN software and that of decreasing central facility data processing time for RAMS data production (Level II) was effectively resolved by major redesign of the PDP hardware and TAPEGEN software. The entire TAPEGEN process, including all validation protocols, now requires 10-11 hours of central facility computer time to produce a fully validated Level II RAMS tape.

During June 22-July 2, 1976, a second, on-site, independent audit of RAMS was conducted (Research Triangle Institute, 1976c). Quality of the data, as well as data completeness, was found to be exceptional by any standards for such a complex, state-of-the-art system as RAMS.

From its inception the RAPS program has been charged with more than the sheer collection of large quantities of data. For our prime objective, submodel development and complex model validation necessitate data of the highest quality and validity, as well as completeness. For RAMS, that objective has been served cost-effectively by implementing the most sophisticated, real-time, on-site, validation-quality assurance-management exception reporting protocols of any major air monitoring system in the world.

RAMS Level II data are available from November 1974 to the present. Fully validated data are complete for the period January 1976 to present. All past RAMS data will be backlogged processed and validated according to the following schedule:

March 1977 : May - August, 1975
May 1977 : January - April, 1975
July 1977 : September - December, 1975
August 1977: All 1974 RAMS data

The RAPS Upper Air Sounding Network (UASN) has been fully operational since November 18, 1974. The UASN consists of 4 stations: Two permanent sites and two temporary sites.

While the RAMS network provides a relatively dense data base for surface winds, temperature, dew point temperature, barometric pressure, and relative humidity, the combination of these surface data with those data obtained from upper-air soundings allows the determination of microscale changes in winds, local stability, and mixing depth throughout the area, particularly as they relate to terrain features and synoptic scale meteorology.

The objective of the UASN is to provide RAPS with a data base of winds, temperature, pressure, dew point and relative humidity aloft in order to define the air structure over the St. Louis regional area. Special emphasis is given to the lower levels (700MB). Temperature accuracy is ± 0.5°C. Reading intervals of winds aloft are every 30 seconds. Table 6 summarizes UASN operations and types of soundings taken for each site.

Installation and operation of the UASN, including quality control and quality assurance activities, is the responsibility of the RAPS contractor -- Rockwell International Corporation. UASN data are available in near real-time for forecasting purposes during the RAPS intensive study periods and for review by the various investigators at that time. Graphical data are provided on standard NOAA low-level sounding adiabatic charts. Radiosonde angular observations and reduced radiosonde data are provided on formatted forms for 30-second intervals. Pibal theodolite data are also provided on formatted forms for 30-second intervals. All original, quality-controlled Pibal and radiosonde data are sent to RAPS Data Management for keypunching, editing, computer processing, and archiving.

Table 6. RAPS Upper Air Sounding Network

Period of performance: 18 November 1974 through 31 December 1976

Locations:

1) Two permanent: Downtown - intersection of 22nd and Clark Streets (141)
SW site - Pevely Farms, Lewis Road, Crescent (142)

2) Two temporary: SE site - St. Clair County Park, St. Clair County (143)
NE site - Civic Memorial Airport, Alton (144)

Schedule: Radiosondes every 6 hours at 0600, 1200, 1800, 2400 CST. This schedule will change with the seasons, based on local sunshine. Pibals each hour in between.

1) Two permanent sites operate five days per week (Mon thru Fri) except for seven-day-per-week operation during intensive study periods.

2) Two temporary sites operate seven days per week during intensive study periods.

Termination criteria:

1) Radiosondes - Temp and humidity up to 700 mb or about 3.0 km; wind direction and speed every 30 seconds up to same height. Temp, humidity, and wind info at measured altitudes.

2) Pibals - Wind direction and speed every 30 seconds up to 10 minutes. 10 gram daytime pibal = 1334 meters; 30 gram nighttime pibal = 1890 meters. Assumed ascension rate because of single theodolite tracking. No problem w/inside inflation.

Pibal Results:

About 200 pibals per week from routine permanent operation. About 560 pibals per week from four-station operation during intensive study periods. Data submitted within 5 working days after being QC'd by RISC, then submitted to RTP for keypunching. Should have printout within one month of observations.

Printout consists of two pages:

1) Wind speed (mps), wind direction, height above sfc, and U,V components every 30 seconds.

2) Wind speed (mps) and wind direction interpolated to 50 meter intervals above surface.

Continuation of Table 6

Radiosonde Results:

About 40 radiosondes per week from routine permanent operation. About 115 radiosondes per week from four-station operation during intensive study periods. Data submitted within 5 working days after being QC'd by RISC, then submitted to RTP for keypunching. Should have printout within one month of observations.

Printout consists of three pages:

1) Temperature, potential temp, dewpoint, relative humidity, and height above sfc and MSL for mandatory and significant pressure levels.

2) Wind speed (mps), wind direction, height above sfc, and U,V, components every 30 seconds up to about 3 km.

3) Wind speed (mps) and wind direction interpolated to 50 meter intervals above sfc.

All UASN data have been completely processed and archived to date.

3.0 AIR QUALITY AND METEOROLOGY

3.1 Climatology

3.1.1 Air pollution climatology

The climatological work on effective chimney heights (based on rawinsonde data) that was started last year has continued. The equations that are being used were modified according to the latest publication of Briggs (1975). Also, rather than effluent heat emission rate, the effluent volume emission rate and temperature were specified as a function of chimney height (based on a statistical summary). Thus for each physical chimney height, three calculations of "effective" chimney height were made for the mean and the mean plus-and-minus-one standard deviation of effluent temperature and volume emission rate. Climatological summaries for 62 stations in the contiguous forty-eight states were completed by the National Climatic Center. Figures 24 and 25 show isopleths of annual average effective chimney heights at 1115 GMT for 50- and 400-meter chimneys, respectively, and for corresponding mean values of effluent temperature and volume emission rate (Table 7). Notice that for 50-meter chimneys (Figure 24) the plume rise is generally 100-150 meters; for 400-meter chimneys the rise is generally 250-300 meters. Table 7 shows certain statistics on effective chimney heights, based on 1115 GMT rawinsonde observations at Denver for 50-, 200-, and 400-meter chimneys. The values of effluent volume emission rate and temperature are averages for the specified chimney heights, based on

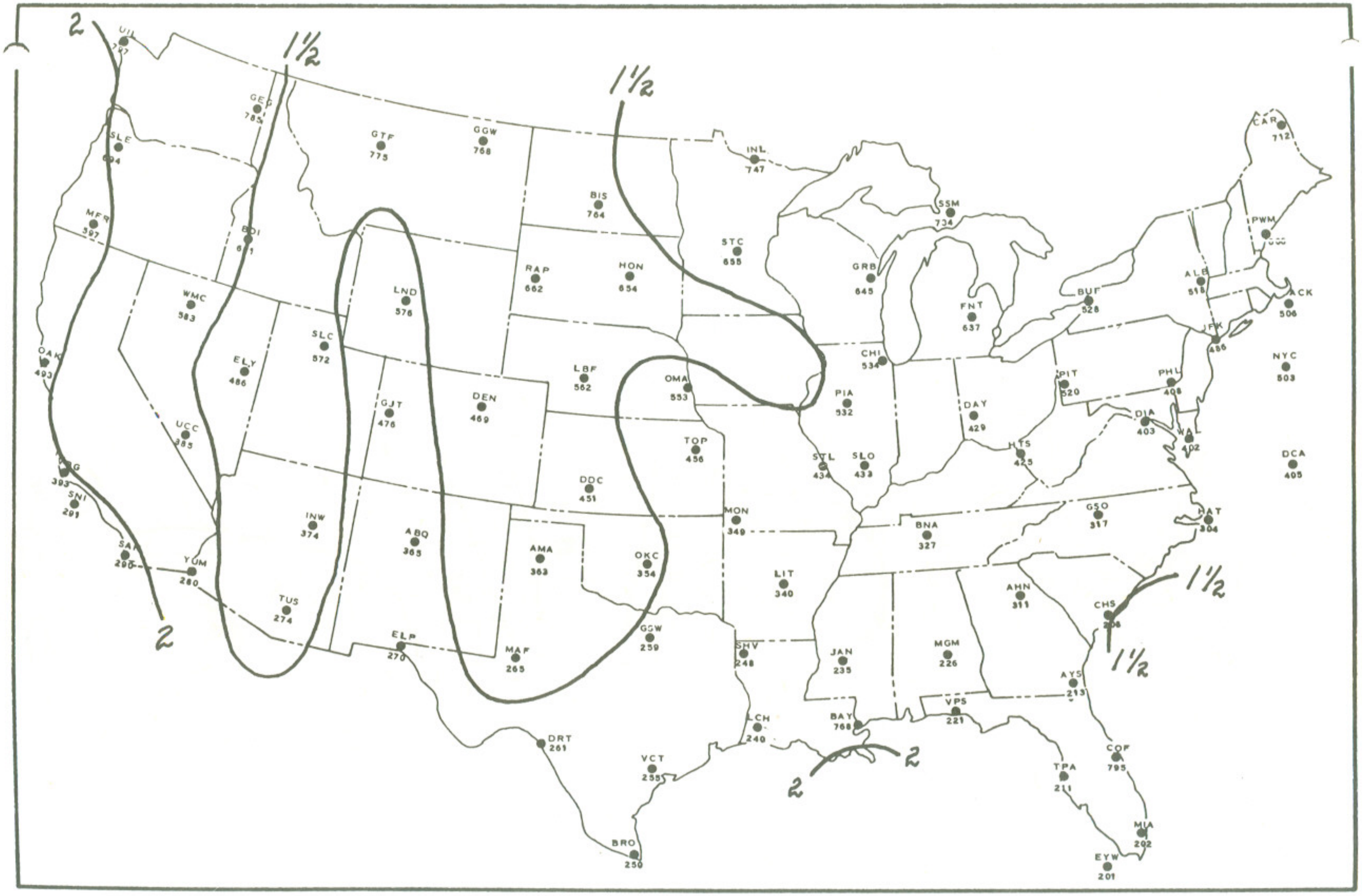


Figure 24. Isopleths (hundreds of meters) of average effective chimney heights above ground-level for 50-meter chimneys, based on 1115 GMT rawinsonde data, 1960-1964 at most stations.

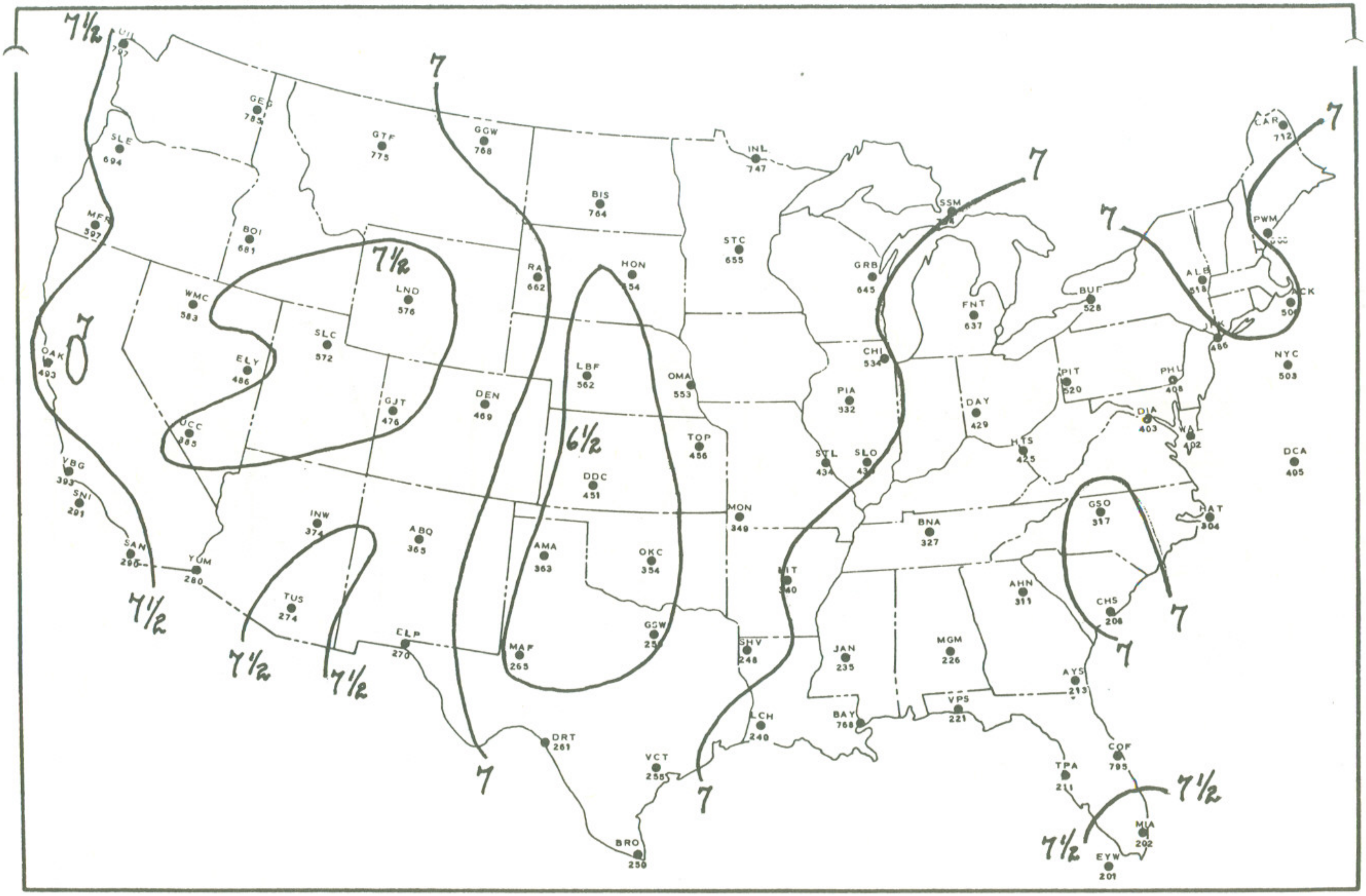


Figure 25. Same as figure 24, except for 400-meter chimneys.

Table 7. Annual Statistics on Effective Chimney Heights Based on 1115 GMT Rawinsonde Data for Denver, Colorado, 1960-1964

	CHIMNEY SIZE		
	SMALL	MEDIUM	LARGE
Avg Effective Ht (meters)	146	411	741
In Inversion (%)	74	34	12
In Inversion, $H_A > H_E$ (%)	72	31	9
Below Inversion (%)	9	7	6
Below Inversion, $H_A > H_E$ (%)	9	7	5
Above Inversion (%)	12	54	77
Above Inversion, $H_A > H_E$ (%)	12	49	66
No Inversion (%)	5	5	5
No Inversion, $H_A > H_E$ (%)	5	5	4

H_E = Effective Height

H_A = Afternoon Mixing Height

Characteristics of Chimneys

Size	Height (meters)	Vol Emission Rate (meters^3 sec^{-1})	Effluent Temp (°K)	Avg Heat Emission Rate (calories sec^{-1})
Small	50	110	445	2.77×10^6
Medium	200	680	416	16.43×10^6
Large	400	2000	410	40.72×10^6

data for power plants in the United States. In the table the average effective chimney height increases from 146 meters for small (50-meter) to 741 meters for large (400-meter) chimneys. At its effective height the plume centerline is in a temperature inversion in 74 percent of the 1115 GMT soundings for small chimneys, but only 12 percent for large chimneys. Accordingly, the plumes are above an inversion in only 12 percent of the observations for small chimneys but in 77 percent for large chimneys. For small chimneys the afternoon mixing height reaches or exceeds the effective chimney height in all but 2 percent of the observations; for large chimneys, in all but 16 percent of the observations. A comprehensive report on this work is being prepared.

3.1.2 Fairbanks heat island study

A two-year study has been conducted by the University of Alaska, under an EPA grant, of the Fairbanks heat island. Fairbanks is located in the subarctic, where the key factors influencing the mid-winter heat island are self heating and the effect of air pollution on the transfer of thermal radiation. Measurements of winds and temperature were made in and around Fairbanks using fixed ground stations, helicopters, mobile ground units, and photographic observations of home and automobile plumes. Forty vehicular traverses were made.

In mid-winter a relatively large heat island existed. Under clear skies the city was normally 10°C warmer than the colder outlying areas, with differences up to 14°C on some occasions. The heat island intensity ranged from 2° to 4°C under cloudy skies. The expected enhancement of the heat island by the presence of ice fog absorbing outgoing thermal radiation and re-radiating it to the ground did not occur. With ice fog present the average heat island intensity was 6°C, with a range of 2° to 10°C.

During the early spring and late fall there is still a snow cover, but the sun is high enough to give a normal diurnal temperature cycle. The daytime heat island disappears at this time, but on clear spring nights the heat island intensity ranges from 8° to 10°C. Figure 26 shows the daily minimum temperatures at several stations during March 1975.

The three-dimensional data were obtained largely for the maximum heat island intensity situations - clear skies, snow cover, and little incoming sunlight. It was not possible to obtain data within fog or below 90 m. The helicopter flights confirmed that direct mixing from the ground did not reach 90 m, but they did show that the temperatures 100-200 m above ground level were influenced by the city (Figure 27). The "wavelength" of the temperature variations aloft seems to be related to the spacing of warm areas on the ground, even though there is an intervening inversion.

The wind observations show a variety of area-wind patterns dominated by local small scale eddies and/or gravity waves. Wind shifts of 180° over a distance of a block are not uncommon at the ground, and similar directional shifts have been recorded frequently in the vertical at a given location.

A theoretical analysis, including both radiative and convective losses from the surface, agrees well with the observed winter heat island if the regional wind speeds are well below 1 m sec^{-1}.

3.1.3 Analysis of tower data

The National Severe Storms Laboratory (NSSL) has installed wind and temperature equipment at 26, 44, 89, 177, 266, 355, and 444 meters on a 481-meter tower in Oklahoma City. In the spring and early summer of 1972 the NSSL conducted special studies in which they collected data every 10 seconds at all seven levels. NSSL data were made available to the ML and have been analyzed

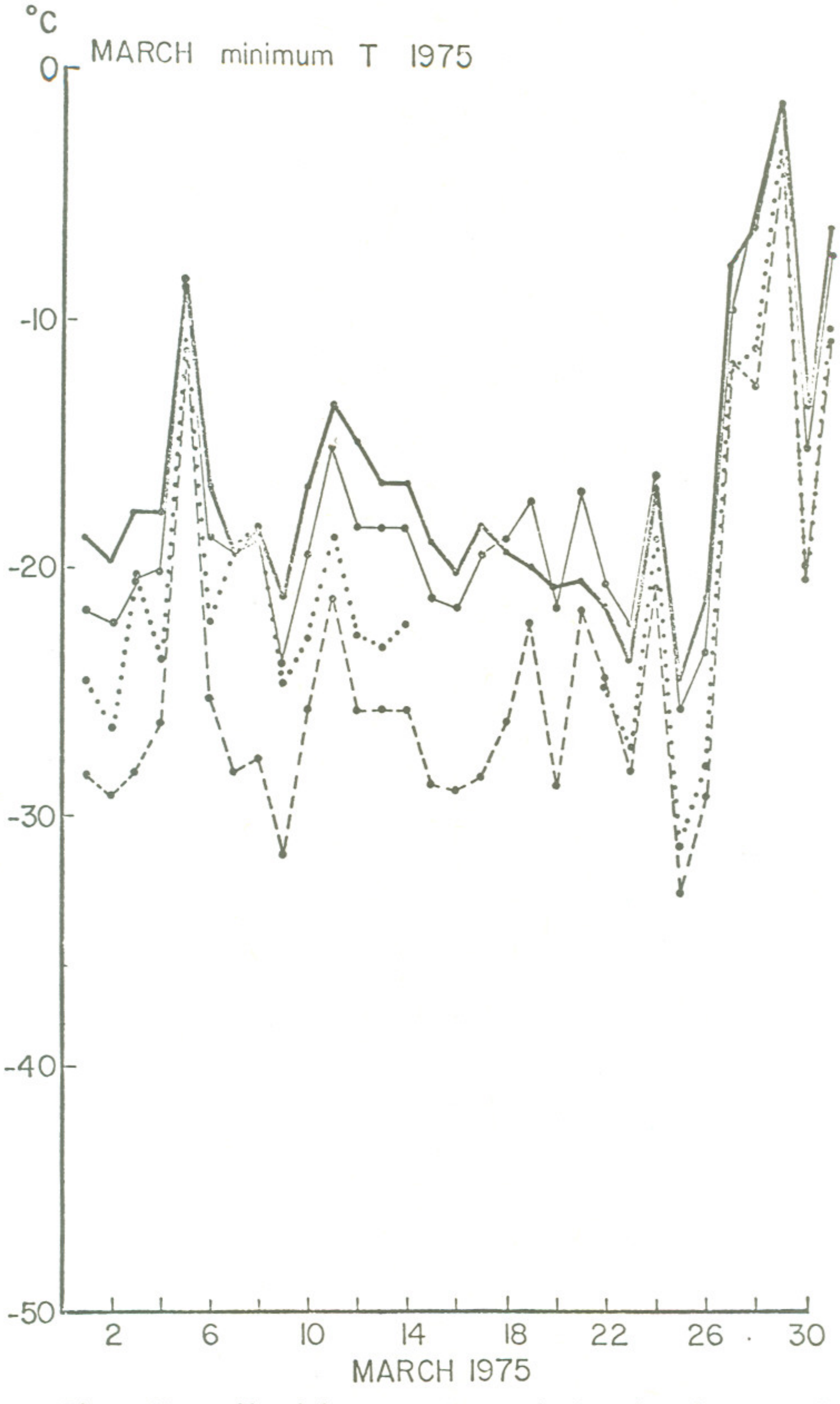


Figure 26. Daily minimum temperatures in four locations around Fairbanks, Alaska, in March 1975. Heavy solid line is for the downtown site, light solid line is for the airport, and the other lines are for outlying stations.

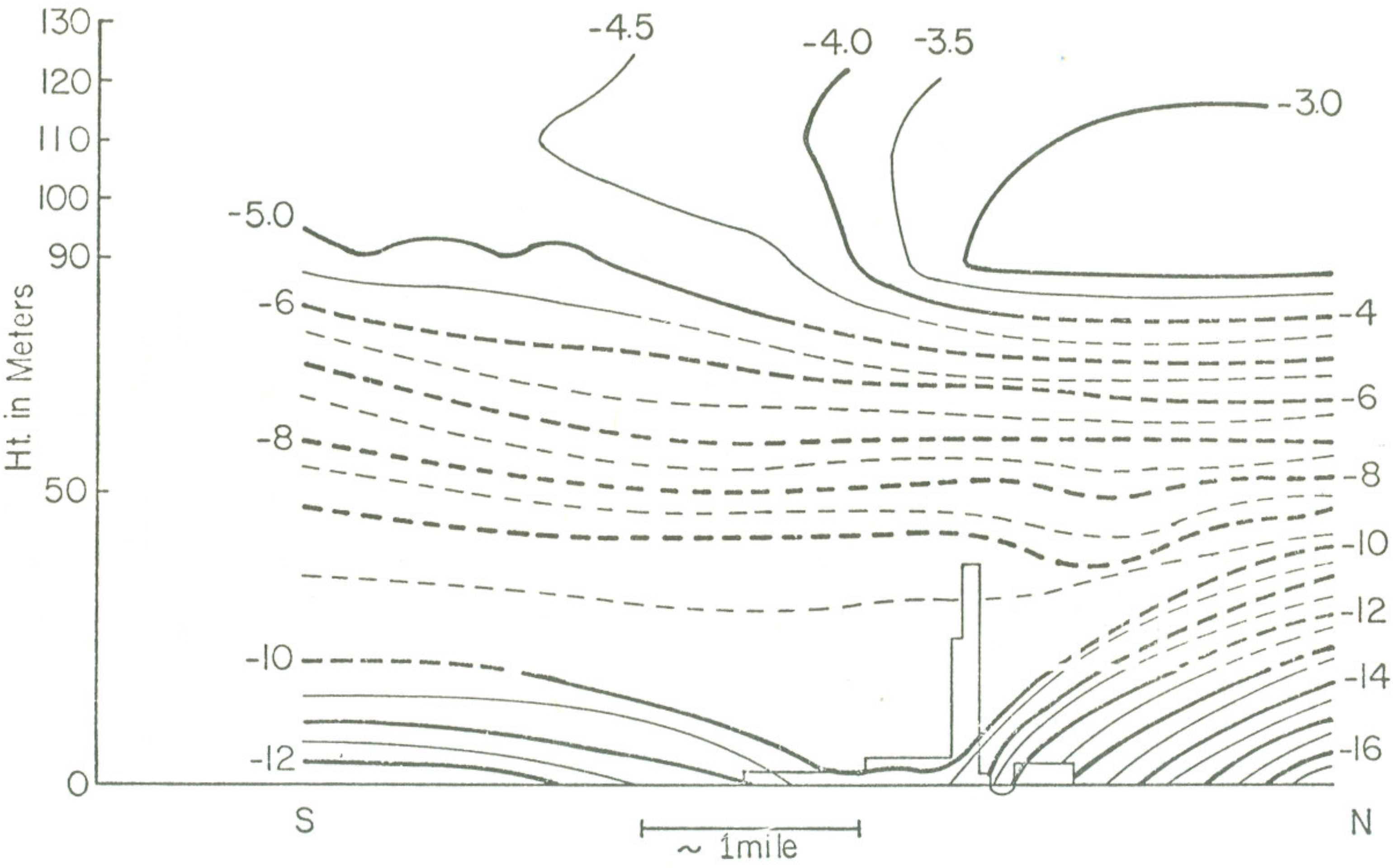


Figure 27. North-south temperature cross-section over Fairbanks, midnight to 0100, March 14, 1975.

by three different techniques for determining Pasquill stability classes. Two of these techniques are recommended by the Nuclear Regulatory Commission (1972). One technique determines the standard deviation of wind direction (σ_{WD}) and equates the result to a stability class. The second method determines the temperature difference between two heights (ΔT) to determine the stability class. Table 8 shows the classification techniques recommended by the Commission. Our analysis includes a third method in which the maximum range of wind direction divided by six (R/6) is equated to one standard deviation and converted to a stability class. The data are analyzed for half-hour periods starting on the tour and each day is separated into three 8-hour periods beginning at midnight.

Examples of the comparison between the σ_{WD} and ΔT techniques are shown in Table 9. Table 10 shows the percent frequency that the techniques indicated identical classes.

Table 8. Classification of Atmospheric Stability

Stability Classification	Pasquill Categories	σ_{WD}* (degrees)	ΔT Temperature Change with Height (°C/100m)
Extremely unstable	A	25.0°	<-1.9
Moderately unstable	B	20.0°	-1.9 to -1.7
Slightly unstable	C	15.0°	-1.7 to -1.5
Neutral	D	10.0°	-1.5 to -0.5
Slightly stable	E	5.0°	-0.5 to 1.5
Moderately stable	F	2.5°	1.5 to 4.0
Extremely stable	G	1.7°	>4.0

*Standard deviation of horizontal wind direction fluctuation over a period of 15 minutes to 1 hour. The values shown are averages for each stability classification. (Nuclear Regulatory Commission, 1972).

On the basis of the data analyzed it is concluded:

(1) The two different classifying techniques show that there is a marked decrease in stability a little above 100 meters.

(2) For heights above 100 meters the σ_{WD} technique generally shows more intense stability than the $\Delta T/\Delta Z$ technique.

(3) For heights above 100 meters, the σ_{WD} technique shows relatively little change in stability through the evening and nighttime periods, while the $\Delta T/\Delta Z$ technique shows increasing stability through the two periods.

(4) Comparison of the σ_{WD} and R/6 techniques showed class agreement two-thirds of the time, indicating the R/6 is a good approximation of σ_{WD} in determining stability class.

Table 9. Cofrequency of Stability Classes Oklahoma City, Spring-Summer 1972

		0001-0800 σ_{WD}							0801-1600 σ_{WD}							1601-2400 σ_{WD}						
HEIGHT 26m																						
		A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G
$\Delta T/\Delta Z$ 26-44m	A								*2*	3	14	10					1	1	8	1		
	B								1	*1*		4										
	C								2	33	*6*							*1*				
	D		2	1	*26*	8			3	3	14	*24*	2			1	1	1	*16*	10		
	E	2	2	3	15	*15*	*		1		1	1				2	1	2	15	*20*	1	1
	F	*	2	*	6	7	*2*					1				3	1	3	1	6	*1*	3
	G	3	*	*	2	1	*						1									
HEIGHT 44m																						
$\Delta T/\Delta Z$ 26-89m	A											2	1					*	1			
	B								1		4	5					*1*	*	1			
	C								1	1	*11*	4	1			*		*	2			
	D		*		*19*	21			4	7	21	*31*	4			2	*	2	*16*	*11*		
	E	2	1	3	9	*22*					1					3	1	4	11	*25*	2	
	F	4	*	*	4	8	*2*						1			1	1	2	3	4	*3*	
	G		*	*		3	1									1						
HEIGHT 89m																						
		A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G
$\Delta T/\Delta Z$ 44-177m	D	*	2		*11*	25			5	3	25	*44*	18			3	*	5	*12*	32	1	
	E	2	3	4	5	*23*	11		1		1		*2*			2	1	2	4	*19*	11	1
	F			*	*	5	*9*									1			2	1	*2*	
HEIGHT 177m																						
$\Delta T/\Delta Z$ 89-266m	D	*		[illegible]	*6*	24	4		4	4	14	*41*	29			3	2	4	*8*	30	13	*
	E	4	*	4	8	*19*	22	2			1	1	*6*			2	1	2	5	*13*	16	1
	F			1	*	2	*2*															
HEIGHT 266m																						
$\Delta T/\Delta Z$ 177-355m	D	2	2	1	*8*	17	7	2	3	4	8	*49*	24			2	2	4	*8*	28	23	4
	E	3	1	3	7	*21*	26	3	1			2	*8*									
	F				1	1	*1*															
HEIGHT 355m																						
$\Delta T/\Delta Z$ 266-444m	D	5	*	1	*3*	11	17	2	2	3	9	*39*	25	1		3	2	4	*8*	27	31	2
	E	1	1	3	8	*15*	31	1	1	1	1	6	*10*	2		1		*	3	*8*	10	
	F						*														*	
HEIGHT 444m																						
		A	B	C	D	E	F	G	A	B	C	D	E	F	G	A	B	C	D	E	F	G
$\Delta T/\Delta Z$ 355-444m	D	2	*	1	*1*	12	20	5	3	5	7	*56*	21	1		2	1	3	*6*	23	26	5
	E	2	2	3	5	*14*	25	7	2	1		6	*8*	4	1	1			5	*9*	20	
	F										1	1	3	*1*								

* = less than 0.5 percent
Italics show class agreement

Table 10. Frequency (Percent) That Compared Techniques Indicated Identical Class

A

σ_{WD} vs ΔT

Height (m)	Time 0001-0800	0801-1600	1601-2400
26	43	33	38
44	43	45	43
89	43	46	33
177	26	47	21
266	24	58	18
355	18	49	16
444	15	45	15

3.2 Air Quality Analysis

3.2.1 Empirical techniques for analyzing air quality and meteorological data

Work under a contract with Technology Service Corporation of Santa Monica, California, to explore the potential applications of specialized regression techniques to air pollution problems was completed in FY-76, and a three-part report has been published.

Part I "The Role of Empirical Methods in Air Quality and Meteorological Analyses" (Meisel, 1976) outlines two specific problems that are considered in much greater detail in Parts II and III, but additionally discusses the extraction of emission trends from air quality trends, the detection of inconsistencies in air quality/meteorological data bases, repromodeling - or the empirical approach to the understanding and efficient use of complex air quality models, and applications to studies of the health effects of air pollution and the short-term forecasting of pollutant levels. Part II "Feasibility Study of a Source-Oriented Empirical Air Quality Simulation Model", (Meisel et al., 1976) examines in detail the feasibility of extracting an empirical source-receptor air pollutant dispersion function, e.g., the common Gaussian-plume kernel, by appropriate analysis of urban air quality data. Part III "Short-Term Changes in Ground-Level Ozone Concentrations: An Empirical Analysis" (Breiman and Meisel, 1976) examines the possibility of deriving empirical difference equations, that would describe the production of ozone (O_3) in the urban environment. Parcels of air were tracked in a Lagrangian fashion from wind data over a region of the Los Angeles Basin. The one- and two-hour changes in ozone levels in the parcel were related to previous hourly readings in the parcel of reactive hydrocarbons, methane, nitrous oxide, nitrogen dioxide, ozone, solar radiation and temperature data. The report also points to the possibility of developing an empirical source-oriented model of photochemical pollution, in contrast to that of Part II which considers a relatively stable pollutant like SO_2.

3.2.2 Air quality and meteorological trends

As part of the on-going analyses and interpretations of air quality trends, a task was completed under contract with Pacific Environmental Services, Inc. to survey all areas of the country with oxidant air quality and precursor emission trend data for at least a five-year period to determine if statistically significant trend relationships could be derived. A main objective was to examine whether downward trends in oxidant air quality, which have occurred in several cities in recent years, could be correlated to trends in hydrocarbon or nitrogen oxides emissions or some combination of these emissions. It was found that only some California regions together with the Denver and Philadelphia areas had sufficient data for such an analysis. The Los Angeles Basin was excluded from the analysis because a similar analysis had been previously performed. Principally because of an ample data base, statistically significant trend relationships between oxidant levels and precursor emissions were found only for the San Francisco Bay area, and then only when data for more than 10 years (1962-74) were analyzed and the data normalized for annual variability in meteorological conditions. Air quality data for various years was normalized by considering only days with comparable meteorological conditions in terms of inversion height and ambient temperature. The highest correlation found was between annual oxidant concentration (average daily high-hour, Apr.-Oct., for days meeting meteorological criteria) for all area stations and the annual ratio of hydrocarbon (total) emissions to nitrogen oxides emissions. The correlation coefficient was 0.92, significant at the 0.1 percent level. An analysis for only the latest available 5-year period, 1970-74, did not result in statistically significant correlations between oxidant air quality and precursor emissions. A summary was presented at an international conference on oxidant control (Martinez et al., 1976).

Input to another air pollution trend analysis focused on oxidant/ozone, nitrogen dioxide, and sulfates. Oxidant/ozone trends were examined for three areas of California: Los Angeles, San Francisco, and San Diego. In brief, the analysis indicated that oxidant levels have declined in all three areas during the period 1966 through 1975. However, little trend was observed during the most recent five years. The largest long-term decline occurred in sections of the Los Angeles Basin where annual average high-hour oxidant levels (Figure 28) decreased 31 percent. Hydrocarbon and nitrogen oxide emission trends were examined along with atmospheric ventilation to explain the oxidant trends in Los Angeles. From this analysis, it appears that although emission trends dominate the overall oxidant trend, annual cycles in ventilation exert a discernable influence which may have masked the effects of reduced emissions during the past five years.

Nitrogen dioxide trends were examined for areas of the nation where historically continuous data are available. This limited the study to Denver, Portland, Ore., Chicago, and cities in New Jersey and California. In general, NO_2 levels are declining in the Los Angeles Basin (Figure 29), in cities studied in New Jersey, and in Denver. However, no clear trend was evident in San Francisco, San Diego, or Chicago, while annual NO_2 actually increased slightly in Portland, Ore.

In contrast to the oxidant/ozone and nitrogen dioxide analyses, sulfate trends were examined on a region-wide scale since sulfate levels are geographically more homogeneous and sufficient data were available for this type of analysis (Possiel and Frank, 1976). The study suggests that sulfate levels in urban areas of the Northeast are declining whereas sulfates in non-urban areas and in other Eastern cities have increased. The effects of air stagnation and total particulate loading are being investigated along with sulfur oxide emission patterns to explain the observed sulfate trends.

3.2.3 Analysis of RAPS aerometric data

Aerometric data collected in the Regional Air Pollution Study (RAPS) in St. Louis, MO, have been examined. Karl (1976) discusses the near-surface (30m) modification of the wind flow by the St. Louis metropolitan area. This affects both urban pollution and local climate. An analysis of two months of data revealed that the average wind speed was stronger within the city in

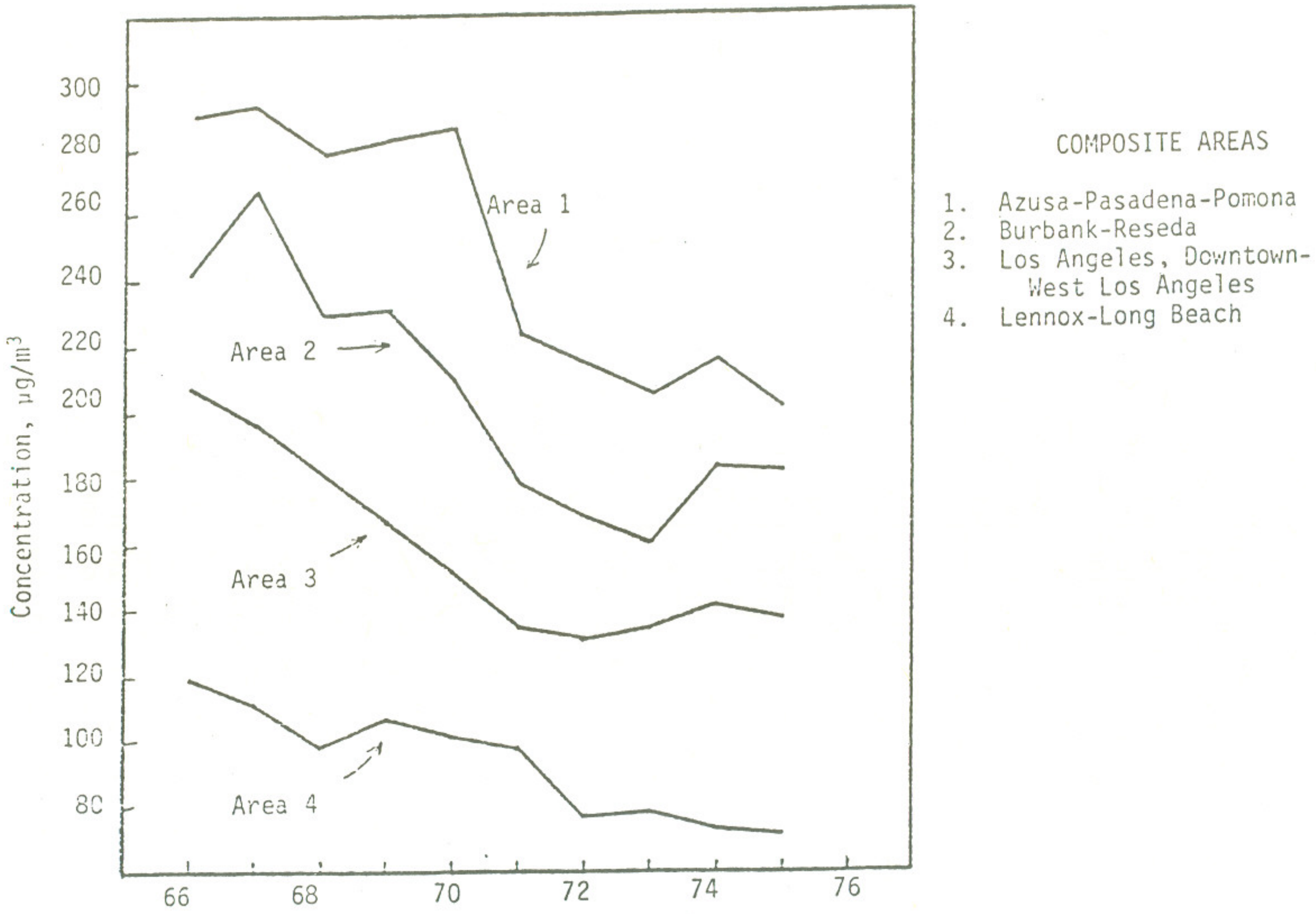


Figure 28. Annual average of daily maximum 1-hour concentrations in the Los Angeles Basin.

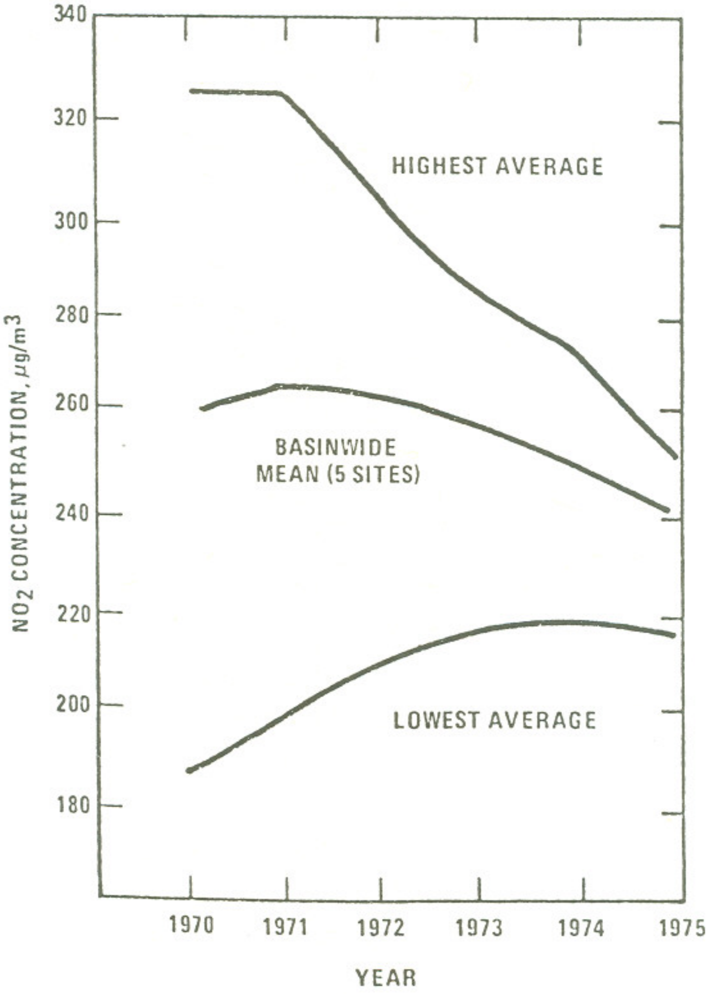


Figure 29. Annual average of daily maximum 1-hour NO_2 (4-year running mean) in the Los Angeles Basin.

unobstructed areas than in unobstructed areas at suburban and rural locations. This condition, occurring both day and night in all the heat island situations studied can be explained by increased vertical mixing over the city. When the average network wind speed is greater than or equal to 4 m sec^{-1}, the wind speeds in nonurban areas were nearly equal to those observed within the city. This indicates that the difference between urban and nonurban wind speeds is partially dependent on the magnitude of the wind speed.

The urban heat island was shown to have a marked effect on the near-surface net convergence in the metropolitan area, and its intensity largely determined the magnitude of the net convergence. The study also revealed, however, that areas of divergence are located within the urban-suburban environs during periods of strong heat island intensity -- even when the data were averaged over two months. This effect tends to complicate the influence that an urban-induced mesoscale circulation would have on the pollution patterns within a metropolitan area.

In another study (Karl and DeMarrais, 1976), the meteorological factors conducive to high concentrations of ozone were investigated. In the St. Louis area, the combination of a few meteorological variables explained, on the average, about 70 percent of the day-to-day variance of the average ozone concentration at the hours of peak concentration. These variables were the daily maximum temperature, wind speed, wind direction, global radiation, number of days since the last measurable precipitation occurred, and the height of the 500 mb surface. Furthermore, it was confirmed that the near-surface advection of ozone and/or its precursors from the city contributes to high ozone levels downwind of the city.

Although it was statistically shown that higher rural ozone concentrations were observed when the air passed over the urban-industrial areas of St. Louis, there were numerous occasions of high rural concentrations when the air did not pass over the St. Louis urban-industrial areas. On those occasions, trajectory analyses revealed that air parcels reaching the outskirts of St. Louis had circulated within an anticyclone east of the Rocky Mountains and west of the Atlantic Coast for about three days. During this time they had passed over sources of pollution outside the St. Louis urban-industrial complex. Synoptic-scale transport of ozone appears to be a regular occurence.

Preliminary results show that hourly average ozone concentrations were as high on weekends as on weekdays during July and August of 1975. This suggests that the effects of ozone remaining aloft are quite important.

3.2.4 Solar radiation and photochemical air pollution

Rade constants (k) for the photodissociation of certain species are important parameters of photochemical air quality simulation models and smog chamber studies. They describe the rate ($time^{-1}$) at which molecules dissociate when irradiated by ultraviolet solar radiation. Since k is directly dependent on incident solar intensity, it provides a link between solar radiation and air quality levels in both mathematical models and chamber studies. Thus, accurate knowledge of the spatial, diurnal, and annual variation of solar radiation (and by analogy k) throughout a metropolitan atmosphere is necessary in various studies of photochemical air pollution.

An extensive set of calculations was undertaken to obtain typical values of the actinic, or volumetric, solar flux as a function of solar zenith angle (0° to 86°) and wavelength (290 to 700 nm). These calculations were intended to update and amplify the original work of Leighton (1961), who used a simple, yet effective, radiative transfer model to determine the actinic solar flux at the earth's surface. A more sophisticated model was used here, along with modern values of atmopheric and boundary conditions, to yield more accurate solar fluxes at the surface and within the atmosphere. Thus, a table of theoretical values of the solar energy available for photochemical reactions, as a function of wavelength and solar zenith angle, was prepared for general application (Peterson, 1976).

A detailed radiative transfer model, based on the work of Braslau and Dave (1973) was used for the flux computations at 40 levels of the atmosphere from the earth's surface near sea level to the top of the atmosphere. Aerosol scattering and absorption, ozone absorption, and Rayleigh scattering were accounted for. The model atmospheric aerosols corresponded to annual average nonurban conditions over the eastern U.S. and to values slightly less than that for annual average U.S. urban conditions. Thus, the calculations were based on typical aerosol amounts so that the computed fluxes would have general applicability.

Subsequently, these data were used to calculate photolytic rate constants over a diurnal period. The vertical variation of the rate constants for NO_2 and formaldehyde (H_2CO) through the lowest several kilometers of the atmosphere was emphasized (Peterson, 1977; Peterson et al., 1976). Using the scheme outlined by Schere and Demerjian (1976), the photodissociation rate constant for species i can be expressed as $k_i\ (\theta,\ h) = \Sigma\ J\ (\lambda,\ \theta,\ h) \cdot \sigma_i\ (\lambda) \cdot \phi_i\ (\lambda)$ where θ is solar zenith angle, h is the height above ground, λ is wavelength, J is actinic flux, σ is absorption cross section, and ϕ is quantum yield. Thus, the time and space variation of k for any species is solely a function of J.

Because of the change of actinic flux with height, the rate constants for both species show significant increases with height. The rate constants generally increase with height and with decreasing zenith angles. For NO_2, for example, at 0.98 km k is 21 to 70% greater than at the surface, depending on zenith angle. Corresponding percentage increases for H_2CO are even greater for zenith angles of 70° and less. The differences between the increasing NO_2 and H_2CO rate constants from the surface to higher atmospheric levels result primarily from the different wavelength sensitivity of the two species. Formaldehyde responds more to shorter wavelengths (290 to 340 nm) than does NO_2 (290 to 420 nm). Since molecular scattering depends on the inverse fourth power of wavelength and aerosol scattering usually is inversely dependent on wavelength, the shorter wavelength energy undergoes more depletion while passing through the atmosphere.

These results were based on average eastern U.S. nonurban aerosol characteristics. In reality, aerosol concentrations over metropolitan areas are often two or three times greater than the model values. Consequently, the vertical gradient of actinic flux, and hence the altitudinal change of rate constants, is often substantially greater than that shown above. For aerosol concentrations double those used here, the increase of k(NO_2) from the surface to 0.98 km was calculated to range from 29 percent for a zenith sun to 103 percent for a solar zenith angle of 78°.

These rather large typical variations of the rate constants through the lower few kilometers of an urban atmosphere are applicable to several areas of photochemical pollution research. It was recommended that photochemical air quality simulation models be tested for their sensitivity to vertical changes of radiation-dependent rate constants. To-date, the large majority of such models do not allow for vertical variation of the photochemical rate constants. The results presented here also have relevance to smog chamber studies. Even though chamber k(NO_2) values may match those for the earth's surface, they likely would not agree with k(NO_2) levels at the top of the urban mixed layer. Moreover, the calculations show the necessity to maintain calibrations of chamber radiation intensity as a function of wavelength. Photodissociation rates for both NO_2 and H_2CO are important in kinetic mechanisms, yet the two species are sensitive to different wavelengths.

3.2.5 Carbon monoxide and meteorology

Studies of interrelationships among CO concentrations and emissions inferred from traffic count data, and meteorology have involved three phases. The first phase made use of CO concentrations from a network of 12 stations in Maryland and was discussed in the previous annual report (Viebrock, 1976). Since this phase showed only 50 percent of the variance of CO explained by the variations of traffic, wind speed, and mixing height, a more detailed study of the individual parameters was pursued. The second phase involved separate analyses of the diurnal variations of traffic count and CO concentration data from a large number of stations in widely separated and dissimilar locations. The purpose of these analyses was to: (1) determine if there are diurnal patterns of traffic count and CO concentrations that are typical; and (2) determine the extent to which diurnal variations of traffic count explain corresponding CO concentration variations.

A report summarizing the results of phase two has been prepared. Data from 18 traffic count and 36 CO monitoring stations in Colorado, Maryland, and New Jersey were used in the analyses. The main conclusions are:

(1) Traffic at the 18 sites, which ranged from resorts in Colorado to the beltline in Baltimore, showed relatively consistent patterns in diurnal variations. The results for January and July, including ± 1 standard deviation, are seen in Figure 30.

(2) The diurnal variations in CO concentrations at the 36 monitoring sites showed large differences and were not well-correlated with

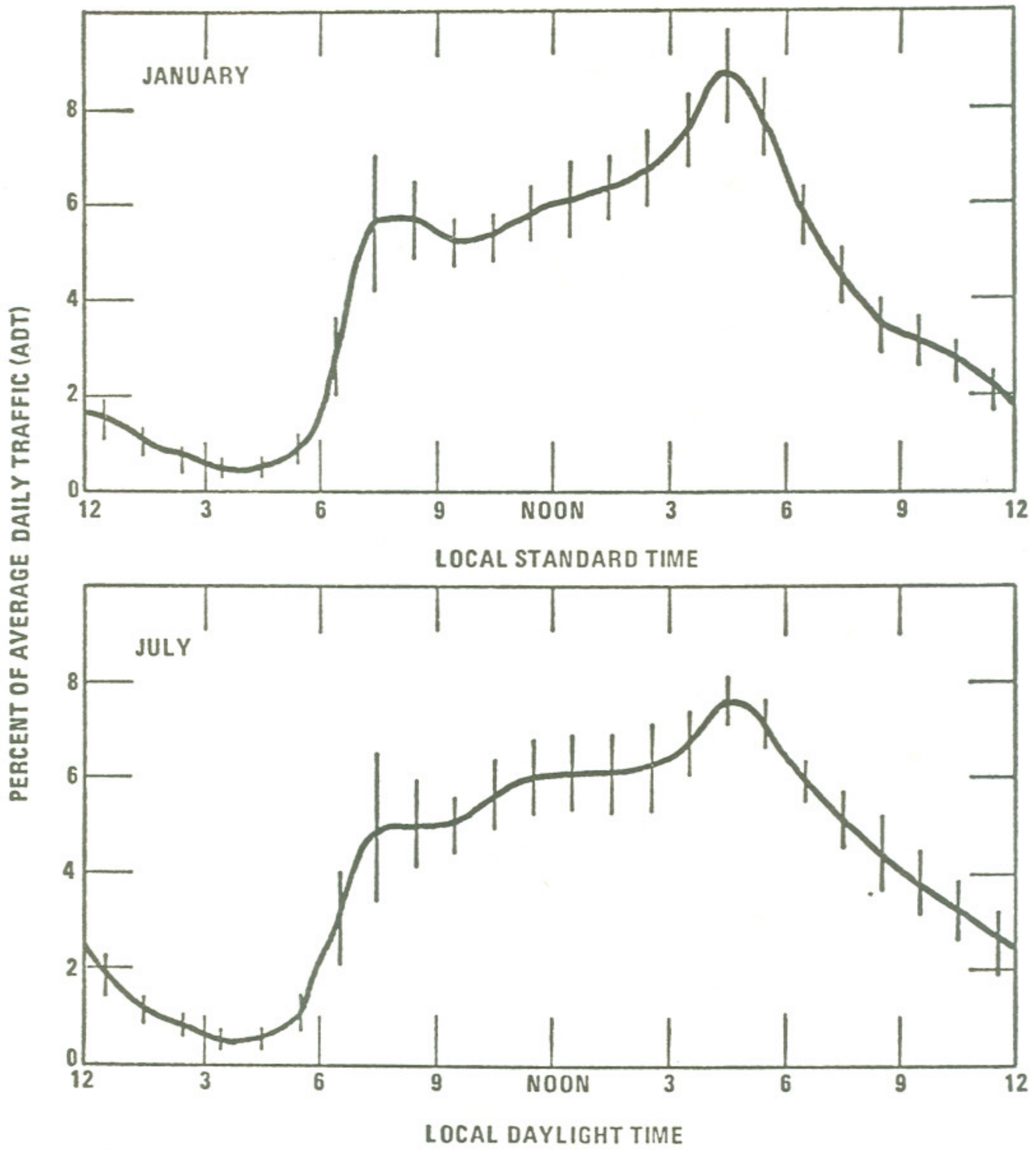


Figure 30. Diurnal variation in average traffic, 18 stations (vertical lines show ranges of ± 1 standard deviation).

traffic patterns. However, eliminating a few monitoring stations which show relatively poor correlations yields groups within each state that have consistent diurnal patterns of CO variations. The result for the Maryland stations is seen in Figure 31.

(3) The poor correlation between traffic counts and CO concentrations is believed to be caused by diurnal variations in vertical mixing and wind speed and differences in locations of the CO sampling intakes with regard to the CO sources (tailpipes). Traffic counts at 4 a.m. and noon (Figure 30) differ by a factor of about 10, while the CO concentrations (Figure 31) at those times are almost identical. This disparity is thought to be caused largely by diurnal differences in dispersion; dispersion is poor at 4 a.m. and is near maximum at noon.

(4) A disagreement in patterns among the three states is believed to be due to fundamental differences in sampling sites; one state collects samples over city streets, another uses trailers in open fields and the third uses trailers in open fields and restricts the air flow around the intake with a box.

The third phase will place greater emphasis on correlating the more detailed meteorological data and traffic counts with CO concentrations. In the Baltimore area hourly wind and CO data have been collected at four sites for a month. These data, along with nearby traffic count data and mixing height data for the area, are being examined.

3.2.6 Ozone and meteorology

The meteorological aspects of the ozone problem in various areas of the United States are being evaluated to determine the similarities and differences. The first part of the study was a literature search of the Los Angeles Basin problem. This review indicated that an understanding of various aspects of the problem existed, but no composite picture had been developed. A composite picture was presented in a paper by Karl and DeMarrais (1976). The Los Angeles problem is attributed to the combined effects of horizontal transport carrying polluted air downwind and vertical mixing downward of "old" ozone from aloft.

The problem was also examined in the Hampton Roads area of Virginia. Since the area is about five miles square, most of the locally emitted ozone precursors normally leave the area during the time required for ozone formation (about two hours). Trajectory analyses for the surface to 700-meter layer show that air masses with long trajectories reach Hampton Roads by circuitous routes, and that air masses arriving on episode days, days violating the 8 pphm ozone standard, frequently pass over areas with only widely scattered small cities. The Hampton Roads ozone problems occur over a wide range of meteorological conditions, thus differing from many other areas of the United States.

Another study area is the Baltimore-Washington-Richmond corridor. Study of the large prolonged episode in 1974 is underway. All 18 stations in the corridor showed a violation of the 8 pphm standard for five days. A preliminary

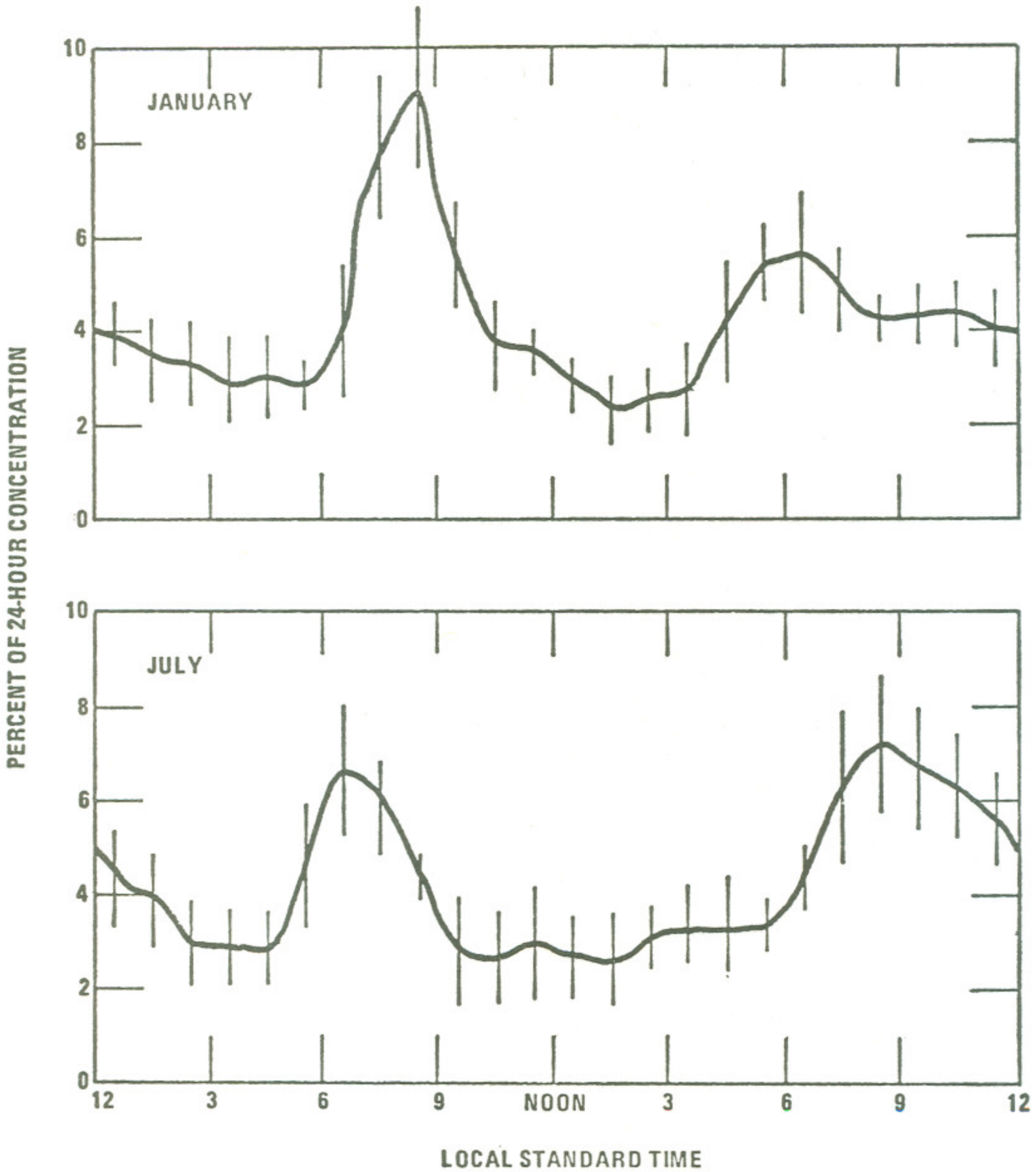


Figure 31. Diurnal variation of CO concentration, composite for selected Maryland stations (vertical lines show ranges of ± 1 standard deviation).

indication is that the westward movement of the Bermuda High into the United States was a significant factor in the episode. A heat wave, with light and variable winds aloft and a flow from the industrialized areas to the northwest, was associated with the situation.

3.2.7 Ozone and oxides of nitrogen production during thunderstorms

The concentration of a particular pollutant at a given location is, in general, dependent on contributions from anthropogenic and natural sources. An assessment of the contributions to the concentrations of a particular pollutant from a natural source is important in considering the amount of control that can be imposed on emissions from anthropogenic sources. The natural source investigated for the production of ozone and the oxides of nitrogen was thunderstorms.

A theoretical paper was prepared on the production of ozone and the oxides of nitrogen by thunderstorms. The basic assumption is that the number of O_3, N_2O, NO, and NO_2 molecules produced is proportional to the amount of energy dissipated by lightning and point discharges during a thunderstorm. These two quantities, the number of molecules produced and the energy dissipated, are related by a proportionality parameter called the efficiency parameter. The crux of theory is to determine an efficiency parameter for each molecule, namely, O_3, N_2O, NO, and NO_2. Details of the determination of the numerical values for the efficiency parameters are very tedious and lengthy; the interested reader should consult Griffing (1977).

The results obtained for the efficiency parameters are contained in Table 11. In the table, entries under the Laboratory heading are to be used for point discharges or experiments in the laboratory. The entries under the headings of Case I and Case II can be taken to represent possible bounds on the values of the efficiency parameters. The validity of theoretical results can be partially assessed when compared with other work. Such comparisons will also serve to illustrate the use of the entries for the efficiency in the table.

Table 11. Efficiency Parameters for the Production of Ozone and the Oxides of Nitrogen

	E(X)*			
	Laboratory		Lightning	
X	Case I	Case II	Case I	Case II
O_3	7×10^{-2}	3×10^{-2}	15×10^{-3}	15×10^{-3}
N_2O	0.0	8×10^{-4}	0.0	4×10^{-4}
NO	4×10^{-2}	1×10^{-2}	10×10^{-3}	6×10^{-3}
NO_2	4×10^{-2}	2×10^{-2}	10×10^{-3}	10×10^{-3}

*The efficiency parameter, E(X), has the units of the number of molecules, X, produced per electron volts of energy dissipated.

The efficiency parameter for O_3 has been measured in the laboratory by Kroening and Ney (1962) to be 0.03 ozone molecules per electron volt of energy dissipated. This result can be compared to the theoretical results for O_3 which indicate that the value for the efficiency parameter should lie between 0.03 and 0.07 ozone molecules per electron volt.

Observations by Noxon (1976) on the number of NO_2 molecules produced by a lightning flash gave a result of 2×10^{26} NO_2 molecules produced per lightning flash. Griffing (1977) has estimated the average energy dissipated by a lightning flash as 2×10^{28} electron volts per lightning flash. Using this estimate and the entries for $E(NO_2)$ under lightning in the table, the theoretical estimate is 2×10^{26} NO_2 molecules produced per lightning flash. Clearly, the exact agreement between the theoretical estimate and the observations is fortuitous.

Recently, Tuck (1976) has estimated that the annual production of NO molecules by lightning flashes is 1.8×10^{35} molecules per year with rather large limits of uncertainties. This estimate was based on a theoretical development which is entirely different from the theory developed by Griffing (1977). The estimate for the annual production of NO molecules can very easily be obtained by the use of the entries in Table 11. Using a value of 2×10^{28} electron volts dissipated per lightning flash, a worldwide frequency of 10^2 lightning flashes per second, 3×10^7 seconds per year, and the entries in the table, the annual production of NO molecules is found to be between 4×10^{35} and 6×10^{35} NO molecules.

More observations are needed for further confirmation of the theoretical results. While thunderstorms are of importance as large interim local sources of ozone and the oxides of nitrogen, further investigations are needed to assess their importance as a background source of these pollutants.

3.2.8 Global atmospheric N_2O budget

Although nitrous oxide, N_2O, is not considered to be a pollutant by the Environmental Protection Agency (1971), it is, nevertheless, very important in pollution problems. At the present time, it is believed that N_2O has a major role in establishing ambient stratospheric ozone concentrations (Crutzen 1970, 1974). The source of stratospheric N_2O is the troposphere.

Research was conducted on the problem of determining the net rate of transport of N_2O from the troposphere to the stratosphere. Since the average tropospheric N_2O concentration is relatively constant, if the net tropospheric-stratospheric exchange is determined, then the rate of N_2O production in the troposphere can be determined. If the rate of N_2O production were known, this would help answer questions concerning the nature of N_2O sources. For instance, are the oceans a net source or sink? The importance of the problem on N_2O sources is reflected in recent publications (Crutzen, 1976; McElroy et al., 1976; Sze and Rice, 1976) on the possible consequences of increased N_2O emissions from the increasing use of fertilizers.

The information required to estimate the net rate of N_2O transfer to the stratosphere is: (1) the mass outflow rate of stratospheric air to the troposphere and (2) the N_2O mixing ratio altitude profiles. Danielsen and Mohnen (1976) have deduced that there is an average mass outflow rate of stratospheric air to the troposphere of 3.6×10^{20} grams per year in the Northern Hemisphere by tropopause folding events. This is not the only transport process, but it may well be the dominant process, by which stratospheric air is transported to the troposphere. Making use of the published N_2O mixing ratios, the N_2O production rate was estimated to be 10^{14} grams N_2O per year. This is about an order of magnitude larger than estimates obtained by making use of the eddy diffusion equation to simulate the transport processes (Crutzen, 1976) for the transfer of tropospheric air to the stratosphere. Since this work was completed an extensive set of measurements on the N_2O mixing ratio profiles at various locations in the Northern Hemisphere has been made (Schmeltekopf et al., 1976). It will be necessary to use the newer and better measurements of the N_2O mixing ratio profiles before firm conclusions can be reached.

Any theoretical result should be experimentally verified insofar as possible. While there is no obvious way to experimentally verify the average global N_2O emission rate, some of the uncertainty in the theory could be removed by measuring air penetrating into the troposphere during tropopause folding events.

3.2.9 Air pollution profiles

San Jose State University, under a grant, made measurements of ozone and carbon monoxide at six levels on a TV tower located on Mt. Sutro in San Francisco. Observations began on June 24, 1974. A general discussion of the data collected for the period from June 24 to September 24, 1974 is given in last year's annual report (Viebrock, 1976).

During FY-76 case studies were made using the data for three periods during the summer of 1974 - July 24-26, September 3-8, and September 14-17. During the first two periods, the ozone values exceeded the 20 pphm oxidant Health Alert Level of the Bay Area Air Pollution Control District. The ozone values were lower during the third period, eventhough the meteorological conditions were similar.

The synoptic pattern showed a lobe of the Pacific subtropical high extending over the California coast, weakening the normal monsoon flow from the Pacific through the San Francisco area. A normal diurnal sea breeze circulation was maintained. A decrease in the westerly wind component occurred at the Mt. Sutro tower in the late morning, close to the time the elevated inversion base began to lower in height. Easterly winds were found during this part of the day during portions of the three study periods. Ozone concentrations at the upper tower levels increased at the same time.

The investigators explain the observations as due to local circulation effects. The circulation is apparently dominated by the effects of local heating and cooling. As a consequence of convective processes due to heating of the inland valleys, ozone and its precursors are mixed in a relatively deep layer. Some of the material is carried to areas above an existing inversion, remains aloft at night, and is recirculated the following day.

Additional observations are being taken and will be analyzed.

4.0 TECHNICAL ASSISTANCE

4.1 Regional and Research Support

4.1.1 Region I - Boston, MA

Meteorological support to EPA Region I, covering the six New England states, can be separated into several major areas: remote sensing, emergency operations, enforcement assistance, particulate problems, state assistance, and pollutant standard index.

Region I is applying remote sensing techniques wherever possible. The Regional Meteorologist is in charge of this effort, which includes a variety of projects. Aerial color infrared photography confirmed the point of maximum SO_2 impact indicated by modeling. Aerial black and white photography supplemented cartographic maps to show the relationship of pollution sources and receptors. A contract research project is underway to determine whether NOAA-VHRR, GOES or LANDSAT satellites reveal suspended particulate or ozone plumes.

Duties of the Emergency Operations Control Center have occupied much of the Regional Meteorologist's time. They included the performance of a system analysis of the desired characteristics for a unified regional center for all environmental emergencies, investigation of use of a contractor and the USCGCHRIS system to provide 24-hour meteorological modeling support for environmental emergencies, and the planning for a regional meeting of public safety and environmental emergency personnel.

Support to the Enforcement Division has created several long term projects. One case, an enforcement action against a manufacturing plant located in complex terrain, has generated several projects and modeling efforts. One such project involved investigating the desirability and costs of erecting a meteorological tower to gather data in a 800' deep valley. Another case required investigating the meteorological characteristics accompanying violations and advising on the incorporation of meteorological factors into a procedure for avoiding future violations. In this case, surveillance of air quality will be maintained for six months.

Particulate levels are of prime importance in Region I. The particulates are the main obstacle to the attainment and maintenance of air quality standards. As a consequence, the Regional Meteorologist has become involved in several investigations of the causes of elevated TSP levels. In most cases, routinely available meteorology has proved insufficient to pinpoint the pollution sources.

Use must be made of archived sounding data and synoptic charts. A study was made of the meteorological characteristics of days with widespread elevated levels of TSP and evidence for the transport of TSP into New England.

A model to predict the impact of open dump burning has been developed for the states. A verification program is now underway. The Regional Meteorologist has been actively engaged in supporting regional adoption of the Pollutant Standard Index (PSI). Correspondence to the states has urged adoption of the PSI. The Regional Meteorologist has coordinated with the Lung Association in their effort to have the Index adopted. The National Weather Service has been requested to instruct forecast offices in forecasting meteorological conditions favorable for oxidant production.

4.1.2 Region III - Philadelphia, PA

During FY-76, the NOAA Regional Meteorologist assigned to EPA Region III, Philadelphia, PA, participated in several major studies.

Two modeling studies of a heavily industrialized area in southern Allegheny County, Pennsylvania, have recently been completed under contract to the U.S. Environmental Protection Agency. One employed a Gaussian type diffusion model, and was done by the H. E. Cramer Company, Inc. The other was a wind tunnel study done at Calspan Corporation's Atmospheric Simulation Facility. The comparison, written for the potential user of air pollution modeling services, compares and contrasts the two studies in terms of their required inputs, cost, and results. Significant differences in input requirements and limitations are found, especially in source description, time variability of emissions, and flexibility of meteorological conditions. Outputs of the two methods are not directly comparable, but with the use of time scaling, comparisons of limited cases can be made. Suggestions are given to facilitate a choice of techniques applicable to various problems encountered in air resources planning and management.

A particulate study in southwestern Pennsylvania, started in 1975, continued in 1976. Preliminary results indicated the need for concentration on the identification of particulates collected in ambient air samples, rather than concentration on stack sampling as had been previously planned. It was found that the present techniques for identifying particulates are for the most part inadequate, and new techniques are being developed. These techniques use comparative results of optical and electron microscopy. Using these techniques, we hope to identify not only the type of particle being sampled but the most logical sources of the particulate. The project is expected to be completed in late 1977 and it is hoped it will be useful in developing new particulate control strategies for the major industrialized portion of the southwestern Pennsylvania region.

A modeling study of particulates from all major sources in a very large integrated steel mill was conducted. Results of the study showed the importance of considering major heat sources, other than stack emission, in modeling such a facility. These heat sources included the coke ovens, cinder lines, blast furnaces, rolling mills, and other major hot operations in the steel facility. We found that large integrated mills may develop their own unique circulation systems similar to an urban heat island circulation. Much more investigation of this problem is needed before truly successful modeling results can be accomplished.

A major monitoring and modeling study was conducted of two power plants in the northern panhandle of West Virginia. Airborne instruments were used to sample sulphur dioxide, particulates, oxides of nitrogen, and ozone. Samples were taken in and around the plumes and close to the ground. Monitoring was carried out by EPA's Las Vegas laboratory. Concurrent meteorological observations were also made. While the monitoring data were being developed, the plants were modeled using the meteorological data measured in the monitoring program and actual stack emissions. The modeling was done under contract by H. E. Cramer Company.

4.1.3 Region IV - Atlanta, GA

Most of the NOAA meteorological support to EPA Region IV in Atlanta, GA, consisted of the application of air quality simulation models. Various dispersion models were applied to State Implementation Plan revision requests.

In Kentucky, the Valley model was used to look at the 24-hour effects of Tyrone, Dale and Pineville Power Plants. This modeling was done as part of a SO_2 plan revision by Kentucky. This plan revision is currently under challenge. This challenge will result in more extensive model applications during 1977.

In Mississippi, several different models were used in a plan revision for particulate control for cotton gins. In Florida, an SO_2 plan revision resulted in modeling some 20 different power plants. Only two of these were disapproved based on the modeling results. As a result of this disapproval, EPA is in litigation with one of the two power plants plus the State of Florida. This litigation prompted this region to obtain 5-years of hourly meteorological data for the Tampa area. Modeling was also done in conjunction with a denial of a variance for U.S. Steel in Birmingham.

Numerous other models were applied to new power plants, paper mills and sulfuric acid facilities. A U.S. Air Force model known as the "Aerial Spray Assessment Model" is being applied to a pesticide misuse problem in Florida.

Within the region the NOAA meteorologist is involved with two model-validation studies. One of these studies involves the "Valley Model" as it applies to an oil refinery in rough terrain. The other study involves the "Power Plant Model", and if practical, may be extended to the "RAM" model since the area involved is semi-urban. Outside of normal or routine Environmental Impact Statement reviews, there have been several major EIS actions. One of these, the I-40 Overton Park route, has been in court for the past three or four years, but a satisfactory alternative appears to have been finally worked out. Other major projects also involved interstate roads which are in metropolitan areas where the oxidant standard is exceeded. In two cities, Jacksonville and Atlanta, we have asked for a reanalysis because of problems with the projects.

4.1.4 Region VI - Dallas, TX

The NOAA meteorologist assigned to EPA Region VI in Dallas, TX, participated in many activities involving consulting and contract monitoring. Consulting services were provided on dispersion modeling within the Region.

A contract was monitored to develop an air quality baseline for southern Louisiana. This effort was related to attempts to evaluate the Environmental Impact Statement for proposed deepwater offshore oil ports off southern Louisiana and Freeport, TX. Nine air quality monitoring trailers were deployed in southern Louisiana from July to October 1976. Stringent quality assurance procedures were established for the project, with a total of 10 audits during the three-month period of operations. Major difficulties had to be overcome because of excessive maintenance problems on the trailer equipment, lack of initial agreement on audit results between the contractor and EPA personnel, and the resignation of four key contractor personnel. Despite the problems, the data gathering effort was successful. A final report is due in January 1977.

A contract is being monitored to study the bromine industry in southern Arkansas. A preliminary field sampling effort was conducted in September 1976 and analysis of collected samples is currently underway. The major sampling effort will be conducted in July 1977.

4.1.5 Region VIII - Denver, CO

The NOAA meteorologist assigned to EPA Region VIII in Denver, CO, provided a wide range of meteorological support.

Assistance was provided in the development of the regulation for several large sources, including Anaconda Copper Company, Kennecott Copper Company, U.S. Steel, and CF&I Steel. This required dispersion modeling, hearing record review, assistance in air quality monitoring program design, and data review.

Environmental Impact Statements were reviewed for several large proposed facilities. Atmospheric diffusion modeling was done for some of these sources to verify results included in the EIS. Diffusion modeling was also done for other Federal Agencies (National Park Service, and Bureau of Land Management) to assist them with improving the EIS.

State agencies were assisted in acquiring and using the UNAMAP models and the EPA Valley Model. The models were needed by the states for new source reviews and air quality maintenance area analysis.

A contract was monitored with Systems Applications, Inc. on regional diffusion modeling in the Northern Great Plains area. The final report will be available approximately May 1977.

The Bureau of Land Management was assisted with contract proposals for atmospheric dispersion modeling and air quality studies. Also, BLM was assisted with the design of field experiments for baseline atmospheric visibility studies and air quality studies. These results are for use in preparing Environmental Impact Statements for facilities proposed to be developed on BLM land within Region VIII.

Designed field experiments to conduct plume studies near a large source in complex terrain. These study results are expected to assist with diffusion model application in complex terrain.

The NOAA regional meteorologist served as a member of the Regional Office emergency response team and responded to requests as needed for air pollution episodes and other air pollution emergencies. A brief internal report was written on the air pollution episode in the Salt Lake City, Utah, area in January 1976.

4.1.6 Region IX - San Francisco, CA

The NOAA meteorologist assigned to EPA Region IX in San Francisco, CA, provided support primarily in dispersion modeling, and State Implementation Plan and Environmental Impact Statement evaluation.

Support was provided for the development of a State Implementation Plan revision for an SO_2 strategy for the State of Arizona. This involved participation in public hearings on the proposed regulations, working with the state agency to improve their regulations for supplementary control systems, and review of public hearings records on the SO_2 strategy and the revised Technical Support Document. In conjunction with the development of a new document, modeling for each smelter was done using CRSTR, VALLEY, and the PT models to determine the short and long term anticipated SO_2 average concentrations. Actual measured data were analyzed for the frequency of violations. A program was written to prepare frequency distributions using a technique developed by Larsen (1971). Both 24-hour and 1-hour samples were summarized in this manner.

A procedure was established and a guideline checklist prepared for the review of the meteorological aspects of Environmental Impact Statements. Approximately 120 Environmental Impact Statements were reviewed.

A computerized system for examining air quality was developed based on regression analyses and Spearman rant correlations. Such an analysis was performed for selected California stations for oxidant and carbon monoxide.

4.1.7 Region X - Seattle, WA

During FY-76, the NOAA meteorologist assigned to EPA Region X in Seattle, WA, provided a variety of meteorological services.

A contract with H. E. Cramer to model SO_2 emissions from the ASARCO smelter in Tacoma, WA, was monitored. The Regional Office was assisted in ensuring that the air quality impact analyses for new sources were commensurate with the modeling state-of-the-art and that appropriate meteorological situations were used to evaluate the effects in terms of the air quality standards and significant deterioration limits. The new sources included the modification of the Martin-Marietta Aluminum Plants at The Dalles, OR, and Goldendale, WA; construction of a refinery at North Pole, Alaska; construction of a refinery at Ranier, OR; and proposed construction of a new power plant near Boise, ID.

Similar assistance was provided for existing sources, including a sulfuric acid plant near Pocatello, ID; a smelter at Kellogg, ID; carbon monoxide in Seattle and Spokane; and particulate problems in several areas. Meteorological assistance was provided during a number of air stagnation episodes.

4.1.8 Health Effects Research Laboratory support

NOAA personnel assigned to the EPA Health Effects Research Laboratory provided meteorological support for various studies of the effects of air pollution on health. Two studies of special interest were the use of a mortality model (Truppi et al., 1975a), and an investigation of the effects of temperature on asthma, cardiopulmonary, and initiation symptoms in ambient air pollution (Truppi et al., 1975b).

An air pollution episode in Pittsburgh, Pennsylvania, in November 1975 presented an opportunity to employ a daily mortality model as an adjunct in a study of the effect of air pollution on health. An estimated excess of 23 deaths was found when the period of the episode was compared with the same month and days in the years 1962 to 1972 (Table 12). However, after fitting a mortality model which accounted for deaths due to air temperature and other covariates, the remainder that might be assigned to air pollution was 14 deaths (Figure 32). Since the mortality model requires daily values of maximum temperature and precipitation, these data were furnished for those regions and days when the model was applied. Although man reacts to pollution through a full spectrum of biological responses ranging from subtle physiological changes to death, mortality is currently the best documented and defined health indicator available. A paper by Riggan et al. (1976) describes this particular model, a single set of forecast equations applicable to metropolitan centers in the northeastern United States. Work is continuing to refine the model and to determine its applicability to other areas of the United States.

Table 12. Comparison of 1975 Deaths With the 1969-1972 Average Mortality

Day of Month	1975	Average 1962-1972	Excess Deaths
17	60	49	11
18	52	47	5
19	47	47	0
20	54	47	7
Total			23

Probability = .002

A six month study of 211 asthmatics residing in the Great Salt Lake Basin, Utah, revealed excessive attack rates could be attributed to both colder days and air pollution, with air temperature unquestionably the most consistent determinant; asthma frequency increased as temperature decreased. It was found that specific pollutants, total suspended particulates and suspended sulfates, caused significant effects on days with minimum temperatures above 30°F. In addition, temperature-dependent thresholds of pollutant concentration were found, below which little aggravation of asthma symptoms was observed, and above which symptoms increased with increasing concentrations. Separate thresholds were found for both pollutants in a low minimum temperature range, 30° to 50°F with different thresholds at a higher minimum temperature range, greater than 50°F (Figure 33). A comparable 32-week study in the New York City area was also conducted where no direct temperature effect was found. However, temperature-dependent thresholds of suspended sulfate concentration were found in the same low and high ranges of minimum temperatures (Figure 33).

A study was conducted of over 500 elderly persons residing in or near New York City, some of whom were well and some reporting cardiopulmonary symptoms. Participants were grouped into those previously diagnosed as being well (no history of symptoms), having heart disease, having lung disease, or having combined heart and lung disease. Both air temperature and pollutant concentrations were found to be associated with changes in symptom status. Decreasing temperatures induced or aggravated symptoms in all but heart disease panelists, who reported worsening symptoms with elevations in temperature.

Irritation symptoms, headache, eye discomfort, chest discomfort and cough were studied in a student nurse population in Los Angeles over a three year period. Average daily symptom rates were compared with pollutant data recorded at a nearby monitoring station and with air temperature recorded at Los Angeles Civic Center. All symptoms increased with maximum hourly oxidant levels. Air temperature, carbon monoxide, and nitrogen dioxide pollutant were found to be not significant with regard to the variations in irritation symptoms.

Work is continuing, with additional panels of asthma patients in Los Angeles as well as a study of a general population in Los Angeles, concerned with the relation of oxidants to acute respiratory disease symptoms. In all studies meteorological data are collected and included in statistical analysis to verify or modify conclusions drawn from previous investigations.

4.1.9 Support to the Environmental Monitoring and Support Laboratory

NOAA activities in support of the EPA Environmental Monitoring and Support Laboratory mostly concerned the choice of monitoring sites for the Field Studies Section and help in analyzing the data produced by those field studies.

During this fiscal year there were field studies to measure any escape of dioxin during incineration at Gulfport, Mississippi; to monitor Kepone raised into the air by wind or traffic near the place of its manufacture in Hopewell, Virginia; and to measure PCB compounds used in a pilot study at El Dorado, Arkansas of ways to dispose of electrical components which contained PCB compounds.

Figure 32. Comparison of deviations from expected deaths generated by the model.

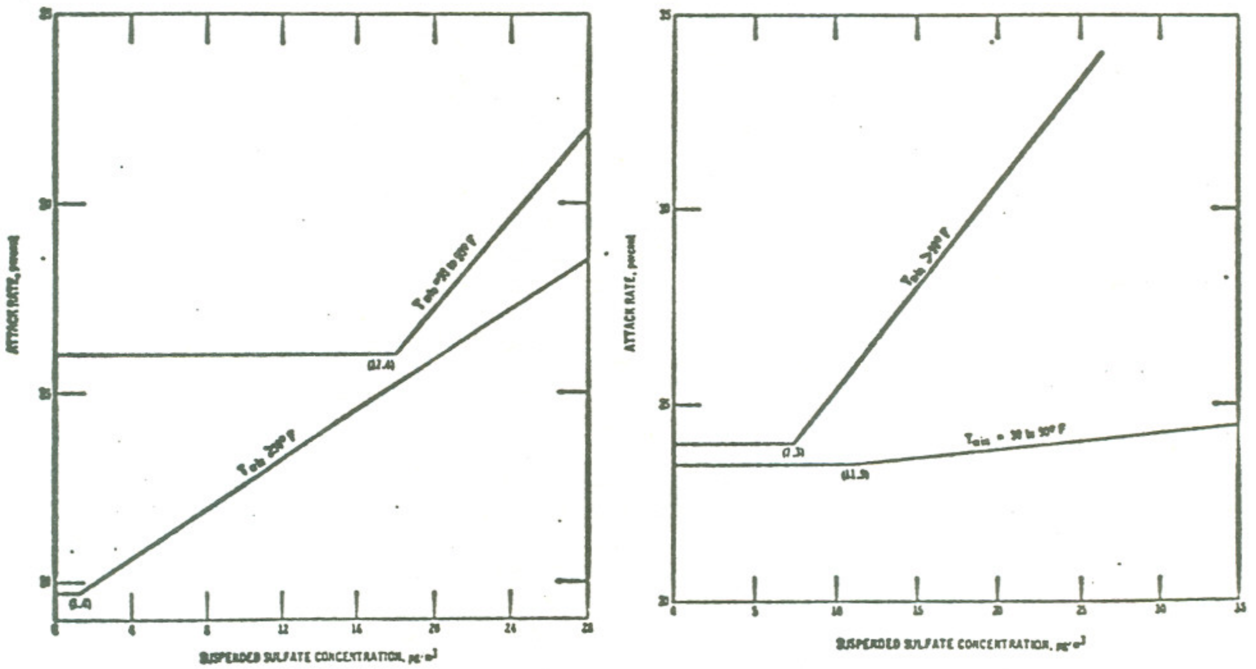


Figure 33. Effect of minimum daily temperature and suspended sulfates on daily asthma attack rates: Salt Lake City and New York City areas.

A continuing field study is the Los Angeles Catalyst Study alongside the San Diego Freeway to measure the sulfuric acid contributions of Freeway traffic. Measurements of CO, O_3, NO, NO_2, and total sulfur as well as 24 hour and 4 hour sampling of particulates are made. Also included are wind, temperature, and humidity measurements as well as traffic counts.

Another field study under way is the placement of ozone measurement equipment in a number of the National Forests. Sites were selected in the Kisatchie National Forests, LA, in the White Mountain National Forests, VT, and in the Custer National Forest in extreme eastern Montana. The next site to be equipped will be in the Croatan National Forest in eastern North Carolina. The primary measurement is for ozone, with supplementary measurements of solar radiation, wind and temperature.

Other support was provided to the Statistical and Technical Analysis Branch. This was concerned with the Los Angeles Catalyst Study. Concentration differences between opposite sides of the Freeway were related to wind direction.

Another activity was the study of high ozone in Florida, especially with respect to the transport of ozone into the area from long distances. Computerized trajectories were obtained for air masses arriving in Florida and compared with maximum concentrations of ozone for the day of arrival. It was found that for a site 9 miles south of Jacksonville the maximum ozone concentrations were highest when the air mass position was to the north at a time 12 hours before arrival. This, of course, could very easily be due to precursors injected into the air while the air passed over Jacksonville. The positions to the northeast also brought high concentrations of ozone. This could still be due to Jacksonville, but the positions to the west were the third highest in ozone concentration.

Another study was made to relate the position of the air mass 36 hours previous to its arrival and the effect on maximum concentrations. It was found that a position to the west of Jacksonville brought the highest concentrations, with the position to the north being second. The trajectories often followed circuitous routes so that air masses, which were to the west at a time 36 hours before arrival, might during the last 12 hours be coming from the north. This could contaminate the air mass by the addition of emissions in the Jacksonville area. To try to eliminate this, the air mass positions at the 36-hour time were again tabulated with the omission of those which were in the north octant during the last 12 hours. This showed the west position to be much more clearly defined as the air mass location, when high ozone concentrations occur in the Jacksonville area.

A slightly different approach was to look at the number of hours during each day that the ozone concentration was equal to or above 120 $\mu g/m^3$. This concentration was arbitrarily chosen as being above the usual background concentrations. This approach emphasizes the occasion of higher O_3 dosage rather than the sometimes brief exposure to the highest value. Again the direction of the position at a time 36 hours before arrival was used. omitting those occasions when the air masses during the last 12 hours were to the north. This count of the hours when ozone concentration was elevated showed an average of 5.1 hours when the 36-hour position was to the west and less than one hour when the position was to the south (Figure 34).

A similar approach was used for the Tampa area. However, the sites at which ozone was measured do not lend themselves so easily to this sort of analysis. The nearby sources surround the sites so that transport from long distances is obscured although it may be present.

In southern Florida, ozone measurement sites were placed in downtown Miami, in the suburbs and farther away to the west in the center of the peninsula and on the west coast. Similar analyses for these sites have not yet been completed, but preliminary work indicates that air masses arriving from the west and northwest usually have higher concentrations than those from the east and south.

4.1.10 Airport modeling support

A NOAA meteorologist is providing meteorological support in an airport modeling program. The United States Air Force, the Navy, and the Environmental Protection Agency share an interest in determining the impact of airport activities on local ambient air quality. It is necessary to establish a suitable method for evaluating the air quality impact of airports both in their current configuration and with proposed operational or other changes. The current vehicle for such an evaluation is a properly verified air quality computer model.

Only a few air quality models have been developed specifically to calculate airport air quality impact, primarily because of the complicated emissions data input required. Essentially, all recent airport model refinements have been in emissions input subroutines. A Gaussian dispersion formulation is used in most current airport models. This method is particularly adaptable to the small distances and pollutant travel times associated with airports.

It was decided that a relatively remote, high traffic volume, military airfield where accurate statistics would be available for aircraft type, mix and activity schedules should be used for the study. The program is underway at Williams Air Force Base with plans to move the monitoring network to Miramar Naval Air Station, California, in the autumn of 1977.

4.1.11 Oxidant transport study support

NOAA meteorological assistance was provided for several EPA oxidant transport field studies, one in the Boston area and one in the Washington, DC, area.

The mesoscale analysis of ozone concentrations measured at ground level and aloft in the Boston metropolitan area have provided some insight into the origin and fate of urban ozone. An intensive period of airborne ambient air monitoring

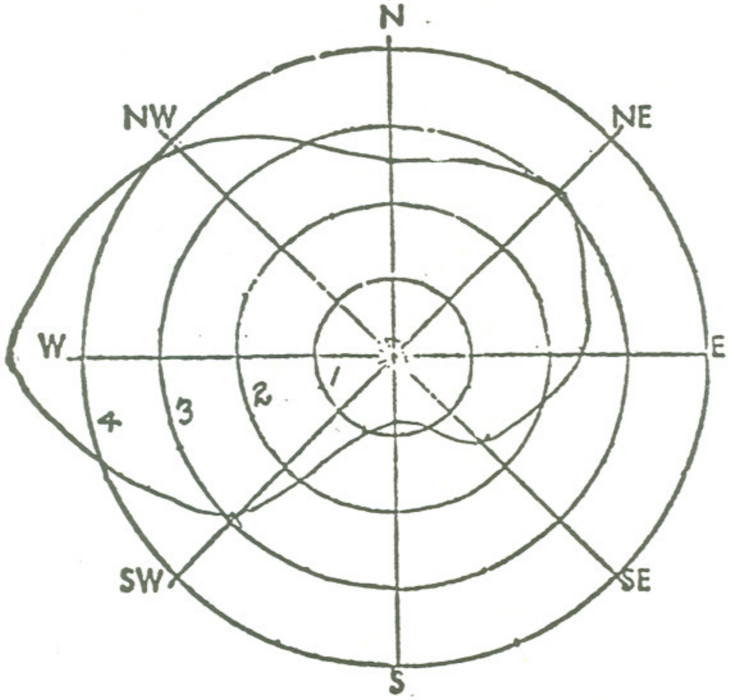


Figure 34. Number of hours per day that ozone concentrations above 120 µg/m^3 occurred near Jacksonville, Florida, as a function of the previous 36-hour position of the air mass.

around Boston was conducted by the Environmental Protection Agency long-range air monitoring aircraft from August 9-14, 1975, which shows areas of semi-persistent high and low ozone concentrations. In addition, data presented identified an urban ozone plume at extended distances downwind of Boston on several days within the sampling period. The importance of the daily synoptic meteorological situation upon the observed ozone distribution was emphasized in the analysis. Data analysis and evaluation are continuing.

Field guidance was provided for the Summer 1976 Bicentennial Ozone Transport Study conducted in the Washington, DC, area. Some interesting aircraft ozone flights were conducted. Nighttime ozone distributions in the vertical are being evaluated.

4.1.12 Support to the Corvallis Environmental Research Laboratory

The NOAA meteorologist assigned to the EPA Environmental Research Laboratory in Corvallis, OR, provided support to the various programs in the laboratory and assisted the biologists and ecologists in determining the environmental effects of atmospheric pollutants. This included the development of programs for automated identification and measurement of microscope images; a field program to determine the relationships bacterial and fungal concentrations in the atmosphere and meteorological conditions; advising on the meteorological aspects of the program for studying the potential impact of a coal-fired power plant on grasslands in Montana; and initiating a study to quantify, in terms of orders-of-magnitude estimates, deposition and uptake of pollutants by vegetation, soil, and water. Work is also underway on the development of a numerical model of the ecology of the system of micro-organisms.

4.2 General Assistance

4.2.1 Reporting air quality status

A standard air pollution index -- Pollutant Standard Index (PSI) -- developed by a Federal Task Force on Air Quality Indicators was issued by EPA for use by air pollution control agencies and the various news media. The Federal Task Force included members from EPA, NOAA, the Council on Environmental Quality (CEQ), and the Department of Commerce's Office of Environmental Affairs.

As shown in Table 13, the PSI utilizes a normalized scale ranging from 0 to 500 based on the concentrations of each of the five major pollutants. Five sub-ranges are categorized by health effect descriptor words from good to hazardous. Ordinarily, only the index for the pollutant with the highest index value will be reported to the public. A recent CEQ/EPA Report (Thom and Ott, 1975) indicated that 33 metropolitan areas in the U.S. used indices, no two of which were exactly alike. The purpose for developing the PSI was to provide greater uniformity in index reporting, thereby reducing confusion created by many different indices and increasing the public's understanding of air pollution levels and their significance.

Table 13. Tabular Summary of Pollutant Standards Index Criteria

INDEX VALUE	AIR QUALITY LEVEL	POLLUTANT LEVELS					HEALTH EFFECT DESCRIPTOR	GENERAL HEALTH EFFECTS	CAUTIONARY STATEMENTS
		TSP (24-hour), $\mu g/m^3$	SO_2 (24-hour), $\mu g/m^3$	CO (8-hour), mg/m^3	O_3 (1-hour), $\mu g/m^3$	NO_2 (1-hour), $\mu g/m^3$			
500	SIGNIFICANT HARM	1000	2620	57.5	1200	3750	HAZARDOUS	Premature death of ill and elderly. Healthy people will experience adverse symptoms that affect their normal activity.	All persons should remain indoors, keeping windows and doors closed. All persons should minimize physical exertion and avoid traffic.
400	EMERGENCY	875	2100	46.0	1000	3000		Premature onset of certain diseases in addition to significant aggravation of symptoms and decreased exercise tolerance in healthy persons.	Elderly and persons with existing diseases should stay indoors and avoid physical exertion. General population should avoid outdoor activity.
300	WARNING	625	1600	34.0	800	2260	VERY UNHEALTHFUL	Significant aggravation of symptoms and decreased exercise tolerance in persons with heart or lung disease, with widespread symptoms in the healthy population.	Elderly and persons with existing heart or lung disease should stay indoors and reduce physical activity.
200	ALERT	375	800	17.0	400[c]	1130	UNHEALTHFUL	Mild aggravation of symptoms in susceptible persons, with irritation symptoms in the healthy population.	Persons with existing heart or respiratory ailments should reduce physical exertion and outdoor activity.
100	NAAQS	260	365	10.0	160	[a]	MODERATE		
50	50% OF NAAQS	75[b]	80[b]	5.0	80	[a]	GOOD		
0		0	0	0	0	[a]			

[a] No index values reported at concentration levels below those specified by "Alert Level" criteria.

[b] Annual primary NAAQS.

[c] 400 $\mu g/m^3$ was used instead of the O_3 Alert Level of 200 $\mu g/m^3$ (see text).

A Guideline for Reporting of Daily Air Quality - Pollutant Standards Index (PSI) (Environmental Protection Agency, 1976d) was issued. ML meteorologists in cooperation with the National Weather Service (NWS) developed a section on qualitative forecasting of the index for up to a day in advance. The qualitative forecast indicators are termed: decrease, increase, or no change. The air pollution control agencies adopting PSI will need to devise local techniques or procedures for forecasting the index using as major input, data and support services provided by NWS through the Air Pollution Weather Forecast Program. NWS Forecast Offices currently use National Meteorological Center (NMC) forecast products such as Forecast Air Stagnation Charts, Air Stagnation Narratives, and Air Stagnation Data to develop and issue, as needed, Air Stagnation Advisories, Special Dispersion Statements, and Dispersion Outlooks to air pollution control agencies and/or the public. In addition, low-level upper air data soundings are obtained routinely or as needed at certain designated stations to support air pollution forecasting. Also, local NWS Offices provide other air pollution weather data needed by local air pollution control agencies.

4.2.2 Power plant modeling analysis procedure

The systematic evaluation of the air quality impact associated with power plants necessitated by State Implementation Plan (SIP) requirements and the Energy Supply and Environmental Coordination Act (ESECA) generated information cn about 700 power plants. A contract effort directed by ML personnel is underway with Walden Division of Abcor, Inc., and has two objectives for further utilization of this information. The first is to develop a procedure for rapid calculation of the effect of changes in plant design or operation upon dispersion modeling results. There will be data files available which will include the most current source (or plant) data required for modeling, the most current model calculated concentrations, and the most current χ/Q values. The procedures being developed will allow rapid, easy updating of these files, either on a temporary (a hypothetical change option) or permanent (a permanent change option) basis.

The second objective is to run or re-run the dispersion model analyses for all plants and place the results in the above data files. This is being done to provide assurance that all the modeling results are based on up-to-date data and are determined by the same procedures.

4.2.3 Industrial studies

Considerable modeling support is provided by NOAA meteorologists to the Environmental Protection Agency for the purpose of assessing the air quality impact of New Source Performance Standards (NSPS). NSPS-related modeling is done for widely varying types of industrial operations. Since the emission standards are set on an industry-wide basis, the dispersion modeling is done on prototype examples of each industry. Within each industry, various plant sizes, plant configurations, and control strategies are modeled. The modeling results are incorporated into the Standard Support and Environmental

Impact Statement which accompanies the promulgation of each New Source Performance Standard in the Federal Register.

NSPS-related modeling involves all criteria, and many non-criteria pollutants and covers the complete spectrum of averaging times from a few seconds to a full year. Extensive use is made of the Single Source (CRSTER) Dispersion Model. The modeling is far from being a blind exercise in "crank-turning", however, as considered judgment is brought to bear in the selection of input data and in the interpretation of model results. Models are also tailored to make them more appropriate for the type of pollutant source being considered. In some instances, no model at all is deemed applicable, and dispersion estimates are generated by techniques specially developed by NOAA meteorologists.

The NSPS-related dispersion modeling this year is summarized on an industry-by-industry basis, as follows:

(1) Station gas-turbine generators - Several sizes and/or designs were modeled, ranging from less than 1 MW to more than 60 MW capacity. The turbines were modeled individually and in various multi-turbine clusters. Aerodynamic complications related to the typical low-profile design were of prime consideration. Pollutants of concern were SO_2 and CO.

(2) Coal gassification plants - Several sizes and modes of control were modeled. The pollutants of concern were CO, NO_x, various hydrocarbons, SO_2, carbonyl sulfide, and H_2S. The control of carbonyl sulfide and H_2S was seen to be quite effective in reducing the estimated ambient air quality levels. In the process, the estimated ambient levels of SO_2 were seen to increase.

(3) Kraft pulp mills - Three sizes and five levels of control were considered. For purposes of considering aerodynamic complications, two different sets of stack heights were considered. The pollutants of concern were particulate matter and reduced sulfur (e.g., H_2S). Good plant design (good engineering-practice stack heights) was seen to be quite important in reducing ground level concentration estimates. The plant treatment pond (where used) was shown to be the dominant contributor to ambient levels of reduced sulfur.

(4) Electric arc furnaces in the steel and grey-iron foundry industries - A matrix of several sizes, configurations, and control-levels was modeled. The pollutant of concern was particulate matter. Emission controls in conjunction with good-engineering-practice stack heights, were seen to be quite effective in lowering the ambient concentration estimates.

(5) Lead-acid battery manufacturing plants - The pollutants of concern were SO_2, particulate matter, and particulate lead. Aerodynamic complications stemming from plant design were seen to be a factor. Nevertheless, emission controls resulted in quite low estimates of

ambient air quality concentration.

(6) Sulfuric acid manufacturing plants - Three sizes and three levels of control were modeled. Acid mist was the pollutant of concern. Controls were seen to be quite effective in reducing the estimated ambient air quality levels.

(7) Lime plants - Three levels of control and two plant configurations (stack heights) were modeled. Emission controls were shown to dramatically lower the resulting SO_2 and particulate matter concentrations estimated at ground level, especially when good-engineering-practice stack heights were assumed.

(8) Carbon black plants - Three plant designs were modeled, each representing a different mode of control. One of the designs involved the emission of all pollutants from a single stack of good-engineering-practice height. This design (emission mode) was clearly shown to be the most effective at reducing the resulting ground-level concentrations estimated for CO, NO_x, hydrocarbons, H_2S, and particulate matter.

(9) Sintering - Three sizes and four control modes were modeled. The pollutants of concern were particulate matter, SO_2, and CO. Controls on particulate matter were shown to be very effective in reducing the estimated ambient air quality levels, especially since the no-control case involved the low-level venting of fugitive emissions. It was also shown that the use of good-engineering-practice stack heights would increase this effectiveness.

(10) Asphalt roofing manufacturing plants - It was shown that the design of typical plants (short stacks and horizontal vents) resulted in relatively high ground-level concentration estimates for hydrocarbons and particulate matter even under the maximum control level modeled. Nevertheless, the estimated ambient concentrations were greatly reduced from the no-control case.

(11) Phosphate rock processing plants - Two sizes, and three control levels, were modeled for each of the calcining, drying, and grinding processes. Particulate matter and fluorides were the pollutants of concern. It was seen in some cases that aerodynamic effects (due to short stacks) caused moderately high concentration estimates even under controlled emission rates. Another interesting finding was that a proposed scrubber device was counterproductive; that is, it resulted in higher estimated concentrations than did the uncontrolled case.

(12) Sulfur recovery in the petroleum industry - The pollutant of concern was SO_2. The analysis of a medium-size plant showed the estimated ambient impact to be relatively small under the proposed NSPS.

(13) Sulfur recovery at natural gas plants - In an analysis of five emission levels of SO_2 at a medium-size plant, the effect of sulfur recovery--

rather than the emission of sulfur as SO_2--was clearly seen since the ambient SO_2 estimates were greatly lowered. It was shown that the highest level of sulfur recovery, involving the use of a tail-gas scrubber, provided little additional air quality benefit.

(14) Grain elevators - Modeling estimates indicated quite high ambient concentrations of particulate matter nearer grain terminals, due mostly to low-level fugitive emissions. Control measures were shown to be very effective in reducing the ambient concentration estimates.

In addition to the modeling support directly related to New Source Performance Standards, NOAA meteorologists provided modeling supoort on a variety of special topics. A prime example of this was the modeling work done for a joint industry/EPA task force on fugitive particulate emissions in the iron and steel industry. As an on-going project, various control strategies are assessed as to their effect on ambient air quality. Another special topic for which modeling support was provided was the EPA concern about possible high ambient levels of arsenic resulting from coal burning power plants and from the glass manufacturing industry. Still another special modeling project was an assessment of the impact of SO_2 emissions from the Nanticoke power plant in Canada upon air quality at a distance of about 100 km in the United States (the Buffalo, NY area).

4.2.4 Supplementary Control Systems

The involvement of NOAA meteorologists in the area of Supplementary Control Systems (SCS) continues, and materials produced by them have been incorporated in three SCS documents this year.

The first publication, Guidelines for Enforcement and Surveillance of Supplementary Control Systems (Environmental Protection Agency, 1975c), contains an extensive section on meteorological instruments extracted from training course materials prepared for the Air Pollution Training Institute. Desirable characteristics and principles of operation for a wide range of meteorological instruments which might be incorporated in an SCS monitoring network are discussed.

The second document, Guidelines for Evaluating Supplementary Control Systems (Environmental Protection Agency, 1976e), was published in February. The original version of the document was prepared under a contract with the H.E. Cramer Company, Inc. but extensive in-house revision was subsequently required, largely because of the increasingly controversial nature of supplementary control systems. The purpose of the document is to provide guidance in evaluating the technical aspects of a supplementary control system. It is intended for use in conjunction with other key EPA documents concerned with SCS, and should be referred to as early as possible in the development phase of an SCS.

The document is intended for use by the control agency and by the user or prospective user of an SCS. It presents an overview of SCS, a detailed discussion of the basic elements and functions of an SCS, and guidance for the control agency in evaluating SCS applications, the SCS background study report, and the SCS operational manual which is to be submitted by the prospective SCS user. A brief discussion of the enforcement aspects of supplementary control systems is also presented. In two appendices, detailed information is presented on (1) the meteorological conditions that are conducive to high ground level concentrations and (2) the information that should be included in the SCS application and background study report.

The third document is Technique for Supplementary Control System Reliability Analysis and Upgrading (Environmental Protection Agency, 1976f). The primary emphasis of the document is on the reliability of supplementary control systems. Reliability is defined as the ability of an SCS to prevent ambient concentrations from exceeding ambient standards. The document presents the fundamentals of a mathematical concept that can be applied to the reliability analysis and upgrading (improving the reliability) of an SCS. Also presented are hypothetical examples that demonstrate the type of information that can be obtained through application of the concept. Specific procedures for applying the concept will be presented in a user manual to be published in mid-1977. The user manual is being prepared, under contract, by Environmental Research and Technology, Inc.

4.2.5 Indirect Source Guidelines

The Indirect Source Guidelines (Environmental Protection Agency, 1975d) were developed to analyze and review potential CO impact of indirect sources. An indirect source is defined as any facility that attracts mobile source (i.e., motor vehicle) activity that results in pollutant emissions for which there are air quality standards. These guidelines provide a manual methodology that results in estimates of the 1-hr and 8-hr concentrations in the vicinity of indirect sources.

Over the past year several changes in the methodology presented in the original Guidelines have been incorporated, through contract work by Stanford Research Institute, into a Revised Indirect Source Guideline (RISG) for more flexibility and usefulness. The new screening methodology encompasses a three-part procedure. First, the physical characteristics of the roadway/parking area network and the projected traffic demand volume are used to determine accompanying model CO emission rates, together with other parameters (e.g., year, temperature, geography, hot/cold start ratio). Third, these derived emissions provide input to an atmospheric dispersion analysis that considers variations in source type (i.e., infinite line, finite line, and area), wind speed and direction, stability, road/receptor orientation, and terrain roughness. The analytical procedure is capsulized using a series of annotated worksheets, together with graphs and tables. Supplemental information is provided in appendices and references. Contractor reports are being reviewed by NOAA meteorologists and a working copy of the RSIG is in the internal review stage.

A second project which involves considerable meteorological effort is the guideline for the identification and evaluation of localized violations of carbon monoxide, termed CO "Hot Spot Guidelines" (HSG). An earlier guideline was initially developed, under contract, by GCA/Technology Division from EPA Region I (Environmental Protection Agency, 1976g), as a procedure for locating violations of the CO standards to support the Boston Transportation Control Plan. Because CO is a nonreactive pollutant whose concentration is highly variable from one geographic location to another, the relatively few existing CO monitoring stations are believed to be dominated by CO sources in the immediate vicinity of the sites; hence, real distributions are virtually impossible to derive from these data.

In these earlier guidelines two stages of review were presented: (1) a preliminary screening, performed with nomograms derived from the Indirect Source Guidelines discussed above that simply identified those locations with the potential to violate CO standards but provided no quantitative estimates of CO concentrations; and (2) a verification screening which considered site-specific conditions and provided quantitative estimates of maximum concentrations.

Since the Hot Spot Guideline was developed for conditions specific to Boston, and because the Indirect Source Guidelines analysis procedures are being revised, revisions to the HSG are also underway. A contract effort by GCA/Technology Division continues with a NOAA meteorologist as project monitor. The revisions will include: incorporation of changes in the Indirect Source Guideline, various emission adjustment factors, and step-by-step explanations of procedures for use by a general technical audience; procedures for evaluation of CO monitor placement; variations in meteorology; street canyon options; refined estimates of CO background concentrations, and an evaluation of area-wide control measures; a validation of the revised screening and estimating procedures; and, an adaptation and/or modification of computer algorithms to supplement the hot spot analysis.

4.2.6 UNAMAP and user liaison

The contents of the User's Network for the Applied Modeling of Air Pollution (UNAMAP) did not change during the fiscal year. Six models are available as part of UNAMAP: APRAC, CDM, HIWAY, PTMAX, PTDIS, and PTMTP. These models are described in last year's annual report (Viebrock, 1976).

The UNAMAP System is available through several different sources. It is available to EPA users for execution on the UNIVAC 1110 in North Carolina. This computer is accessible to users in the ten EPA Regions.

For users outside of EPA, UNAMAP is available two ways. For those who have a computer or ready access to a computer, the UNAMAP system Accession Number PB-229-771, Users Network for Applied Modeling of Air Pollution (UNAMAP) is available on a magnetic tape for $175 (U.S. Orders) from:

National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

The tape can be ordered in several configurations (tracks, bits per inch and codes). The FORTRAN source code for each of the programs is on the tape as well as a test data set for each model. Any or all of the models may be installed and executed on the user's computer.

A second method of accessing UNAMAP is to execute the programs (primarily interactively) on a nationwide computer network, INFONET. This network is operated by Computer Sciences Corporation (CSC), a contractor to the General Services Administration. In order to execute UNAMAP programs on this network, users must make arrangements through the INFONET representatives at the nearest CSC office. Charges are made for computer time used and any data storage required.

Near the end of FY-76, registered purchases of the UNAMAP tape totaled 105, and the known users of INFONET totaled 38. The distribution by category of user is given below:

	NTIS Magnetic Tape	INFONET
Consultants	49 in 22 states	25 in 13 states
Industries	27 in 16 states	4 in 4 states
Universities	12 in 10 states	None
Government	13 in 9 states	9 in 7 states
Foreign	4 in 4 countries	None
Total	105	38

Although no additions were made to UNAMAP during this fiscal year, it is expected that several models will be added to the system during the next year.

The Meteorology Laboratory serves as the point of contact for those wanting to discuss air quality model applications as well as questions related to UNAMAP. Many of these contacts are made by telephone. A large number of callers have problems estimating air quality (frequently for a proposed source) and expect that some air quality simulation model should be able to help them examine this problem. It is estimated that the six models in UNAMAP are applicable to approximately 10 to 15 percent of the problem areas faced by the people seeking assistance.

The contacts with model users and potential users are very valuable; in addition to any assistance provided it is possible to identify the problem areas where models should be useful. The following six general problem areas have been identified through these contacts: (1) transformations, including removal and generation; (2) complex terrain; (3) long-range transport; (4) maximum 24-hour concentrations within urban areas; (5) aerodynamic downwash; and (6) settling particulates. Research is underway both in-house and through contracts on most of these problem areas.

During FY-76 there were a total of 1690 user liaison telephone contacts, and 72 domestic and 38 foreign direct visitor contacts.

4.2.7 Monitoring guidance

Various technical reports and guidelines have been issued or are being completed to assist air pollution control agencies in designing aerometric (air quality and meteorological) monitoring networks and selecting proper instrument exposure. NOAA meteorologists have played an active role in the development of these documents, primarily in assessing meteorological requirements, source-receptor relationships, and exposure characteristics.

A technical report, entitled Selecting Sites for Carbon Monoxide Monitoring (Environmental Protection Agency, 1975e), developed under contract by Stanford Research Institute, has been published. It provides general information and suggested criteria for proper exposure and representativeness for various monitoring objectives and spatial scales (micro-scale, neighborhood, regional, etc.). Similar reports are being prepared under contract for total suspended particulates, sulfur dioxide, and photochemical pollutants (including oxidants or ozone, nitrogen dioxide, and non-methane hydrocarbons). These are general guidance documents which may be used by EPA to formulate recommended specific criteria or regulatory requirements. These reports also provide technical guidance on relative validity of data in cases where variances from recommended or required criteria may be necessary. EPA held an Air Monitoring Siting Workshop in Las Vegas on July 12-16, 1975, during which monitoring experts from governmental agencies and several private consultants developed joint recommendations on siting criteria for major pollutants and the form that the issuance of future criteria should take -- recommended guidelines vs. regulatory requirements. The Workshop participants were about equally split on the latter issue.

Two special purpose monitoring guidelines involving point source dispersion were prepared in FY-1976. First, Guidelines for Air Quality Monitoring and Data Reporting Under ESECA (Environmental Protection Agency, 1976h) was issued. It outlines monitoring requirements and recommendations for monitoring, determining air quality impact, around large power generating sources converting from oil to natural gas to coal. ESECA is the Energy Supply and Environmental Coordination Act of 1974, whose provisions attempt to assure an adequate domestic supply of essential fuels through fuel switching, as necessary, while still maintaining health-related ambient air standards. Second, Guidance for Air Quality Monitoring in the Vicinity of Large Point Sources (Environmental Protection Agency, 1976i) is nearing completion. It will be issued as Supplement B to OAQPS Guideline 1.2-012, Guidance for Air Quality Monitoring Network Design and Instrument Siting (Environmental Protection Agency, 1975f), which covers multi-purpose monitoring networks. The supplement will contain an appendix entitled "An Objective Approach to Air Quality Monitor Siting in the Vicinity of a Point Source".

The appendix referred to immediately above is directed to situations where ambient pollutant monitoring is to be conducted in the vicinity of an isolated point source to determine if air quality standards are being attained. The basic approach is to use dispersion modeling in conjunction with meteorological data from an extended period of record to estimate the expected frequency of occurrence of excessive concentrations at various locations about the source. The locations can then be ranked in proportion to those respective frequencies, providing an objective basis for deciding where to place air quality monitors.

As part of monitoring criteria development, by the Office of Air Quality Planning and Standards, EPA, several field experiments were included as part of the Regional Air Pollution Study in St. Louis to determine the distance at which ozone and nitrogen oxides concentrations are usually found downwind of St. Louis, and also their magnitudes downwind of St. Louis. It was expected, based on studies in other areas, that at times the maximum concentration levels could occur beyond the surface monitoring network. Experiments were performed during the intensive measurement periods of the summers of 1975 and 1976. Instrumented helicopters from the EPA Environmental Monitoring and Support Laboratory, Las Vegas, were used in the study. Flights were made along the plume axis with lateral and vertical cross-sectional flights made near the observed downwind maximum for the pollutant being tracked. Flights seeking NO_x maxima were flown during late mornings, while afternoon flights sought the ozone maxima along the expected plume centerline. The 1975 flight tracks seeking the ozone maxima were shown in Figure 35. Figure 36 shows the gradients along the downwind track. Maxima near the urban center tended to occur with light wind flow, while stronger wind flow seemed to cause maxima well downwind of the urban center and beyond the outer ground stations in the network. More detailed results of the 1975 experiments were presented by Hester et al. (1976) at a recent international oxidant conference. Results from the 1976 experiments will be integrated with those of 1974 in a final report on this field study.

4.2.8 Special support

NOAA meteorologists during FY-76 provided special assistance to various EPA organizational units. These are briefly described below.

(1) Special Assistance to the EPA Regional Offices - NOAA meteorologists provided technical assistance, such as comments on reports, advice on sampling networks and approaches to running and evaluating dispersion models, to the EPA Regional Offices on request. They served as technical experts in the area of modeling applications and monitoring data analyses involving meteorological interpretations. A few examples of this assistance are provided below.

The Valley model was applied by EPA Regional Office personnel in several Regions to many types of facilities. NOAA meteorologists have been the focal point for resolving problems encountered in applying the model and have assisted the Regions in responding to comments on the techniques used. The Valley model has been applied primarily to ore processing facilities, ore smelters, and electric generating

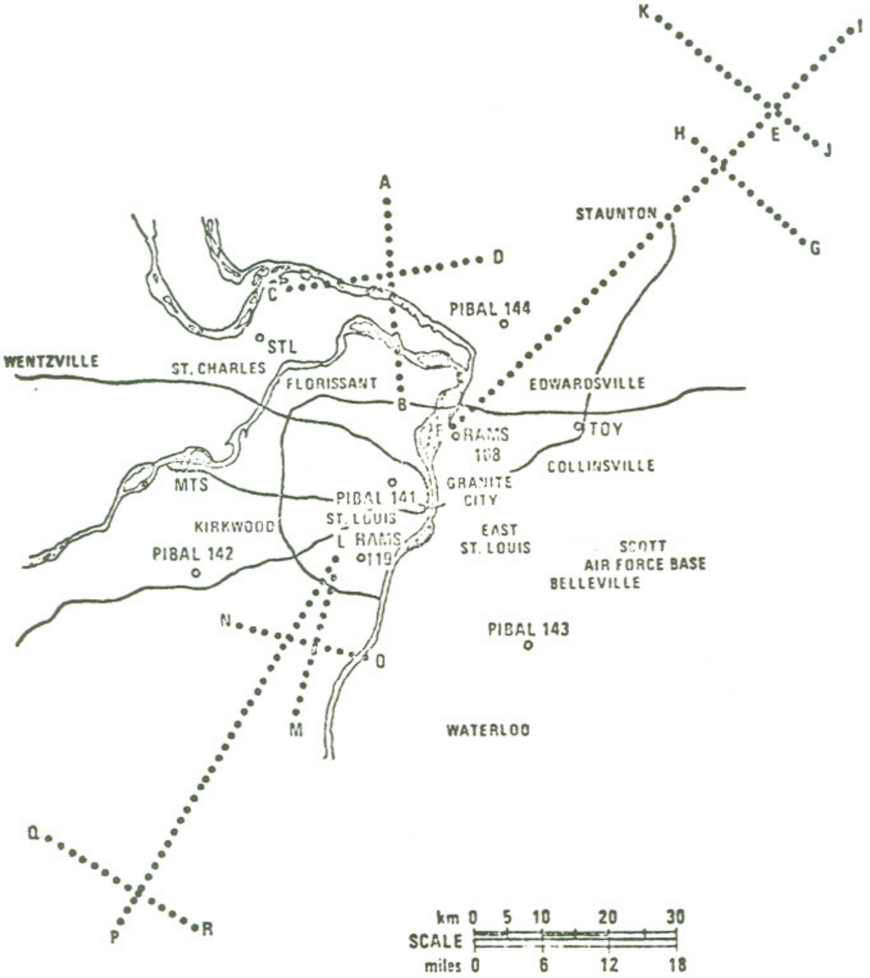


Figure 35. Flight patterns, special St. Louis ozone maximum study. 1975.

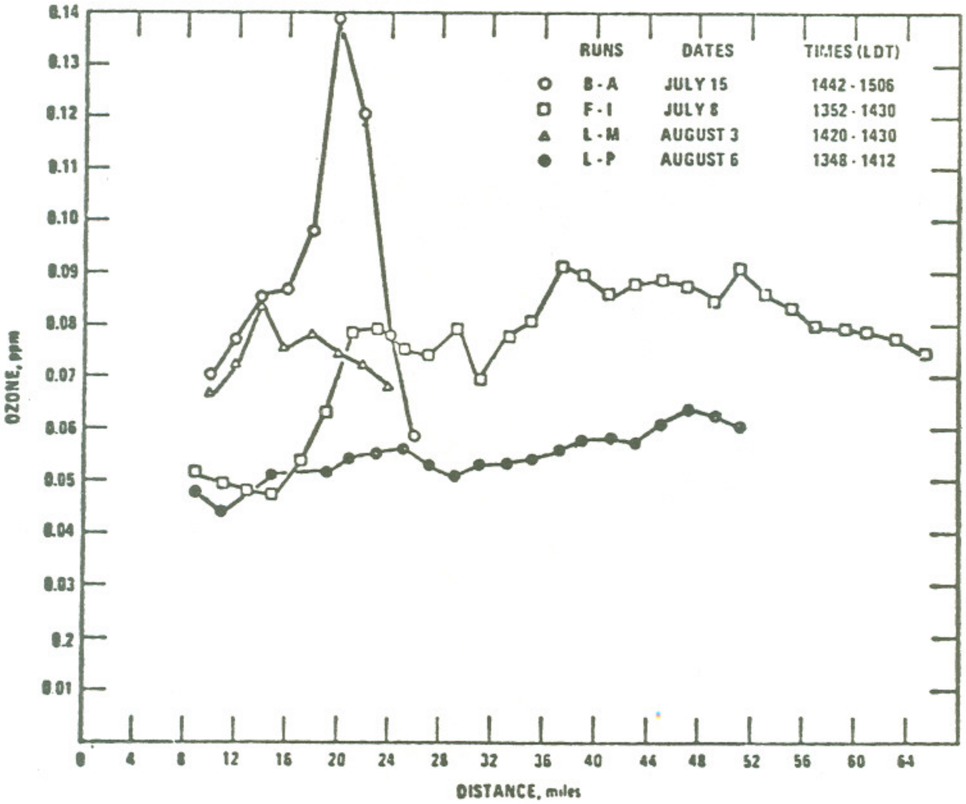


Figure 36. Ozone gradients relative to center of St. Louis, Missouri, four summer afternoon cases, 1975.

stations in the West, and to electric generating stations and pulp mills in the East, although other types of sources have also been evaluated.

At the request of EPA Region VIII, a modified version of Valley was furnished for their use. For this application the Pasquill-Gifford vertical dispersion coefficients were replaced by those determined from a field study at the Colstrip generating station (Montana) over distances from about 1 to 50 km from the facility. The Colstrip report was prepared by the Department of Earth Sciences, Montana State University.

Technical guidance was provided to the Surveillance and Analysis Division of EPA, Region VI, in the development of a contract designed to determine those areas in Region VI where non-attainment of the TSP standard is due to fugitive dust, incorrect monitoring procedures, or data processing errors. This effort required input on the use of meteorological variables in the study and the sources of meteorological data.

Assistance was also provided to the Air and Hazardous Materials Division, EPA, Region VIII, in the review of contract proposals for a regional air pollution modeling study. The contract required the modification and application of existing large scale models to areas of the Rocky Mountains and Northern Great Plains. These models will be used for long-range air pollution studies of the impact of energy conversion facilities.

Substantial assistance was provided to the Air and Hazardous Materials Division of Region V in the development of the Ohio State Implementation Plan (SIP). Estimates of SO_2 concentrations were made for 15 utility power plants and 6 industrial plants in Ohio. These estimates were combined with background concentrations and compared with the National Ambient Air Quality Standards (NAAQS) for SO_2. Based on these comparisons, the percent changes in pollutant emissions necessary to just meet the NAAQS were determined. As a result the emission limits in pounds of SO_2 per hour were determined for each stack and were incorporated into the SIP as a regulation.

In support of this activity, two additional analyses were performed. These concerned (1) techniques for determining background concentrations and (2) the use of maximum versus nominal source operating rates to specify emission limits. Background concentrations were determined by first identifying meteorological conditions for days when the plant had its maximum impact. Then concentrations on days with similar meteorological conditions were identified from measurements made in the vicinity of the plant. To insure that the measured concentrations were representative of background, care was taken to exclude from consideration those concentrations which included some impact from the plant itself. Other techniques for determining background were considered but were found to be inferior.

Maximum or design operating rates were used in obtaining all concentration estimates. However, it was questioned whether this would result in overly restrictive emission limits since the plants frequently operate at less than design capacity. Thus, for 6 of the plants the air quality impact under average operating conditions was determined. Averaging operating conditions were based on monthly variations in load and sulfur content of fuel. As a result it was found for 5 of the 6 plants that the maximum impact was at least as great with average operating conditions. This was due to the fact that occasionally higher loads coincided with higher sulfur contents in fuel. Thus it was concluded that emission limits based on design operating conditions are not overly restrictive.

(2) Air Pollution Training Institute - Support was provided to the Air Pollution Training Institute through the assignment of a meteorologist who developed and presented blocks of instruction in several Institute courses and was responsible for presenting three specialized week-long courses.

The basic course, "Air Pollution Meteorology", was recommended for meteorological technicians and for scientists and engineers having little or no training in meteorology. There were four presentations of this course; in all 125 persons received certificates of completion.

The second course, "Diffusion of Air Pollution - Theory and Application", was designed primarily for meteorologists working in air pollution control. Other scientists and engineers who have completed the basic course could enroll. This course was presented twice and 60 persons received certificates of completion.

The third short course, "Meteorological Instrumentation in Air Pollution", was designed for engineers and technical personnel responsible for designing, procuring, and maintaining air pollution monitoring networks that include meteorological sensors. Although this course was not given in the U.S. this year, a modified version, including portions of the course "Air Pollution Meteorology", was presented to 40 professionals in Mexico City.

The self-instructional correspondence course, SI-406, "Effective Stack Height/Plume Rise", which was introduced in February 1975, was completed by 52 students. The packaged course may be purchased for $30 from the National Audiovisual Center, Washington, DC 20409.

In July 1976, the direct operation of the Institute was changed to a contract mode, directed by Northrop Services, Inc. (NSI). NSI staff members are now responsible for presenting most Institute courses, including the four described above.

(3) EPA Task Force - Reserve Mining Company - NOAA meteorologists are providing support to the Reserve Mining Task Force of EPA, which is investigating the possible air quality effects of dumping taconite tailings (with asbestiform fibers) into inland tailings basins rather than into Lake Superior. Comments were provided on two environmental impact analyses. Also, input was provided to the protocol for ambient monitoring near the land disposal site for taconite tailings.

(4) Nitrosamines - Late in 1975, a NOAA meteorologist participated in field studies to sample the air for nitrosamines in Baltimore, MD, and Charleston, WV. The NOAA meteorologist selected the times and places, based on meteorological conditions, for sampling. Two EPA contractors, Thermo Electron Research Center and the Research Triangle Institute, operated new sophisticated equipment for detecting n-nitrosodimethylamine in the air. Results of the field studies are being prepared for publication.

5.0 INTERNATIONAL AFFAIRS

5.1 North Atlantic Treaty Organization Committee on the Challenges to Modern Society (NATO/CCMS)

5.1.1 General

Meteorology Laboratory personnel participated in the activities of the NATO/CCMS as part of the United States delegation during FY-76, as they have since the committee was formed.

The first of several meetings under the new NATO/CCMS air pollution pilot study was held at the Battelle Institute, Frankfurt, Federal Republic of Germany on September 24-26, 1975 and reported on in the "Proceedings of the Sixth International Technical Meeting on Air Pollution Modeling and Its Application" (NATO/CCMS, 1976). Some 71 experts attended the meeting representing Belgium (4), Canada (1), Denmark (1), France (3), Federal Republic of Germany (29), Italy (11), Japan (1), Netherlands (5), Norway (2), Spain (1), Sweden (3), Switzerland (2), U.S.A. (6), and the United Kingdom (3). Thirty technical papers were presented, covering a wide variety of topics. Dr. Dieter Jost of the Umweltbundesamt, Berlin, acted as Chairman and Mr. K. L. Calder (U.S.A.) as Co-Chairman.

This meeting was followed by a joint meeting of the NATO/CCMS Pilot Study Working Group, Assessment Methodology Panel, and Panel on Modeling, at Meersburg (Lake Constance) on September 29-October 1, 1975. At the meetings of the Panel on Modeling, plans were developed for (1) a comprehensive joint "practical demonstration", by the participating NATO countries, of multiple-source Gaussian plume models for SO_2 against a common data base for Frankfurt, Federal Republic of Germany. This would include preparation of supporting documentation on the details of the models used, and the results of the model application; (2) preparation of a NATO/CCMS bibliography (with comprehensive abstracts) of "grey" literature in the NATO countries relating to air quality modeling (i.e., literature outside the regular open scientific literature); and (3) preparation under a contract of a report to illustrate the full variety of current uses of air quality models in air quality management.

Following the Meersburg meeting, a second meeting of the Panel on Modeling was held in Venice, Italy, on March 29-31, 1976. This was concerned primarily with the documentation being prepared in support of the above projects and discussion of the Frankfurt data base that had been made available to the countries participating in the practical demonstration.

The 7th International Technical Meeting (ITM) on Air Pollution Modeling and Its Application was the first meeting of the NATO/CCMS to be held in the U.S. It was held at Airlie House, Airlie, VA, on September 7-10, 1976. Some 78 persons attended the meeting representing the UK (2), Belgium (3), Netherlands (3), Norway (1), Sweden (1), Italy (6), FRG (16), France (1), Canada (1), and U.S.A. (35). Papers were presented relating to:

(1) Examples of model validation
(2) Sensitivity analysis for air quality simulation models
(3) Numerical grid air quality simulation models
(4) Interregional and regional models
(5) Tall stack plumes, including sulfate transformation and removal processes
(6) Dispersion in conditions of low wind speed
(7) Diffusion parameters and stability categories
(8) Innovative modeling techniques

A Proceedings will be published. During the course of the meeting a small ad-hoc group considered topics for the 8th ITM (Ghent, Belgium - September 1977) and prepared a tentative technical agenda for the meeting.

Immediately following the 7th ITM, a 3rd meeting of the NATO/CCMS Panel on Modeling was held at Quail Roost Conference Center, Rougemont, NC, on September 13-15, 1976. Again, this was concerned primarily with the status of the various reports under preparation in support of the modeling project and some problems relating to the Frankfurt data that were being used in the practical demonstration. Also discussed was the availability for the NATO/CCMS project of data bases for St. Louis (U.S.A.) and Oslo (Norway). The desirability was indicated of a study to document the current accuracy, among the NATO countries and under practical operational conditions, of the Gaussian-plume models and also their sensitivity properties. It was suggested that this study might be performed under a special contract, and this will be discussed further in Spring 1977 at the next meeting of the Panel (Appledoorn, The Netherlands). Also to be discussed is the possibility of annual NATO/CCMS national progress (status) reports relating to modeling. The primary goal of such new documentation would be to provide important additional communication between the participating NATO countries. The status reports would provide information on such topics as research programs, advances, new applications, significant reports and references, contracts, research grants, technical meetings, etc.

5.1.2 Frankfurt study

As discussed in the previous section, at a NATO/CCMS meeting in 1975 it was decided to conduct a "practical demonstration" of multiple-source Gaussian plume models for SO_2 against a common data base for Frankfurt, Federal Republic of Germany. The Meteorology Laboratory is participating directly in the study.

The purpose of this exercise is to demonstrate the utility of Gaussian plume modeling of the dispersion of SO_2 during a 1-year period in an urban situation. The participating nations are to execute their respective multiple-source Gaussian plume models on a common data base which specifies the seasonal emission inventory and the seasonal meteorological conditions for Frankfurt, Federal Republic of Germany, for the period from August 1971 through July 1972. Depending on the capabilities of the various models, estimates are to be made of the annual concentration of SO_2 at six designated receptor locations, of the annual concentration pattern of SO_2 in a designated area, and of the frequency distribution of SO_2 concentration values at the six receptor locations. The limited amount of ambient air-quality measurements of SO_2 will be collated with the various dispersion modeling results beginning in February 1977, with publication of the results to take place late in 1977.

Two models were applied, a modified version of the Climatological Dispersion Model (CDM) and an experimental model called the Sampled Climatological Air-Quality Model (SCAM). CDM was modified to accept a joint-frequency function of meteorological conditions having 10° wind directions (Turner, 1976a). SCAM (Irwin, 1976a) incorporates the techniques of three existing models: The Sampled Chronological Input Model (SCIM), the Climatological Dispersion Model (CDM), and the Real-Time Air-Quality Model (RAM). The data required to execute SCAM are the same as are required to execute CDM. Sampling of the meteorology in CDM is performed as in SCIM, but the sampling in SCAM is done using the joint-frequency function of the meteorological conditions. The dispersion estimates are performed using a "stripped-down" version of RAM. Thus SCAM uses climatological information for meteorology input, but calculates the dispersion using a short-term dispersion algorithm. This allows SCAM to estimate the frequency-distribution of hourly concentration values. The results of executing CDM and SCAM were summarized and forwarded to the NATO modeling panel for later review (Turner, 1976b; Irwin, 1976b). Both models yielded very similar results for estimates of annual concentrations at the six receptor locations. The CDM was also able to estimate the annual concentration pattern for SO_2 in the designated area, whereas, due to the excessive running time of the SCAM, it only estimated the annual concentration estimated at the six receptor locations.

5.2 Visiting Scientists

Dr. Frank Pasquill visited the Meteorology Laboratory during the winter of 1975-76. On this visit he had extensive discussions with several U.S.

scientists regarding the atmospheric dispersion parameters used in Gaussian plume modeling, i.e., the system which he himself first introduced in 1958 in the British Meteorological Office. The effort was a collaborative one involving Dr. A.H. Weber, Associate Professor of Meteorology, Department of Geosciences, North Carolina State University, Raleigh, NC. The outcome is in a two-part report on the topic, Part I "Review of Current Systems and Possible Future Developments" by A.H. Weber (1976), and Part II "Possible Requirements for Change in the Turner Workbook Values" by F. Pasquill (1976a). In addition, following his return to Great Britain in April 1976, Dr. Pasquill documented a discussion on the "Gaussian-plume" with limited vertical mixing (Pasquill, 1976b). Atmospheric dispersion from an elevated point source in a mixing layer of limited depth normally involves consideration of multiple reflections of the plume between the upper and lower boundaries. Pasquill's analysis considers some simple approximation formulae that should be useful in practical applications.

Dr. Michael M. Benarie, Institut National de Recherche Chimique Appliqúee, visited North Carolina and presented a series of three lectures on September 15-17, 1976, on "Computer-less Urban Air Pollution Modeling". This was under the support of the Meteorology Laboratory, and as part of the "Continuing Seminar on Air Quality Research", which is a joint activity of the Meteorology Laboratory and North Carolina State University.

The seminar emphasized simple and efficient models for urban air quality, that can often be employed without recourse to large computers. The guiding idea was to recommend the use of models that correspond with the utmost economy of structural elaboration to the end results that must be achieved by the model. It was shown that there are many circumstances when simple models will be preferable to more complex ones.

Some specific topics included were the limits set by atmospheric predictability, forecasting pollution concentrations in real time for pollution episodes, applications of the simple box model, the frequency distribution of pollution concentrations, and the need to consider several indices of goodness-of-fit for model validation purposes, if pitfalls are to be avoided. In the interests of wide distribution of the information this material has been published (Benarie, 1976). Dr. Benarie also repeated the seminar on September 20-22, 1976 at Pennsylvania State University, where the Meteorology Laboratory supports a major research grant relating to the meteorology of air pollution (see Section 2.2.8).

During FY-76 visiting foreign scientists included:

Dr. F. Pasquill, United Kingdom
Mr. H.H.J.M. Goumans, Ministerie Van Volksgezundheit En Mileuhygiene, Holland
Dr. A.W.C. Keddie, Warren Spring Laboratory, United Kingdom
Dr. K.H. Muller, Physics Department, EURATOM, Italy
Dr. Arnaldo Longhetto, Enel Crtn. Laboratorio Riverca Ambientale, Italy
Dr. Michael M. Benarie, I.R.C.H.A., Centre de Recherche, France

Dr. Bjarne Sivertsen, Norwegian Institute for Air Research, Norway
Dr. Andre Berger, Institut de l'Astronomie et de Geophys., Universite Catholique de Louvain, Belgium
Dr. E. Runca, IBM Italy - Scientific Research Center, Italy
Mr. Christer Persson, Swedish Meteorological and Hydrological Institute, Sweden
Dr. R. Hyde, School of Earth Sciences, Macquarie University, Australia

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8.0 METEOROLOGY LABORATORY STAFF
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