NOAA Technical Memorandum ERL ARL-62

FISCAL YEAR 1975 SUMMARY REPORT OF NOAA METEOROLOGY LABORATORY SUPPORT TO THE ENVIRONMENTAL PROTECTION AGENCY

Herbert J. Viebrock, Editor

Meteorology Laboratory
Research Triangle Park, North Carolina

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PREFACE

The work reported herein was funded by the Environmental Protection Agency (EPA) under agreement EPA-IAG-D5-0305 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.

Much of the EPA research, development, and operational effort in the atmospheric sciences is the responsibility of 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 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 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.

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FISCAL YEAR 1975 SUMMARY REPORT OF NOAA METEOROLOGY LABORATORY SUPPORT TO THE ENVIRONMENTAL PROTECTION AGENCY

Herbert J. Viebrock, Editor

During Fiscal Year 1975, the Meteorology Laboratory, Air Resources Laboratories, National Oceanic and Atmospheric Administration, provided research and operational meteorological 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 the review of the meteorological aspects of environmental impact statements, requests for variances, implementation plans, and grant and contract proposals; the application of dispersion models; and the preparation of dispersion studies and evaluations. Research support was in the areas of model development and application, climatic analysis, and atmospheric effects of pollutants. Dispersion models for inert and reactive pollutants were under development and evaluation, as were regional and boundary layer meteorological models and models of the pollutant removal processes. The fluid modeling facility began experiments in the wind tunnel, and construction of the water channel/towing tank neared completion. The Regional Air Pollution Study observing network of surface and upper air stations in the St. Louis, MO, metropolitan area went into full operation. Climatic studies undertaken included an analysis of the effects of meteorological variations on observed CO values, an examination of the relevance of nocturnal heat island intensities to mixing height forecasts, and the initiation of an effective plume height climatology.

1.0 INTRODUCTION

Much of the Environmental Protection Agency's (EPA) research and development effort in air pollution meteorology is performed by the NOAA Meteorology Laboratory (ML). The Meteorology Laboratory also provides operational meteorological support and technical assistance to various EPA organizational components. During fiscal year 1975, the ML program was divided into three major areas: model development, evaluation, and application; air quality and meteorology relationships; and technical assistance. The ML effort during fiscal year 1975 was approximately evenly divided between research and operational support, even though the research effort will receive greater coverage in this report.

2.0 MODEL DEVELOPMENT, EVALUATION, AND APPLICATION

The development and implementation of air quality simulation models provide one technique for carrying out the mandates of the 1970 amendments to the Clean Air Act. Mathematical models currently available and under development simulate the impact of anthropogenic emissions on ambient air quality by considering source emissions data, meteorological variables characterizing transport and dispersion processes, and reaction mechanisms describing chemical transformation and removal processes of atmospheric pollutant species. The complex nature of the physical and chemical dynamics of the atmosphere presents a formidable challenge to the air pollution modeler and has been the subject of continued research and development within the Meteorology Laboratory in FY-75.

2.1 Basic Modeling Studies

2.1.1 A turbulence model for air quality prediction

The prediction of wind, temperature and moisture fields in the planetary boundary layer is very sensitive to the turbulent transfer of heat, momentum and moisture. At night, radiative transfer of heat becomes quite important. The major thrust in attacking the problem of representing these transfer processes has been to review all current efforts, especially those supported by EPA; then to seek simple but physically realistic representations. A radiative transfer model is nearing completion. This model accounts for the absorptive properties of water vapor in a detailed way by the use of a statistical band model for the transmission function. The variation of line properties with temperature and pressure are included. The model will be optimized for the minimum number of spectral intervals in the 4 to 100 micron region which gives acceptable recovery of profiles of radiant flux measured in the atmosphere. This model will then be utilized for planetary boundary layer prediction, especially the nocturnal cases where radiation effects are dominant.

The turbulent transfer model is being developed along the lines of a minimum closure procedure. That is, to seek the minimum set of time dependent equations for turbulent transfer which approximate the results of more sophisticated models such as those being supported by EPA funds. The effort is to reduce the set of model equations to the minimum.

2.1.2 A planetary boundary layer model for simulating urban air quality

The research and development of meteorological models for the urban boundary layer, which incorporate large scale flow parameters in the basic formulation, was initiated by the Meteorological Laboratory in FY-75. By eliminating the usual restrictions of steady, homogeneous conditions, a more realistic PBL (Planetary Boundary Layer) will result which should then improve the quality of air pollution models. A feature such as inertial oscillation in quasi stagnant meteorological condition is possibly one phenomenon to be investigated. This phenomenon is directly related to nocturnal boundary layer dynamics and is sufficiently dramatic to be an important consideration in ventilating urban and surrounding areas. These efforts should indicate the rural and urban meteorology coupling under various large scale "synoptic" conditions and thus have direct applicability to air quality modeling. It is foreseen that solution of this difficult problem must proceed in stages. Initially, a highly parameterized scheme was developed where all mixing characteristics in time and space are explicitly represented by a "K" (space,time) diffusivity function. Further development in this generalized approach should result when the "K" theory is replaced by the more basic turbulence closure methods. In addition, it is foreseen that the more general PBL model will yield information that should be useful in evaluating and improving long range transport models that must include variation in large scale parameters.

2.1.3 Some topics relating to modeling of dispersion in the boundary layer

Dr. F. Pasquill while visiting the Meteorology and Assessment Division prepared a special report on six topics, all of major current interest in modeling of dispersion in the atmospheric boundary layer. It includes an extensive discussion relating to the 2nd-order closure schemes for modeling atmospheric turbulence, e.g., the work being conducted by Dr. W. S. Lewellen under contract (Aeronautical Research Associates of Princeton, Inc.) that is discussed elsewhere in this report. Specifically the point in question, that is discussed in the first section of the report, is the feasibility of solving the equation to give the time rate-of-change of the vertical flux ($\frac{\partial F}{\partial t}$) near the surface of an effectively infinite, uniform, but time-dependent source. Such a solution would be useful for investigations of the diurnal cycle of natural evaporation, or cases where a distributed pollutant source varies in strength in the alongwind direction. Other topics include the crosswind spread from a continuous point source and the properties of the crosswind component of turbulence in the atmospheric boundary layer, wind direction fluctuations over long sampling times, "local similarity" treatment of vertical spread from a ground source, representations of dispersion in terms of distance or time, and modeling for elevated sources.

2.1.4 Turbulence modeling and its application to atmospheric diffusion

The work on turbulence modeling initiated by Dr. C. du P. Donaldson (Aeronautical Research Associates of Princeton, Inc., Princeton, NJ) has been continued during FY-75 by Drs. W. S. Lewellen and M. Teske under an EPA contract. The major aim of this work is to develop a viable computer model based on a second-order closure of the turbulent correlation equations for predicting the atmospheric transport and diffusion of nonchemically reacting pollutants released in the atmospheric boundary layer. During FY-75 the model capability has been extended by increasing the dimensions of the program to permit calculation of two-dimensional unsteady turbulent flow, which opens up the possibility of making a wide variety of important calculations. Some specific conclusions from detailed model calculations are:

(1) Modeling of the temperature fluctuations is given strong support by the close agreement between model predictions and experimental observations in the wake of a two-dimensional, slightly heated cylinder.

(2) Comparisons between laboratory results and model predictions of turbulent fluctuations in the limiting case of free convection when the turbulence is completely produced by buoyant forces rather than mean velocity shear verify the model's basic validity.

(3) Comparison of the model predictions with laboratory simulation of diffusion in a free convection, mixed layer is good, with the model able to predict the maximum concentration rising from the ground as observed in an instantaneous line release.

(4) Comparison with the Gaussian plume dispersion estimates given by Pasquill shows close agreement for a line source released at ground level under neutral atmospheric conditions. But the calculations indicate that Pasquill's variation with z_0 should be interpreted as a variation with Rossby number.

(5) The specification of one stability parameter, a stability class or Richardson number, does not adequately specify the influence of atmospheric stability on plume dispersion. Some information on the time history of the turbulence must be provided, such as is contained in the mixing layer height.

(6) For a point source release in a stable atmosphere, a strong departure from a Gaussian plume distribution is caused by variation in mean wind direction with altitude. The horizontal dispersion due to the wind veering with altitude appears much greater than that caused by horizontal wind fluctuations.

The work is reported in Lewellen and Teske (1975).

2.1.5 Spectral modeling of atmospheric flows and turbulent diffusion

The specification of turbulent dispersion effects for air quality simulation models is normally done through the use of diffusion coefficients (eddy diffusivities) or by more sophisticated turbulence parameterizations that are developed through various "closure" schemes for the governing equations of the flow. These closure approximations are necessary because of the well-known mathematical intractability of the general non-linear time-dependent Navier-Stokes equations that govern the turbulent flow of a viscous fluid. Closure approximations all involve the use, at some stage in their development, of empirically-based constants or parameters, that in many cases may require ad hoc field experiments or observations.

During the past few years a major break-through has been made in developing powerful new mathematical-computational approaches for the accurate numerical simulation of turbulent flow. It has been shown that many aspects of turbulent motion may be numerically simulated with impressive accuracy, directly from the equations of motion, and without the somewhat arbitrary closure approximations involved in the normal parameterizations. It was these remarkable results that stimulated a contract during FY-75 with Flow Research, Inc. (N.E. Division), Cambridge, Massachusetts. It was hoped to provide an initial step towards providing a basic technique for atmospheric turbulence and dispersion estimates by accurate non-empirical methods. In due course such results could provide a set of diffusion data against which various approximations might be tested.

The newly developed methods involve so-called spectral techniques, along with sophisticated computer programming. These techniques require expansion of the dependent variable into a Fourier (or other orthogonal) series of smooth functions. The calculation proceeds by performing certain of the mathematical operations in Fourier (or other) space and others in physical configuration space, according to the mathematical form of the operation and its relative efficiency. Transformations between the two spaces are made by Fast Fourier Transform (FFT) methods and the use of special computational techniques. In addition to having very powerful applications to the problems of turbulent flow and dispersion, the spectral technique has a wide potential for numerical simulation of many atmospheric flows. The contract also compared the accuracy and advantages of spectral techniques, with the more conventional finite-difference numerical techniques for the solution of partial differential equations. This was done primarily to bring the potential of spectral methods to the attention of air quality modelers. The initial turbulence research was to develop direct solutions, without parameterization approximations, for turbulent dispersion of an inert pollutant in a thermally stratified atmospheric layer that is governed by the Boussinesq approximation.

Unfortunately, computational resource limitations precluded successful evaluation of the basic turbulent dispersion problem during the relatively short period of the contract, although some new results were obtained relating to the rate of relaxation of anisotropic flows. A detailed report is in preparation (Bass and Orszag, 1976) that discusses the research, and suggests specific problem areas where spectral techniques should be useful in air quality simulation modeling.

2.1.6 Atmospheric turbulence properties in the lowest 300 meters

Supported by an EPA Meteorology Laboratory grant, Prof. A. H. Weber and three degree-candidates of North Carolina State University used the 366-meter WJBJ-TV tower located at Beach Island, South Carolina, to measure and study atmospheric turbulence statistics which are relevant to dispersion of air pollutants in the atmosphere. This tower has been instrumented as a meteorological facility by the Savannah River Laboratory for reactor safety studies.

Climet cup and bivane systems and slow-response aspirated temperature sensors (platinum resistance-wire thermometers) were mounted at six levels on the tower. Also, at the 18.3 meter level were a Gill u-v-w propeller anemometer with a fast response thermistor mounted on its vertical arm, and a sonic anemometer. To further examine the planetary boundary layer, pibal measurements of the wind were taken using double-theodolite techniques.

Many other studies of atmospheric turbulence have been accomplished in the surface layer (i.e., the region below 100 meters) but few have examined data above 100 meters, or for non-homogeneous fetches, as was done in this case. Results are expected to be useful in the application of the Gaussian

Diffusion Model for tall stack problems, or perhaps lead to better models of diffusion in the future.

Roughness lengths were found to be about 8 cm and 36 cm for the two predominant wind directions at the tower site. Height dependencies were characterized by a decrease in the rate of change of σ_E, standard deviation of the wind elevation angle, and σ_A, standard deviation of the wind azimuth angle, with z/L as the height of measurement increased, where z is the vertical coordinate and L is the Monin-Obukhov length scale. The value of σ_E and σ_A at the lowest level seemed to be a predictor for values at higher levels.

The variation of σ_E and σ_A with z, z_0, and L agree qualitatively with the nomograms prepared by Panofsky and Prasad (1965), and the spectral scale, λ_m, and the mixing length were found to be consistent with the results of Pasquill (1972). Further, properties of spectra measured at 18.3 meters were found to agree well with previously published results. Other analyses of turbulence data are included in the report. In general, the results are as would be expected from the work of earlier investigators.

It was concluded that similarity theory can be extended upward beyond the usually defined surface layer over non-homogeneous terrain. However, the simple equations predicted by similarity theory for the surface layer cannot be extended much above 160 meters except as a first approximation. Comparisons of observations by the various instruments used suggest that the quality of the data is good. Therefore, further studies of the tower data were recommended, especially those demonstrating laminar flow at night.

2.1.7 Development of mesoscale models suitable for air pollution studies

The Select Research Group at Pennsylvania State was first established in May 1972 as a five-year program, under sponsorship of the U.S. Environmental Protection Agency through the Meteorology and Assessment Division. Its primary aim is to identify and research long-range interdisciplinary problems in air pollution meteorology, and involves a joint effort at PSU involving the Department of Meteorology, the Department of Aerospace Engineering and the Center for Air Environmental Studies. The miscellaneous research activities under the grant include the development of a regional-scale meteorological and air pollution model. Research conducted under this grant on boundary layer turbulence modeling will be discussed in the next section of this report, and the work on observing systems for urban and regional environments will be reported in Section 2.6.5. The scope of the research is very broad. For details reference should be made to the comprehensive 2nd Annual Progress Report, Volumes I and II (Select Research Group, Sept. 1974), which has been given a very wide distribution.

Details of the regional modeling effort are included in Section 2, 4 and 5 of the PSU Annual Progress Report. Section 2 first gives the basic equations for using Lambert Conformal map coordinates. Then the structure of the grid, the finite difference equations, and the lateral boundary conditions are described. Finally some results from the 3-D model and its two-dimensional analog are presented.

PSU is developing a general, hydrostatic model suitable for forecasting flows with characteristic horizontal wavelengths of 100-600 km under a variety of synoptic conditions and flows induced by terrain variations, land-sea and land-lake contrasts, etc.. This model, which is three-dimensional, is complementary to a general, non-hydrostatic model for forecasting smaller scale circulations (horizontal wavelengths 5 to 30 km) and flow over and in cities that EPA is developing. Both the regional and urban models will predict flows for time periods of 1 to 24 hours, and hence, will be directly suitable for estimating maximum and average pollutant concentrations over a few hours.

The models will not be directly capable of predicting annual averages, but stratification of short-range model forecasts according to synoptic conditions, together with frequency distributions of synoptic regimes, may make annual estimates possible. The usefulness of the general three-dimensional models is not restricted to air pollution, but includes resolution of regional and urban variability in cloud cover, rain and snowfall, temperatures, etc. that are important for effective land use. As research continues it may be desirable to allow the urban and regional models to interact.

A somewhat surprising finding of the regional modeling effort is that large-scale imbalance induced by the incompatibility of the lateral boundary conditions on mass and the mean wind over the model domain produce low-frequency inertial gravity waves which affect the mean motion over the domain to a large extent.

Section 4 of the PSU Annual Progress Report describes numerical experiments with a two-dimensional nested grid. A fine mesh grid is needed over populated regions and over atmospheric phenomena that have sharp gradients and fine scales. Furthermore, by nesting a fine mesh model such as the regional model within a synoptic-scale model, some of the deleterious effects of the proximity of lateral boundaries to the center may be avoided. A summary of 11 experiments is given with different wavelengths and grid structures.

At least two approaches to the nested grid problem exist. In the first, and simplest, a large scale model is integrated independently of the fine mesh model, and the output from the coarse mesh model utilized to provide time-dependent boundary conditions for the fine mesh model. In the other approach, the model equations on the two (or more) meshes are integrated simultaneously so that two-way interactions are possible. Results showed there is a clear choice as to the preferred methods. In all cases the two-way mean square errors and correlation coefficients were better. However, the two-way interacting mode is considerably more difficult to treat within operational constraints. The results are considered promising because experiments showed that when only a single scale of disturbance was present there was little difference in the two techniques. Also, as the grid lengths increase it is possible that the one-way system will prove more viable. Another encouraging result of these experiments is that meshing of a grid with finer resolution in a larger domain does produce a better solution on the fine mesh grid than on the coarse mesh grid, with improvement for all variables. The use of nested grids is warranted when the fine mesh contains energy in shorter wavelengths than does the coarse mesh. However, for a long wave that can be well-resolved on a grid with uniform size, the addition of a nested fine mesh grid will not necessarily produce a better forecast.

Section 5 of the PSU Annual Progress Report, the last section dealing specifically with mesoscale models, is concerned with the investigation of semi-implicit models, which allow the use of greater time steps (Kwizak and Robert, 1971; Gerrity et al., 1973). The "rule of thumb" appears to be that the time required to make a forecast can be reduced by a factor of four to six through the use of "semi-implicit" techniques for treating the terms in the model equations that are primarily responsible for the propagation of gravity waves.

The model was run in both the explicit and semi-explicit form with various time steps, and it was concluded that the development of one and two-dimensional semi-implicit models was reasonably successful. The forecast accuracies of these models were comparable to the accuracies of the explicit models, and the semi-implicit models were roughly two to four times faster. Consequently, with this result and the experience gained it is reasonable to begin the development of a three-dimensional semi-implicit numerical mesoscale model.

2.1.8 Boundary layer turbulence modeling

Progress in the area of boundary layer turbulence modeling is reported in Volume II, Part III, of the Second Annual Progress Report of the Select Research Group, Pennsylvania State University (Select Research Group, 1974).

The task group is engaged in the development of model equations for the description of turbulence and diffusion in atmospheric boundary layers. Two major efforts are in progress. A complete set of second-order turbulence model equations is being developed and simplified equations are used to study the development of convective boundary layers and the daily cycle of the mixing height. This latter work aims at improved boundary-layer parameterization schemes for use with the regional computer model of the Select Research Group.

An inversion rise model which was described in a paper presented at the AMS-WMO Symposium on Atmospheric Diffusion and Air Pollution (Tennekes and van Ulden, 1974) appears to have the potential to produce short-term forecasts of temperature and mixing height. This prospect has been explored and it was concluded that on days without major advective changes, the simple inversion-rise model appears to be able to describe the essential features of the daytime development of convective boundary layers quite well. The usefulness of this model is limited because relatively few days during a year are characterized by stationary large-scale weather conditions. Particularly during the winter months the daily cycle of the surface heat flux plays only a minor role in the development of the boundary layer, so that a state of free convection does not often occur. Another problem is that the forecasts with the model cannot be made before the midnight radiosonde data are available. This limits the forecasting period to about 18 hours.

These findings suggested that a more detailed study of the convective boundary layer and the turbulence dynamics near the inversion capping the boundary layer would be worthwhile. Consequently, a program was developed that forms the foundation for further studies of the entrainment mechanism by which a boundary layer grows into the stable air aloft. A pressure gradient-velocity (PG-V) model was developed that gives realistic values of the turbulent stress components in the surface layer. The model consists of three terms: a nonlinear return-to-isotropy term, a mean vorticity term, and a mean strain-rate term. In the neutral surface layer, the turbulent stress equations can be reduced to three independent equations; and for a given turbulent stress distribution, a unique set of three constants can be determined. Calculations for six cases, representing experimental and arbitrary turbulent stress distributions, showed that the return-to-isotropy constant appears to be relatively insensitive to a variety of turbulent stress distributions. One of the members of the select group has been concerned with the programming difficulties experienced with the simulation of a plane isothermal turbulent wake. The first part of the year was spent in trying to find the reasons behind multiple roots for solutions to the turbulent shear equations.

A number of programs were written that could give new and random starting positions in the space defined by certain constants. Consequently, it was possible to find a definite relationship among them and use the smallest (in terms of absolute value) in the turbulent shear program. Work on the equations for this program is continuing.

In an inhomogeneous flow, the flux of a passive scalar admixture can be modeled to first order by a linear combination of gradient transport and convective transport, where the convective transport is proportional to the <u>gradient</u> of the (gradient)-transport coefficient. A simple model has been presented that allows determination of the coefficient of proportionality. The equation derived provides a means of estimating the convection velocity, which is necessary for modeling convective transport.

An interesting discovery has been made concerning the shapes of the Lagrangian and Eulerian (sometimes called quasi-Lagrangian) correlation functions and spectra, crucial to the understanding of turbulent diffusion in the atmosphere. The spurious advection effects of the Eulerian spectrum strongly suggest that the evolution of turbulence in wave number space is best computed on a Lagrangian basis. From this point of view certain Lagrangian-history models are to be preferred to their Eulerian counterparts.

The research tasks of the Select Research Group encompass a great range of scales, ranging from the turbulent microstructure to synoptic scales of motion. Turbulence is generally analyzed with statistical methods, but mesoscale and large-scale atmospheric motions are handled with deterministic equations. The differences in approach make it difficult to maintain effective communications between those who study the larger scales and researchers concentrating on a small-scale turbulence. In an attempt to provide a better understanding of these problems, a study was started of the similarities and differences between two-dimensional turbulence (which is a crude model for large-scale atmospheric flows) and three-dimensional turbulence. Predicting the evolution of synoptic flows (two-dimensional), it was found, is a lot easier than the evolution of their 3D counterparts. It was concluded that statistical techniques are a necessity in 3D turbulence, but fortunately this is not so for large-scale atmospheric flows.

In the system of equations developed by two members of the Group, there is a large number of coefficients that have to be determined from experimental data. A search program for the optimum values of those coefficients in a plane isothermal turbulent wake was developed.

Other work included consultations on boundary-layer parameterization, discussions with the EPA-staff on a visit to Research Triangle Park in December 1973, continuing discussions on coherence measurements and turbulent eddy structures and consultations on the design of the isokinetic aerosol sampling probe.

2.1.9 Documentation of data from NYU pollution dynamics project

Under a service contract with San Jose State University the data from the New York University Urban Air Pollution Dynamics Project of 1964-1969 are being prepared for publication by Professor Robert D. Bornstein of the Meteorology Department at San Jose State University. A summary of the data collected in New York City during the original project, which was under the direction of Professor Ben Davidson, is shown in Table 1.

The original project consisted of 12 test periods (T-1 to T-12), of three to five days duration, during the period from September 1965 to December 1966. In addition, preliminary data were obtained before T-1 during the period from July 1964 to April 1965, and additional data were obtained on days intermediate between several of the test periods (I-2/3 to I-8/9).

One of the 12 test periods (T-3) had to be cancelled before any data were collected, and over the years data have been lost from T-1, T-4 and T-11. Of the remaining eight tests, three (T-6, T-10 and T-12) were selected for complete documentation because of their interesting meteorological conditions, SO_2 patterns, and general overall quality of data.

For these three test periods, hourly surface mesoscale wind charts (Fig. 1) were reanalyzed from wind observations at about 60 anemometer sites within 50 miles of New York City. These are listed as "SJSU" in the column in Table 1 entitled "Mesoscale Wind Maps." For each chart, streamflow lines were constructed, as were isotachs in mph.

For the same three test periods, bi-hourly surface SO_2 concentration analyses in pphm (Fig. 2) were reanalyzed at "SJSU." The original data were obtained from a network of about 24 fixed surface sites, and from three mobile instruments. These charts are on the same microfilm roll as are the surface wind analyses. The original "NYU" analyses are available for six additional test periods at San Jose State University.

The following data were reanalyzed for all the periods listed in the Table: 1) helicopter soundings of temperature; 2) helicopter soundings of

Table 1: Summary of NYU/NYC Data Set

Test	Period	Mesoscale Wind Maps	Helicopter Temperatures	PIBAL Winds	Mescoscale SO_2 Maps	Helicopter SO_2
PT-1	7/7/64-4/30/65	-	150 SIGN-X 7 IBM 23 SJ25	853 S 74 D 136 DD	-	49 SIGN-X 7 IBM
T-1	9/19-24/65	-	15 IBM	43 S	-	15 IBM
T-2	10/14-16/65	36 NYU	53 SIGN-X 3 IBM	63 S	61 NYU	45 SIGN-X 25 IBM
I-2/3	10/18/65	-	3 SIGN-X	-	-	-
T-3	Cancelled	-	-	-	-	-
T-4	12/7-12/65	-	61 SIGN-X 15 SJ25	126 S	61 NYU	36 SIGN-X
T-5	2/2-5/66	96 NYU	33 SIGN-X 38 IBM	116 S	113 NYU	38 IBM
T-6	3/8-12/66	120 SJSU	5 SIGN-X 98 IBM	202 S	60 SJSU	5 SIGN-X 98 IBM
I-6/7	3/22-23/66	-	7 SIGN-X 2 SJ25	-	-	-
T-7	5/2-7/66	72 NYU	59 IBM 15 SJ25	240 S	106 NYU	59 IBM 49 SIGN-X
I-7/8	5/24/66-9/9/66	-	134 SIGN-X 29 SJ25	2 S	-	-
T-8	10/3-6/66	72 NYU	5 SIGN-X 46 IBM	83 S	62 NYU	46 IBM 5 SIGN-X
I-8/9	10/25-27/66	-	17 SJ25	18 S	-	-
T-9	10/31/66-11/1/66	24 NYU	17 IBM	86 S	36 NYU	17 IBM
T-10	11/15/66-11/17/66	108 SJSU	19 IBM 16 SIGN-X 37 SJ10	170 S	50 SJSU	19 IBM 16 SIGN-X 37 SJ10
T-11	11/23-25/66	48 NYU	-	-	72 NYU	-
T-12	12/5-8/66	72 SJSU	1 SJ10 42 SIGN-X	209 S	36 SJSU	7 SJ10 33 SIGN-X

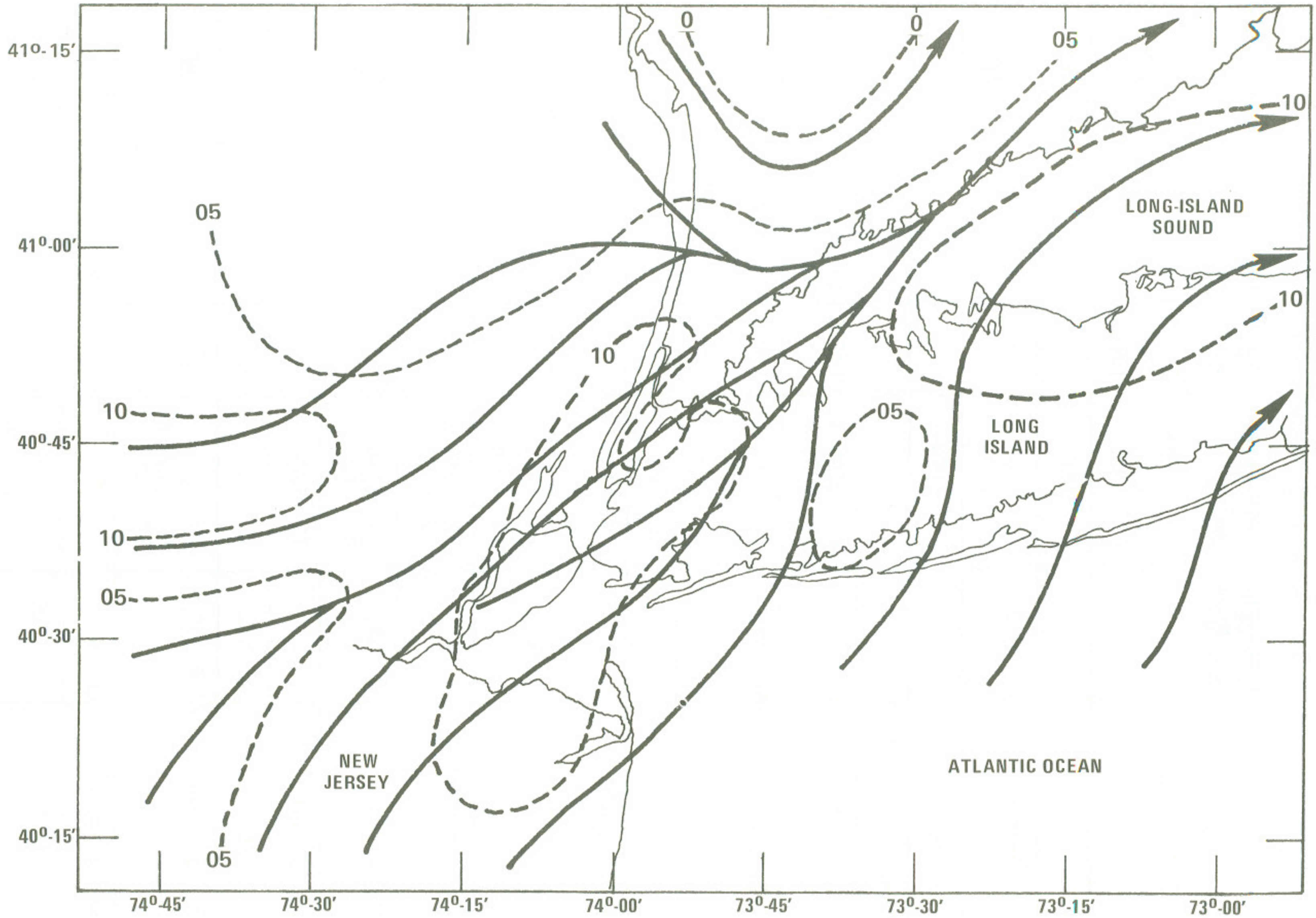


Figure 1. Example of air flow (solid lines) and isotach (dashed lines, miles per hour) analyses for 1900 EST, March 10, 1966.

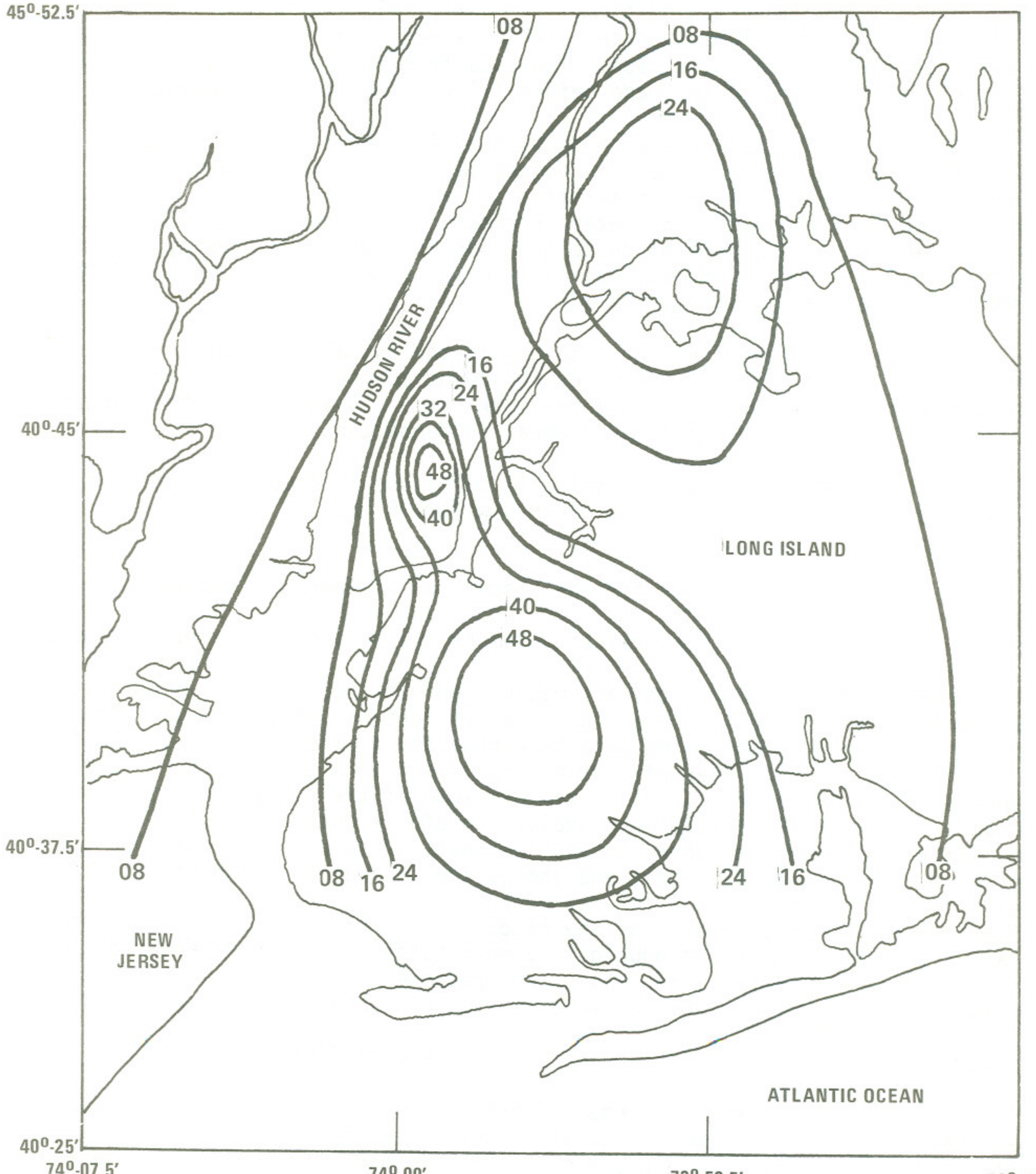


Figure 2. Example of SO_2 concentration (pphm) analysis for 1030 EST, December 6, 1966.

SO_2; and 3) PIBAL wind observations. The original data from all of the "single" theodolite PIBAL launches yielded winds at 37.5-meter intervals and have been put on a magnetic tape. The data from the "double" and "double-double" theodolite launches made before T-1 have yet to be reanalyzed.

The helicopter temperature and SO_2 soundings from each of the periods in Table 1 are to be reproduced in Volume II of the final report from this project. Volume I will be a description of all of the data from the project. These soundings are either 50-meter averages, i.e., those from "IBM," 25-meter averages, i.e., some of those from San Jose State University ("SJ25") and from the "Sign-X" Corporation, or 10-meter averages, i.e., some of those from San Jose State University ("SJ10").

The final component of the data set is the annual emission inventories of SO_2, heat, and moisture from over 400 point sources and 1200 one mile square area sources in and around New York City. In addition, emissions are presented for 0.5 by 0.5 mile grid areas in Manhattan.

It is hoped that this data set will be of use to those contemplating modeling the urban boundary layer over New York City.

2.2 Numerical Models for the Dispersion of Inert Pollutants

2.2.1 Statistical questions relating to the validation of air quality models

During FY-75 a small contract was placed with the well-known statistical-meteorological expert, Dr. Glenn W. Brier of Fort Collins, Colorado, to examine some of the ways in which the data base provided by the Regional Air Pollution Study (RAPS) could be used effectively for validating air quality simulation models. The study (Brier, 1975) examined some of the statistical problems that arise in the validation and evaluation of air quality models. It considered the various scores or indices that can be used in measuring the predictive accuracy of a model and showed how the verification statistics are affected by errors in the input and output data and imperfections in the model. Suggestions were made regarding the major problem of separating input-output data errors from those introduced by a poor mathematical representation of the physical and chemical processes, and recommendations were made regarding validation procedures to be followed as the RAPS data base becomes available.

2.2.2 An air quality simulation model for use with RAPS data

IBM Research Laboratory under an EPA contract, further developed and adapted an existing urban air quality model (Shir and Shieh, 1974) for the St. Louis RAPS. The model, based on numerical integration of the concentration equation, computes temporal and three-dimensional spatial concentration distributions resulting from specified urban point and area sources for relatively inert pollutants. Since the RAPS emissions inventory is not yet available, the model was exercised in the St. Louis area using emissions from NEDS (National Emissions Data System). All other input requirements of the model were in a form compatible with the RAPS data base. The model program has been contracted in a modular form which allows the user to change or improve each component conveniently. An input auxiliary module has also been provided for processing geographical source emission, and monitoring data. The final report, in two volumes, (Shir and Shieh, 1975 a,b) includes a users' guide to the model program.

2.2.3 Mesoscale pollution transport in southeast Wisconsin

EPA grant support to Dr. Walter A. Lyons and his colleagues at University of Wisconsin - Milwaukee has resulted in a number of papers during 1974 and 1975 (Lyons et al. 1974a, 1974b, 1974c, 1974d). These papers deal with modeling of particulate and SO_2 levels, the transport of ozone, inadvertent weather modification by air pollution, the application of satellite observations, trajectory analyses, fumigation of power plant plumes, and related subjects, all with respect to the lakeshore environment.

2.2.4 Complex terrain studies

Since EPA's first attempts (Environmental Protection Agency, 1972) to account for the effects of complex terrain on air quality, interest in this subject has increased greatly. The techniques used to estimate concentrations in complex terrain include (1) simple Gaussian diffusion models with straight-line transport; (2) modified Fickian diffusion models with three dimensional, modified potential flow; (3) physical models in various fluid modeling facilities. Meteorologists are involved in the use of all three techniques.

Wide ranges of concentration estimates can be obtained using the different computational models. Appropriate air quality data are generally inadequate for thorough validation tests of the complex terrain models. However, the terrain impaction model currently used within the Monitoring and Data Analysis Division (MDAD) has been tested on the only available, appropriate air quality measurements. These measurements are for daily average SO_2 concentrations. The monitoring site is located on a mountainside 6.4 km from a major, remote copper smelter located outside Salt Lake City, Utah. The measurements are for a period of 21 consecutive months beginning May 1973. The measurements are taken at an elevation that is near the calculated plume centerline of the smelter under stable, light wind conditions.

The terrain impaction model estimates a second-highest 24-hour concentration of 2480 $\mu g/m^3$ at the measurement site. This compares favorably with 2470 $\mu g/m^3$ which is the second-highest measured concentration during the first 12 months of observations, and with 3130 $\mu g/m^3$ measured during the last 12 months; these two 12-month periods (21 continuous months of observations) overlap during the months of February, March and April 1974. The ten highest 24-hour measurements occurred outside this period of overlap. The model estimate of the average annual concentration at the sampling site is 45 $\mu g/m^3$. This is a small fraction of the measured maximum 12-month averages of 287 and 394 $\mu g/m^3$ for the two periods described above. For the same hillside site the impaction model used in the Southwest Energy Study (Van der Hoven, 1972) estimates a 1-hour maximum SO_2 concentration of 145,000 $\mu g/m^3$; the highest 1-hour measured concentration was 15,000 $\mu g/m^3$.

2.2.5 Model validation studies

NOAA meteorologists are involved in the routine application of dispersion models to a wide variety of point sources. Analyses resulting from such applications are frequently used in making decisions on pollution control measures for individual sources. Thus, knowledge of the confidence with which model estimates can be used in setting emission limits is of concern to the policy-makers. Unfortunately, there are few validation studies of these models, which are based on observed air quality data. Thus such validation is of major interest.

The validation of the terrain impaction model was discussed in the previous section. However, another model has been used in the analysis of numerous power plants. This is the model for estimating 24-hour maximum concentrations which is described by Hrenko et al., (1972). Although the model is based on accepted techniques, it has not been validated. Under contract to EPA, GCA/Technology Division is validating this model using extensive emissions and air quality data which are now available for the Canal Power Plant in southeastern Massachusetts and for 3 power plants in Ohio--Stuart, Muskingum River, and Philo. The analyses for the Canal and Stuart plants have been completed (Mills, 1975; Mills and Stern, 1975). The analyses for the Muskingum River and Philo plants are nearing completion. At the Stuart Plant, the model estimates the highest percentile values of the 3-hour and 24-hour concentrations reasonably well, but severely underpredicts the rest of the distribution (see Tables 2 and 3). Thus, annual averages are seriously underpredicted by this model. For the Canal Plant, the model tends to underestimate concentrations for all sampling sites and averaging times. Future plans include (1) determination of the cause(s) of errors in the model, and (2) recommendations on model revisions.

Another phase of these studies is an analysis of the peak-to-mean ratios and their distribution for 1-hour peak to 3-hour mean, and 1-hour peak to 24-hour mean concentrations at each sampling site. Table 4 from the Canal Plant study indicates peak-to-mean ratios which are relatively low compared to those recommended by Turner (1970).

A case study sensitivity analysis is also being performed on this model. The purpose of the sensitivity analysis is to identify those parameters whose uncertainty may introduce considerable error into the model estimates. With data for the three Ohio power plants, the effects of source parameters (those factors affecting emission rate and plume rise) and meteorological parameters are being tested. Specifically, stack gas exit velocity, stack gas temperature, stack diameter, wind speed, mixing height, and stability class are arbitrarily biased, with resulting changes in maximum 1-hour, 24-hour and annual average concentrations noted. The model is also being tested for each of the 3 plants with meteorological data from three different National Weather Service stations.

2.2.6 General activities

A number of Gaussian plume algorithms were developed, and a number of Gaussian models were evaluated or modified.

Table 2. 3-Hour Concentration Distribution Statistics for Measurements and Model Validation Run ($\mu g/m^3$)

Station	Fifth percentile[a]		First percentile[a]		Second highest		Highest	
	M[b]	P[c]	M	P	M	P	M	P
1	230	11	540	260	751	762	768	763
2	160	15	800	330	823	415	826	575
3	130	50	610	140	917	355	1048	395
4	90	10	610	110	705	315	960	395
5	41	< 10	650	53	683	415	685	455
6	80	< 10	640	107	859	275	982	355
7	80	< 10	670	100	675	505	715	875
All	120	13	650	150	917[d]	762[d]	1048	875

Table 3. 24-Hour Concentration Distribution Statistics for Measurements and Model Validation Run ($\mu g/m^3$)

Station	Fifth percentile[a]		First percentile[a]		Second highest		Highest	
	M[b]	P[c]	M	P	M	P	M	P
1	83	55	245	128	259	149	277	161
2	46	28	160	52	63	75	159	98
3	50	36	110	75	181	91	225	102
4	40	24	63	41	79	45	83	49
5	31	5	52	50	63	57	77	75
6	42	21	135	46	147	69	195	83
7	45	23	69	60	69	73	77	120
All	47	21	115	63	259[d]	149[d]	277	161

[a] Percentile values given in terms of cumulative percent of concentrations greater than given values.

[b] Measured concentrations with subtracted background.

[c] Predicted concentrations.

[d] Highest concentration not exceeded more than once per year at any given station.

Table 4. Statistics for Ratio Distributions[a]

Ratios	Mean	Standard deviation	50%	95%	99%	Maximum	Minimum
1 to 3 hour (all data)	1.81	0.70	1.50	1.02	1.02	3	1
1 to 24 hour (all data)	7.84	6.31	5.37	1.69	1.23	24	1
1 to 3 hour (only down-wind stations)	1.90	0.65	1.66	1.10	1.02	3	1
1 to 24 hour (only down-wind stations)	8.54	5.63	6.75	2.15	1.69	24	1

[a]Given in terms of cumulative percent of ratios greater than given values

A Gaussian plume multiple source algorithm was developed and tested by the Meteorology Laboratory. A grant was awarded to Clark College to compare the model output with air quality measurements. SO_2 measurements are to be used for this purpose. A Gaussian plume algorithm for point, area, and line sources was also developed.

A contract has been awarded to modify several existing models and algorithms to use multiple station wind data input. The initial models and algorithms being modified are the climatological dispersion model, the Gaussian plume multiple source algorithm, and the sampled chronological input model. This work is being done by Environmental Research and Technology, Inc.

A grant was awarded to the New York State Department of Environmental Conservation to partially support a field study to measure the meteorological and air quality parameters in the vicinity of an at-grade expressway. The study, to be conducted on the Long Island Expressway, is scheduled to begin in January 1976.

2.2.7 Validation of point source models

Dr. Werner Klug, Professor of Meteorology, Technical University at Darmstadt, Federal Republic of Germany while a visiting scientist at the Meteorology Laboratory made comparisons of sulfur dioxide measurements at five sampling stations in the vicinity of TVA's Paradise steam plant in Kentucky with model estimates made for the same sampling locations.

Emphasis was on the one-hour averaging time. Comparison of measured and estimated concentrations are not highly correlated; linear correlation coefficients of 0.12 to 0.16 were obtained. Differences in actual wind direction at plume height from wind direction input to the model is suspected as the dominant cause of the correlations obtained as shifting of the input wind directions was demonstrated to improve the correlations obtained from 0.35 to 0.47 for the 5 locations.

Of perhaps greater interest is the comparison of frequency distributions at a station over a year for the one-hour averaging time for both estimates and measurements. For the five locations, the top 1 to 4 percent of the distribution has concentrations overestimated by the model. For each location, however, there is a crossover between the first and fourth percentile from the top of the distribution such that the observed frequency of concentrations above the threshold of measurement is 19 to 33 percent but the estimated frequency of concentrations above the threshold is only 3 to 5 percent.

2.3 Numerical Models for the Dispersion of Reactive Pollutants

2.3.1 Numerical photochemical grid point model

Further development and refinement of a photochemical grid point model proceeded in FY-75 under contract with Systems Application, Inc. The 1973 version of the model, which is now published in the open literature in its entirety, [Reynolds et al., (1973); Roth et al., (1974); and Reynolds et al., 1974], has undergone major improvement in FY-75.

Preliminary results from the initial phases of this work were discussed in the FY-74 NOAA annual report. The contract final reports will be available and sections of the reports are appearing in the open literature (Liu and Seinfeld; 1975; and Lamb et al., 1975).

In FY-76 development activities in the grid point photochemical air quality simulation modeling area will be aimed at concluding a second phase of development which began late in FY-74. This, so to speak, second generation model will undergo extensive verification using the data from the Regional Air Pollution Study (RAPS).

2.3.2 Photolytic rate constants for photochemical air quality simulation models

A research and development program has been initiated by the Meteorology Laboratory to compute theoretically the diurnal variation of photolytic rate constants for several species present in the lower atmosphere. An experimental study has begun to measure the rate constant values for NO_2 photodissociation in the atmosphere directly. These results will be compared with the theoretically generated rate constants for NO_2 and an evaluation of the theoretical approach will be considered.

2.3.3 A prognostic air quality simulation model

The numerical predictive grid point model for a meteorological and air pollution field of the Los Angeles urban boundary layer that was developed by CEM (Center for Environment and Man) (Pandolfo & Jacobs, 1973) is currently being refined and evaluated under EPA contract 68-02-1767. Currently, an evaluation of the accuracy of the air quality aspects of the model is being considered, based on refinement of the horizontal grid for carbon monoxide emissions from an earlier 8-mile to the present 2-mile square grid resolution. This refinement was prompted by an evaluation by Nappo (1974) who suggested that model sensitivity and accuracy are dependent mostly on the degree of detail of the source emissions inventory.

The model is presently being adapted to run on the UNIVAC 1110 at the RTP site. Modification and refinement of the CEM model will continue via an in-house Meteorology Laboratory program. An improved version of the model will be considered for possible operational studies by EPA. Plans to adapt the model for the St. Louis region and perform extensive verification studies using RAPS (Regional Air Pollution Study) data have been made.

2.3.4 Los Angeles reactive pollutant program (LARPP)

The LARPP was jointly sponsored by the Coordinating Research Council and the EPA for the purpose of obtaining a complete data package suitable for describing the transport, diffusion, and chemical reactions associated with a parcel of air undergoing photochemical reactions within the Los Angeles Basin. The program, conceived in 1971 as a Lagrangian type experiment to evaluate trajectory type photochemical diffusion models, was carried out in October-November 1973. Aerometric measurements were made within a moving air parcel, identified by tetroons and tagged by fluorescent tracer, as it traversed the Los Angeles Basin. Extensive surface air sampling networks and mobile sampling units provided additional air quality and meteorological information.

The data archive includes measurements of O_3, NO, NO_x, CH_4, non-methane hydrocarbon, CO, tracer concentrations, and air temperature. Bag samplers for GC analysis were obtained by mobile vans. Aircraft also measured dew point and aerosol light scattering. Radiation measurements at selected wavelengths were measured in the Basin and on Mt. Disappointment, above the polluted layer.

The data archive, recorded on magnetic tape, including a modeler's archive, are available through the National Technical Information Center. These archives represent the end product of the LARPP.

2.3.5 LARPP lidar study

A mobile system housed in a van was used during the LARPP by Systems Innovation Development Corporation to observe the temporal and spatial variations of the atmospheric mixing layer within the Los Angeles Basin. Comparisons of the lidar data depicting mixing depth to temperature and moisture profiles obtained from radiosondes and helicopter measurements were good. Variability in signal return of the ruby laser (6943 Angstroms wavelength) was noted with slight changes in ambient humidity; observations suggest that optical scattering changes, reflecting changes in particle size, occur at humidities above 70%. The lidar observations are part of the LARPP data archive.

2.3.6 LARPP radiation measurements

As part of the Los Angeles Reactive Pollutant Project (LARPP), scientists from the Meteorology Laboratory conducted a solar radiation measurement program, with emphasis on the ultraviolet (UV) wavelengths. The program had two objectives: to provide input data to photochemical diffusion models and to document urban-rural and intra-urban spatial and temporal differences of incident solar energy. A description of the measurements and a report of some preliminary analyses were included in the FY-1974 report. Some additional results from the continuing data analysis are presented below.

Measurements were made of the incident UV and all-wave solar flux at sites in the Los Angeles area. The urban sites, oriented approximately west-east, were at Los Angeles International Airport, downtown Los Angeles, El Monte, Upland and San Bernardino. The rural data were collected on Mt. Disappointment at 1820 meters elevation, 26 kilometers northeast of downtown Los Angeles. Instruments were operated continuously from September 1 to November 7, 1973.

To study the effect of the urban atmosphere, all periods were identified when cloud-free skies occurred at both Mt. Disappointment and El Monte for at least one hour between 1000 and 1400 PST. Average urban-rural radiation differences were computed for each of the 47 days selected. For the complete experiment, the UV and all-wave fluxes measured at El Monte average 71.3 and 88.9 percent, respectively, of those measured at Mt. Disappointment. For the entire 47 days the El Monte/Mt. Disappointment daily average UV fluxes varied between 56.0 and 84.7 percent. The corresponding all-wave flux values were 80.3 and 95.9 percent. Visibilities at El Monte at the times of the greatest radiation reductions were generally three miles or less; they generally exceeded 25 miles during periods of the least reduction. The air on the mountain site was relatively uncontaminated.

The data point out the significant attenuation of solar radiation as it passes through the hazy atmosphere over Los Angeles and the strong wavelength dependence of that attenuation. Rayleigh (molecular) and Mie (aerosol) scattering and ozone absorption of solar energy all are more effective at UV than at longer wavelengths. The El Monte/Mt. Disappointment percentages on the cleanest days (84.7 percent for the UV component) can be used as a reference to account for the elevation differences between sites. Thus, the average UV depletion <u>due to smog</u> measured at Los Angeles was 84.7 - 71.3 = 13.4 percent.

The El Monte/Mt. Disappointment daily average ratios were also stratified by day of the week. The UV Sunday to Saturday averages were: 0.79, 0.74, 0.68, 0.67, 0.65, 0.69, and 0.77. These radiometric measurements indicate that, during the autumn of 1973, the Los Angeles atmosphere was optically thickest on Thursdays and most transparent on Sundays and Saturdays.

An example of the variability of UV flux across the Los Angeles Basin is shown in Figure 3. Ten-minute average values (watts m^{-2}) are plotted vs. time for October 25, 1973, which was a relatively hazy day for this time of year in

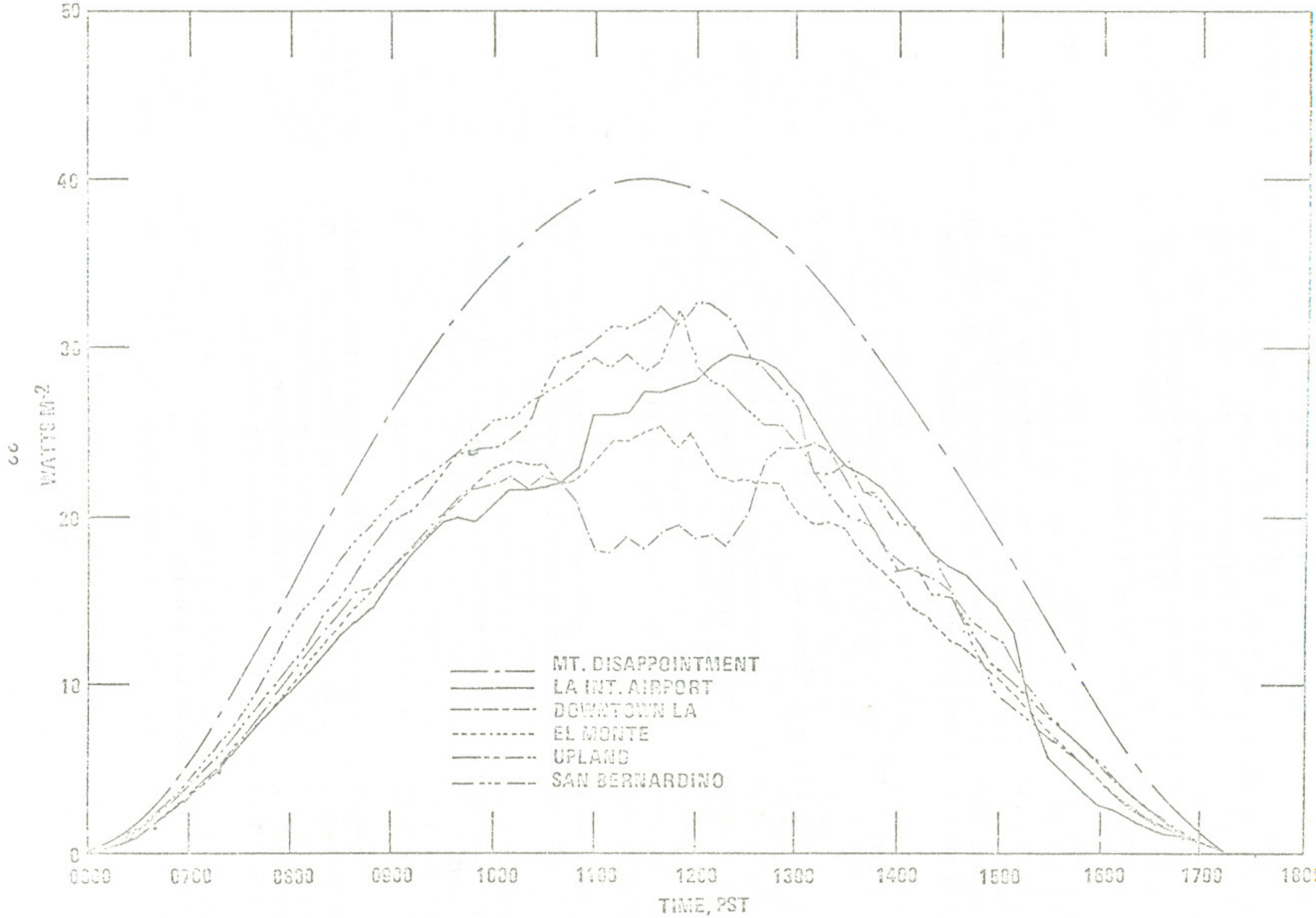


Figure 3. Measured ultraviolet flux (watts m^{-2}) at five urban sites and one rural (Mt. Disappointment) site near Los Angeles during October 25, 1973.

Los Angeles. The visibility at El Monte, for example, was 4 and 5 miles between 1000 and 1600 PST. No clouds were reported, except late in the afternoon at Los Angeles International Airport.

These data show one of the greatest differences of UV flux (not due to clouds) between the rural site (Mt. Disappointment) and any of the urban sites. Between 1100 and 1200 PST downtown Los Angeles received only 46.7 percent as much UV energy as did the rural location. The corresponding value for the all-wave measurements was 75.0 percent. On other, relatively clean days, UV urban-rural differences occasionally were less than 10 percent. The variability of UV flux between urban stations is also evident from Figure 1. Between 1100 and 1200 PST, the difference between downtown Los Angeles and Upland averaged 42 percent.

2.3.7 Precipitation scavenging of fossil-fuel effluents

A predictive model for the scavenging of fossil-fuel effluents by precipitation was developed by Battelle-Pacific Northwest Laboratories. The scavenging model incorporating chemical kinetics (SMICK) is an extension of the SO_2 only model (EPAEC), developed under a previous EPA contract (Dana et al., 1973), to include other species and the chemical reactions occurring within a raindrop as it passes through a plume. The initial application of SMICK was limited to the sulfur compounds.

Part of the effort involved the conduct of field experiments at the Centralia Steam-Electric Plant near Centralia, Washington. Both fixed and mobile precipitation collectors were used in the experiments. The data show that sulfate concentrations in rainwater due to the presence of the plume do not appear to be significant at downwind distances less than 10 km; ammonium, nitrite, nitrate, and soluble (ortho) phosphate ion concentrations were at or near normal backgound levels; and SO_2 and hydrogen ions were the only species showing plume-related deposition patterns at all collection distances (0.4-11 km).

The numerical model, SMICK, was used to examine the liquid phase oxidation mechanism involving ammonia. The Scott and Hobbs (1967) mechanism for the formation of sulfate in water droplets was investigated with SMICK using the input conditions from the field studies conducted at the Centralia Steam-Electric Plant under this contract and under a previous contract effort (Dana et al., 1973). Two values of K, the rate constant for the oxidation of SO_3 to SO_4, were tested, the Scott and Hobbs value and the value proposed by McKay (1971). They differ by an order of magnitude. The results were compared with the actual observations.

Table 5 shows the results of a sample comparison. The observed data shown in the table were measured on December 10, 1974, with a wind speed of 705 cm/sec, rainfall intensity of 0.8 mm/hr, and a sulfur source strength of 25.4 gram moles/sec. The table shows that the absence of ammonia results in very low sulfate at all distances, though the SO_2 and H^+ concentrations are in more agreement with observations than the other sets of computations. Adding ammonia results in very high values of SO_2 and low values of H^+ (high pH) for

Table 5. Sample SMICK Plume Centerline Rain Concentration Calculations with Scott and Hobbs' Mechanism: Run F3 Input Data and PCO_2 = 311 ppm. Concentrations are in (gram moles/cm^3) x 10^9

x (km)	SO_2	$SO_4^=$	NH_4^+	H^+
Observed PNH_3 = 1.7 ppb				
4.5	33.0	14.0	2.4	79.0
7.0	28.0	28.0	3.6	79.0
10.2	22.0	33.0	2.5	63.0
PNH_3 = 0		K = 0.013 sec^{-1} (McKay)		
4.5	66.0	0.20	0	66.0
7.0	46.0	0.28	0	47.0
10.2	34.0	0.37	0	35.0
PNH_3 = 1 ppb		K = 0.0017 sec^{-1}		
4.5	519.0	2.2	531.0	5.0
7.0	356.0	2.9	371.0	4.0
10.2	256.0	3.6	274.0	2.5
PNH_3 = 1 ppb		K = 0.013 sec^{-1} (McKay)		
4.5	512.0	16.0	551.0	5.4
7.0	352.0	20.0	396.0	3.9
10.2	251.0	25.0	305.0	5.4
PNH_3 = 7 ppb		K = 0.0017 sec^{-1}		
4.5	841.0	11.0	944.0	1.3
7.0	564.0	14.0	669.0	0.8
10.2	403.0	17.0	511.0	0.6

both values of K. In the PNH_3 = 1 ppb cases, use of the McKay value for K results in $SO_4^=$ values closer to those observed. A significant effect of the addition of the ammonia is an increase in SO_2 absorption due to the increase in alkalinity, as is shown by comparing the third and fifth sets of numbers. These results would appear to indicate that the Scott and Hobbs mechanism alone cannot account for the Centralia observations.

Further details of the field and numerical experiments can be found in Dana et al. (1976).

2.4 Model Application

2.4.1 Use of air quality simulation models for comparison of pollution control strategies

During FY-75 a small research grant was placed with the School of Urban and Public Affairs of the Carnegie-Mellon University, Pittsburgh, PA, to apply innovative statistical and analytical techniques to the above topic. The principal investigators are Professor K. O. Kortanek of the Carnegie-Mellon University, and Professor Sven Gustafson of the Department of Numerical Analysis, Royal Institute of Technology, Stockholm, Sweden. The study will compare various abatement strategies (roll back, maximum control, least-cost, etc.) and evaluate their consequences. Statistical theory, such as the theory of experimental design and time-series analysis, will be used in order to explore optimal ways of extracting information from the data base and an important task will be to remove unnecessary complexity in the air quality models. In the spirit of "repromodels" this may be done by approximating the air quality distributions with piecewise linear functions, or considering higher-order splines or finite-element methods. A final report will be available during FY-76.

2.4.2 Application of complex terrain models

INTERCOMP Resources Development and Engineering, Inc., under contract to EPA, has compared three dispersion models with peak concentration data collected during a field study in complex terrain at Huntington Canyon (Start et al. 1975). INTERCOMP (1975) concluded that (1) the INTERCOMP (Fickian diffusion) model does well in estimating average concentrations and concentration patterns, (2) the model used in the Southwest Energy Study (SWES) overestimates by more than an order of magnitude and (3) terrain impaction model used underestimates concentrations. However, NOAA personnel interpret the same data as follows: (1) the Huntington Canyon observations are for short-term periods only (up to 1 hour) and are thus inappropriate for evaluating the terrain impaction model which estimates concentrations for 24-hour and annual averages; (2) the INTERCOMP model underpredicts peak concentrations by about one order of magnitude, and the SWES model estimates concentrations essentially on the loci of the highest concentrations observed at three of the four sampling arcs utilized during the tests for which the highest concentrations were observed; (3) the degree of impingement of elevated plumes on elevated terrain during stable atmospheric conditions cannot be determined from the Huntington Canyon data.

2.4.3 Power plant studies

Recent developments in the energy field have necessitated review of State Implementation Plan (SIP) requirements in the light of known or predicted shortages of low sulfur coal, oil and gas. In addition, the Energy Supply and Environmental Coordination Act discussed above requires analyses relating to power plant fuel use and the resultant impact on air quality. As a result, short-term modifications to SIP requirements may be necessary to accommodate the types and grades of fuel available; also, longer term alterations in fuel types and usage patterns may be required.

To develop an information base which would assist such analyses and determinations, a systematic evaluation of the air quality impact associated with power plants has been undertaken. Previous studies performed by and for EPA have evaluated the probable air quality impact for about 200 power plants which burn coal in the eastern half of the United States (Walden Research Division, 1973). Thus, similar techniques which employ a model for estimating 24-hour maximum concentrations (Hrenko et al., 1972) have been applied to most other utility power plants greater than 25 MW. This includes approximately 500 power plants located throughout the United States (GEOMET, 1975; Walden Research Division, 1975a, 1975b).

In addition to their use in the analysis of SIP revisions, these studies have been invaluable in generalized analyses which assess the overall effect of various national policy proposals on the power plant industry. Although these studies have certain limitations, they have been used effectively in a number of energy/environment policy deliberations which include: the Clean Fuels Policy, SO_x scrubber hearings, proposed oil-to-coal conversions, actions required under the Energy Supply and Environmental Coordination Act, tall stack policy, Supplementary Control System evaluation, the Ohio SO_x hearings, and testimony on options for SO_2 control before congressional committees. In addition, several EPA Regional Offices have been assisted in the use of these techniques to evaluate specific control strategy revisions to SIP's under their purview.

2.4.4 Industrial studies

NOAA meteorologists have performed dispersion analyses on numerous industries for the purpose of assessing the air quality impact of proposed standards of performance (emission limitations). The results of the analyses are submitted for use in the preparation of the Standards Support and Environmental Impact Documents, e.g., EPA (1975), which accompany the emission standards promulgated for the various industries. Analyses have been performed on the following source types: gas turbine generators, kraft pulp industry, sulfuric acid manufacturing, by-product coke ovens, lignite-fired steam generators, refuse-combustion steam generators, crushed stone industry, gray iron foundry industry, carbon black plants, mercury-cell chlor alkali plants, and grain elevators. Routinely these analyses include a description of (1) one or more characteristic source configurations, (2) the dispersion model and associated meteorological conditions considered in the analysis and (3) an assessment of the impact of each source configuration on air quality.

Two such studies are of major concern for setting emission limits for hazardous materials, e.g. lead and vinyl chloride monomer (VCM). One study considers the impacts of the following industries on ambient concentrations of particulate lead: primary lead smelters, secondary lead smelters, primary copper smelters, lead oxide plants, and battery manufacturing plants. It has been found that the impact of primary lead smelters on ambient lead concentrations is much greater than that of other source categories in both flat and complex terrain. Also fugitive emissions have a much more significant impact than do emissions from stacks.

The other study is assessing the impact of vinyl chloride monomer and polyvinyl chloride plants on air quality. This assessment also will be used in setting emission limits for such plants. Preliminary analyses have shown that the most stringent reasonably available control technology, when applied to these plants, can reduce VCM concentrations by 15% to 30% for 24-hour and annual averages and by negligible amounts for 5-minute peak concentrations.

As a result of the above noted studies of industrial sources, a technique for incorporating the aerodynamic effects associated with poor stack height-building height relationships has been developed into a computerized dispersion model. This model is based on work by Briggs (1973). A plan for evaluating the physical assumptions made in the model is in preparation. This plan will involve simulations in the EPA wind tunnel facility. Those wind flow conditions which result in aerodynamic downwash or plume rise retardation for various building/stack configurations will be identified.

2.4.5 Dispersion models for control strategy evaluation

General guidance on the types and availability of a wide range of dispersion models continues to be given to EPA Regional Offices and to state and local air pollution control agencies. The use of multi-source models to evaluate State Implementation Plan control strategy revisions for one or more pollutants is of particular concern. This guidance has culminated in a proposed revision to Appendix A of Regulations for Preparation, Adoption and Submittal of Implementation Plans (Environmental Protection Agency, 1971). The Appendix A revision summarizes the models, and their characteristics, which are applicable for each pollutant and averaging time (see Table 6). It indicates dispersion models (see Table 7) which are required in the evaluation of plan revisions (unless justification for use of another model can be made).

2.4.6 Averaging-time model

As noted in previous annual reports, an empirical mathematical model has been developed to express air pollutant concentration as a function of averaging time and frequency. The model has three basic characteristics: (1) concentrations are lognormally distributed for all averaging times; (2) median concentration is proportional to averaging time raised to an exponent; (3) maximum concentration is approximately inversely proportional to averaging time raised to an exponent.

Table 6. Summary of Simulation Model Characteristics

Model Name	Pollutant Specification	Averaging Time Specification	Emission Data	Meteorological Data	Concentration Estimates	Ease of Use	Availability	Reliability	Applicability to AQM
Rollback	Any	Any	1	1	3	1	1	3	3
Appendix J	O_x	1 Hour	1	1	3	1	1	3	3
Miller-Holzworth	SO_2,TSP	1 Hour, Annual	1	3	3	1	1	1	3
Hanna-Gifford	SO_2,TSP CO	Annual	1	2	3	1	1	1	3
Hanna-Gifford	SO_2,TSP	1-24 Hour	2	5	2	2	1	1	2
w. Point Source Model	SO_2,TSP	1-24 Hour	3	5	1	2	2	1	1
w. HIWAY	CO	1-24 Hour	3	5	1	2	2	1	1
AQDM/CDM	SO_2,TSP	Annual	3	4	1	3	2	1	1
SCIM*/RAM*	SO_2,TSP	1-24 Hour	3	5	1	3	3	2	1
APRAC-1A	CO	1-24 Hour	3	5	1	3	2	2	1
SAI	CO,NO_2,O_x	1-10 Hour	2	5	2	3	3	2	2

*These models are currently in a developmental and debugging phase; they are not available for general distribution as computer programs.

Key to Table 6

A. Pollutant Specification
   Any pollutant
   Specific Pollutants (SO_2, TSP, CO, O_x, NO_2)

B. Averaging-time Specification
   Any averaging-time
   Annual Average
   1 to 24 Hour Average

C. Emission Data
   1. Area-wide Emissions Total
   2. Total emission distributed as finite area sources
   3. Detailed point, line and area sources

D. Meteorological Data
   1. None
   2. Average wind speed
   3. Average wind speed and mixing height
   4. Frequency distribution of wind direction, wind speed, stability and mixing height
   5. Hourly variations of wind direction, wind speed, stability and mixing height

E. Concentration Estimates
   1. Estimates at any specified point
   2. One estimate for each area source grid
   3. One estimate applicable to entire AQMA

F. Ease of Use
   1. Slide-rule
   2. Small computer effort
   3. Major computer effort

G. Availability
   1. Open literature
   2. National Technical Information Service
   3. EPA, upon request

H. Reliability
   1. Can be verified and calibrated
   2. Verification is incomplete, possibility of calibration is uncertain
   3. Questionable, acceptable for crude estimates only

I. Applicability to AQM
   1. Can distinguish between specific source and land use types only
   2. Can distinguish between land use types only
   3. Considers no distinction between sources or land uses

Table 7. Multi-Source Models Applicable to Specific Pollutants and Averaging Times*

SO_2 and TSP Annual Average	SO_2 and TSP 24-Hour Average	SO_2 and TSP 3-Hour Average
AQDM/CDM	AQDM**CDM**	AQDM**/CDM**
Hanna-Gifford	SCIM***/RAM Hanna-Gifford*** with point source model	SCIM***/RAM Hanna-Gifford*** with point source model
Rollback	Rollback	Rollback
Miller-Holzworth****		Miller-Holzworth****

CO 1- and 8-Hour Average	O_x 1-Hour Average	NO_2 Annual Average
APRAC-1A***	SAI	Rollback
Hanna-Gifford*** with HIWAY	Appendix J	
Rollback	Rollback	

* Listed according to level of detail and applicability for evaluating control strategies.

** Statistical conversion of averaging times required.

*** Repetitious application of model to each hour under consideration is required for averaging times longer than 1-hour.

**** Not acceptable for control strategy evaluation.

Technical assistance on the application of the model has been given throughout the year to those within and outside of EPA. Examples of some applications within EPA follow.

When carbon monoxide (CO) from automobiles is inhaled, it unites with the blood to form carboxyhemoglobin and thereby reduces the blood's ability to transport oxygen. The averaging-time model was applied to carboxyhemoglobin data available from a sample of persons working in Los Angeles and Milwaukee to calculate the expected carboxyhemoglobin body burden for each day of a year, arrayed from the most to the least polluted.

Sulfuric acid mist is emitted by automobiles equipped with oxidation catalysts. When the ratio of mist emission to CO emission is know, CO can be used as a tracer to indicate expected mist concentrations. In addition, if carboxyhemoglobin levels in a city's population are known, the concentration of CO they were breathing can be calculated, and in turn, the mist they would have inhaled can be determined. Such techniques were used in conjunction with the averaging-time model to estimate potential population exposures to mist as a function of how many model years of catalyst-equipped cars might be produced in the United States before some other control system might be developed.

When sulfur dioxide is emitted by power plants and other sources, atmospheric reactions over a period of hours or days transform it into particulate sulfates. Health studies indicate that some species of these particulate sulfates are more harmful to health than is the original sulfur dioxide. The health effects seem best related to particulate sulfate concentrations averaged over about 24 hours. Such data for every day of the year are available at very few air sampling sites, but data for about 60 samples per year are available at many sites in the United States. From these samples the standard geometric deviation can be calculated. This information, together with annual arithmetic mean concentrations for these various sites, has been used with the averaging-time model to calculate expected concentrations of particulate sulfates and expected health consequences for the few worst days in a year.

The technique used for particulate sulfates has also been applied to nitrogen dioxide, but going the opposite direction. Based on health effects studies, potential future nitrogen dioxide air quality standards for an averaging time of 1 hour have been considered. The averaging-time model has been used to calculate the annual arithmetic mean concentration that would be needed at a particular site to achieve such a 1 hour standard by using the standard geometric deviation for that site. This value has then been compared with the current annual arithmetic mean nitrogen dioxide standard to determine if the proposed new 1 hour standard is more or less stringent than the present 1 year standard for that particular site.

2.5 Physical Modeling

2.5.1 Fluid modeling facility

Much can be learned about atmospheric dispersion processes by fluid modeling. Controlled laboratory studies in wind tunnels and water channels can be performed to determine atmospheric transport characteristics over urban areas or complex terrain. The design and location of new emission sources can be evaluated to minimize pollutant concentrations at given locations.

The fluid modeling activities of the Meteorology Laboratory are performed in the Fluid Modeling Facility (FMF) located in the Grand Slam Building, Research Triangle Park, N.C. In June 1974 the FMF obtained a meteorological wind tunnel designed for modeling neutral atmospheric flow. A PDP 11/40 minicomputer was also acquired for digital processing of data. A machine shop and electronics shop were set up to enable in-house construction of complex models and repair of instruments and electronic gear.

A water channel/towing tank was under construction during FY-75 by Aerolab Supply Company of Laurel, Maryland. Installation at the FMF began in May 1975. The system is expected to be completed and turned over to the EPA in August 1975. By filling the channel with stratified solutions of salt water, stably-stratified atmospheric conditions can be modeled.

Major efforts during FY-75 were directed at testing and evaluating the operational characteristics of the meteorological wind tunnel and developing measurement and analysis techniques for air velocity and tracer-gas sampling. Work was done on the development of boundary layers suitable for atmospheric modeling in the wind tunnel test section. Four research projects were undertaken, two of which were completed in FY-75.

2.5.2 Systems and equipment

The FMF meteorological wind tunnel (MWT) provides the Meteorology Laboratory with a facility for in-house modeling of neutral atmospheric flow. The open-return wind tunnel, 38 meters in overall length, has a test section 3.7 m wide, 2.1 m high, and 18.3 m long. A 75 KW AC motor and eddy current coupler drives a 1.8 meter diameter fan to produce steady velocities in the test section of 0.5 to 10.0 meters per second. An instrument carriage controlled from an operator's console positions a probe anywhere in the test section with the three-dimensional location displayed to the nearest millimeter. The test section is made up of five identical subsections which have interchangeable windows and floor units. One floor unit contains a 3.4 m diameter removable turntable. A model fastened to the turntable can be easily rotated to change the relative wind direction.

A contract for the construction of a water channel/towing tank was awarded to Aerolab Supply Company at the close of FY-74. An artist's conception of the water channel/towing tank is presented in Figure 4. The test section is 25 m long, 2.4 m wide, and 1.2 m deep. Most of the fabrication of this system was performed at their Laurel, Maryland plant. Installation at the FMF Grand Slam Building began in May, 1975. The system will operate in two modes; as a recirculating water channel with models fastened to the floor of the test section, and as a towing tank with the test section ends blocked off to form a tank of still water. Inverted models are to be mounted to a moving carriage and towed through the still water. Operation in the towing tank mode with the tank filled

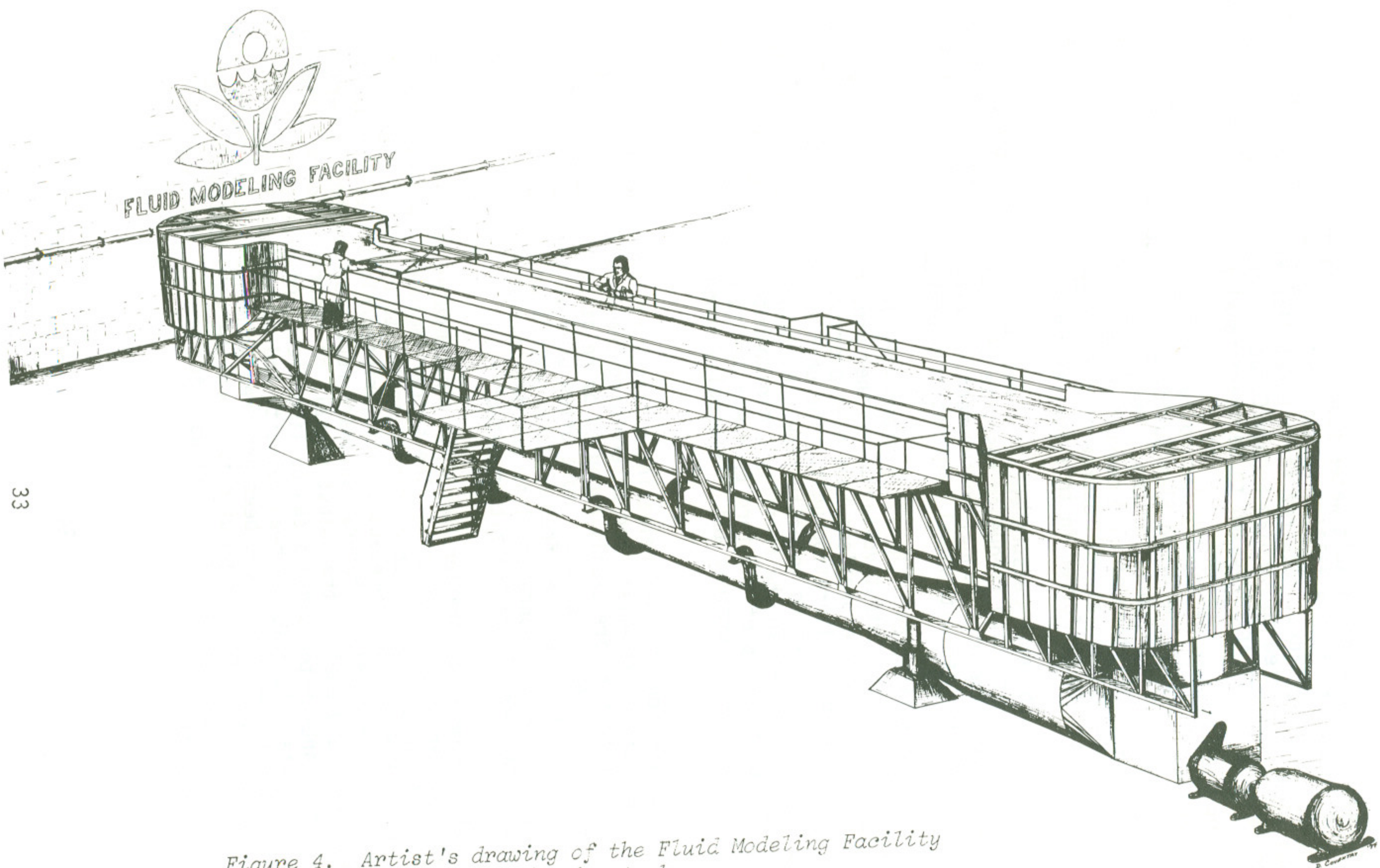


Figure 4. Artist's drawing of the Fluid Modeling Facility water channel/towing tank.

with a stratified solution of salt water models stratified atmospheric conditions. The installation of a filling system including a brinemaker and five 16,000 gallon holding tanks, required for a stratified filling of the towing tank, was also contracted to Aerolab Supply Company. The water channel/towing tank and filling system are expected to be operational by August 1975.

The FMF has made use of the EPA Air Pollution Training Institute wind tunnel which is housed in the Grand Slam Building. This tunnel has a test section 1 m wide, 1 m high, and 3 m long. The primary use of the tunnel is the demonstration and calibration of wind-measuring instruments. Small-scale fluid modeling studies such as near source dispersion and the initial plume rise from stacks can be performed in this smaller tunnel.

Velocity and turbulence measurements are made with hot-film anemometers. The small probe size and high frequency response of hot-film anemometers make them highly suitable for wind tunnel measurement. Thermo-Systems, Inc. model 1054A anemometers are used with model 1210 hot-film probes.

The primary complication of hot-film anemometry is the non-linear relationship between velocity and output voltage. Another problem is obtaining accurate calibrations. Both of these problems have been overcome with the purchase of a commercially available calibration unit. The unit contains a chamber where probes can be placed in a known velocity flow. By taking several calibration points and processing them in the facility's minicomputer, a best fit velocity, U, voltage, E, relationship of the form $E_2 = A + BU^{\alpha}$ is calculated. "A" and "B" are constants to be determined and α is usually found to be in the range .35 to .50.

Modeling dispersion involves releasing a tracer gas from the modeled source, sampling at locations of interest, and determining the levels of tracer in the samples. Dilution factors are easily computed by relating the sample tracer levels to the source level. Methane i most often used as the tracer. A small amount of methane in air, released from a stack, will disperse as a neutrally buoyant effluent. Downwind concentrations are detected with a Beckman model 400 hydrocarbon analyzer (flame ionization detector).

A Digital Equipment Corporation PDP 11/40 minicomputer performs on-line real-time analysis and storage of data. The system includes: a 16 K memory core, two 1.2 million word discs, an 8 channel analog to digital converter, a nine track magnetic tape unit, an electrostatic printer/plotter and an automatic-refresh graphics display. Several software routines have been generated to digitally sample and analyze the output signals of laboratory data gathering devices. Hot-film anemometer signals can be linearized and processed in real time to provide instant feedback on mean velocity and turbulence intensity measurements. Plotting routines have been prepared which make it a simple exercise to prepare a hard-copy graph of data immediately following an experiment. Fast Fourier Transform techniques are used to compute power spectra from digitized velocity signals.

2.5.3 Tunnel flow characteristics

Flow uniformity tests and measurement of turbulence levels in the empty tunnel were made. Background or reference empty tunnel characteristics must be known before attempting to produce simulated boundary-layer flows. Hot-film anemometer measurements indicated a uniform mean velocity (order of 1%) and low turbulence intensity (order of 1/2%) over the test section with the exception of a shallow boundary layer near the walls, floor and ceiling.

2.5.4 Vortex generators

Boundary-layer development for modeling atmospheric flows in the Meteorological Wind Tunnel is patterned after a method devised by Counihan at the Central Electricity Research Laboratories, England (Counihan, 1969). To develop a boundary layer naturally, with scaled surface roughness, would, in many cases, require an excessively long test section. Using Counihan's method, thick atmospheric boundary layers may be generated in approximately 4 boundary layer heights. A castellated barrier is placed at the entrance to the test section just upwind of elliptically shaped fins (Figure 5). Sets of generator fins of various heights (from 15 cm to 183 cm) have been constructed. The thickness of the boundary-layer produced is approximately the height of the generators. By fastening suitable roughness elements to the test section floor downwind of the fins, mean velocity and turbulence intensity profiles similar to those occurring in the atmosphere can be generated.

An extensive study of the mean velocity and turbulence intensity behind 60 cm generators for various heights and spacings of roughness elements resulted in a combination that produced a 1/7 power law velocity profile. The geometry was scaled up to the 183 cm generators and a 1/5 power law was found (Figure 6). Further study is required to determine arrangements of vortex generator-roughness element combinations to produce additional boundary layers.

2.5.5 Highway study

The near-highway dispersion of automobile exhaust is complicated by the initial mixing induced by the mechanical turbulence of the vehicle wake. The nature of this turbulence is not well enough understood to be properly incorporated in numerical dispersion models. A 1/32nd scale model of a two-lane highway with moving vehicles has been constructed for study in the Meteorological Wind Tunnel (Figure 7). Polyurethane foam cars are fastened to a chain which is driven by sprockets mounted at each side of the test section. First attempts are to model an at-grade highway with a high vehicle-speed-to-crosswind-speed ratio. This requires a high model vehicle speed which produces large acceleration forces as the vehicle reverses direction at the ends of the track. Much effort went into the construction of a system which could withstand the accelerative forces.

The size of the initial mixing cell was determined by emitting a chemically produced smoke from the cars. Concentration levels in the near field of the roadway are determined by using butane, emitted from small tanks mounted in the

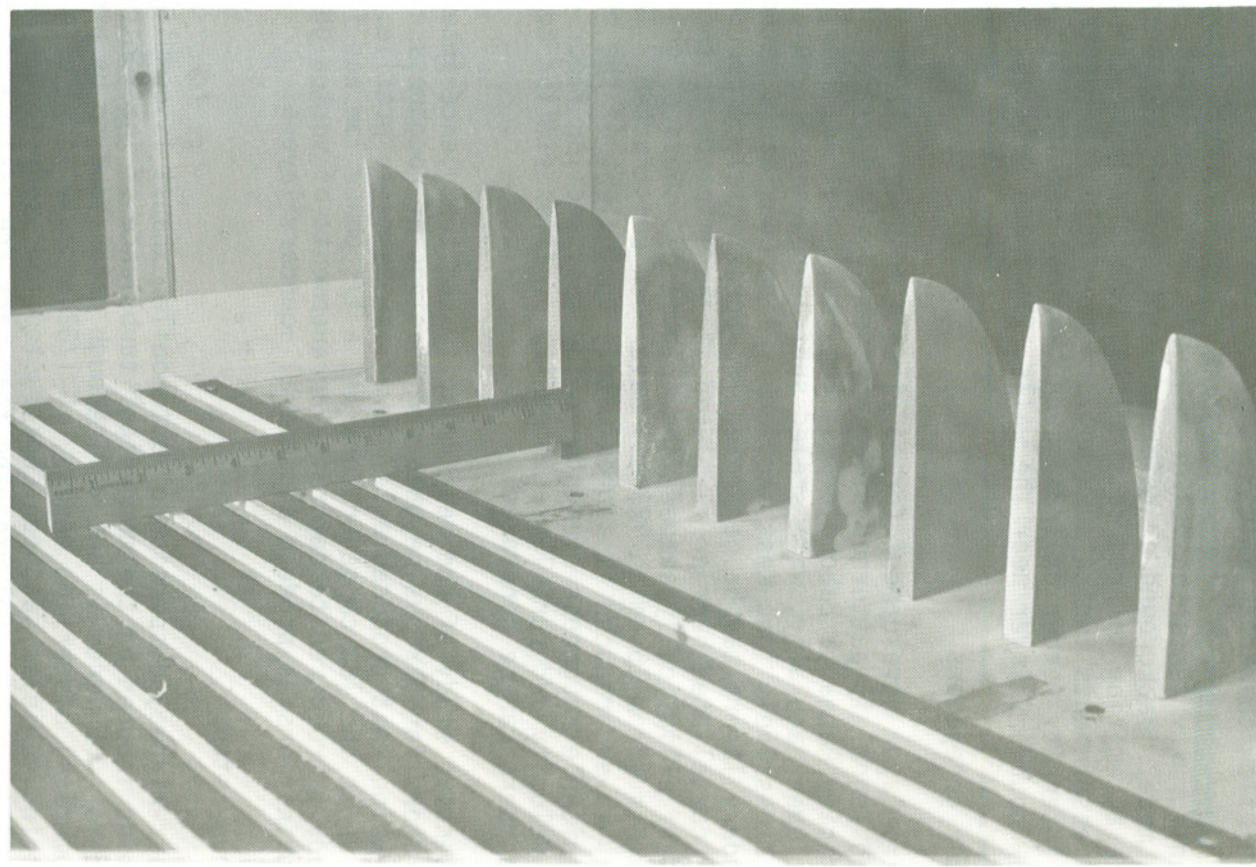
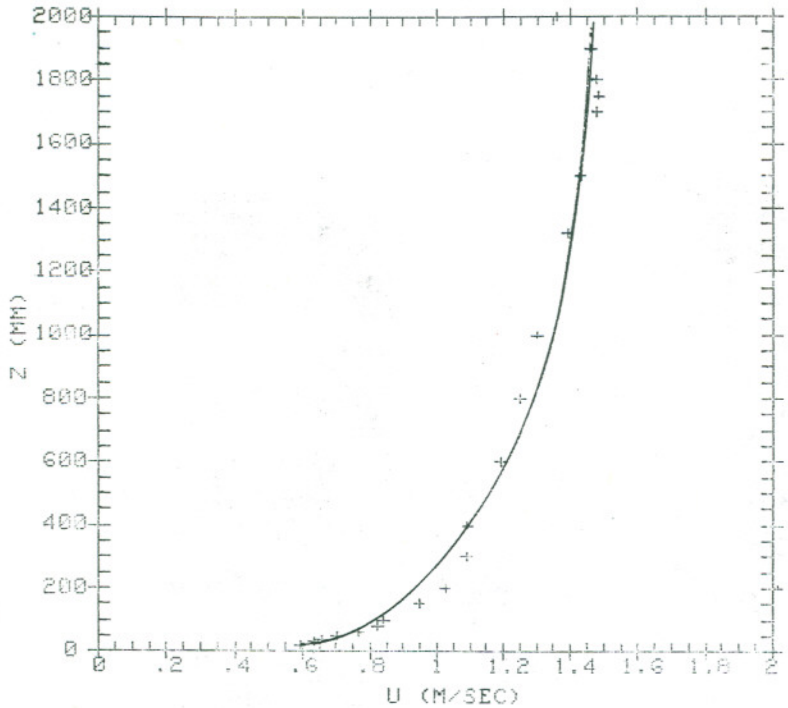
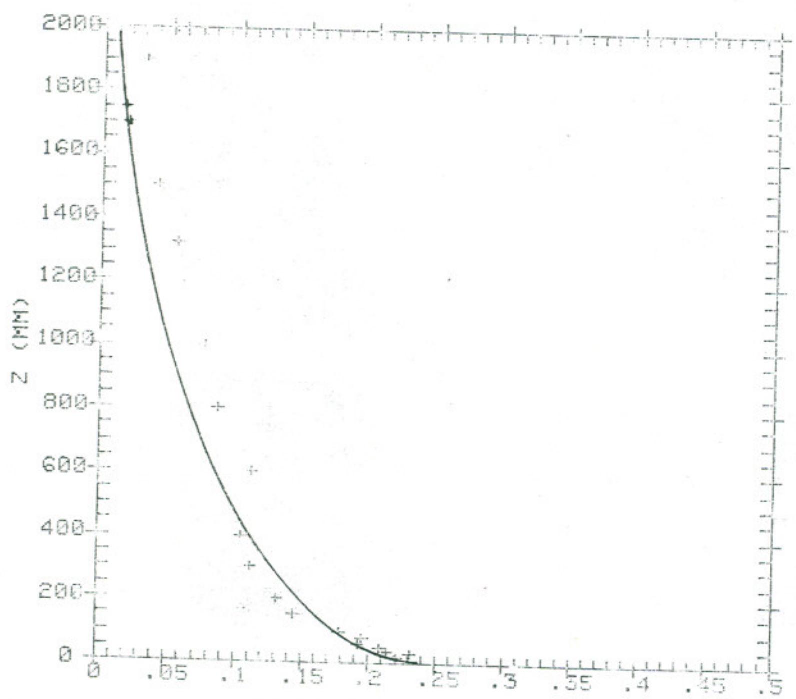


Figure 5. Typical Vortex Generator - Roughness Element Arrangement in APTI Wind Tunnel.



a) Mean Velocity



b) Turbulence Intensity

Figure 6. Mean velocity and turbulence Intensity profiles 4 1/2 generator heights downwind of 183 cm Vortex Generators.

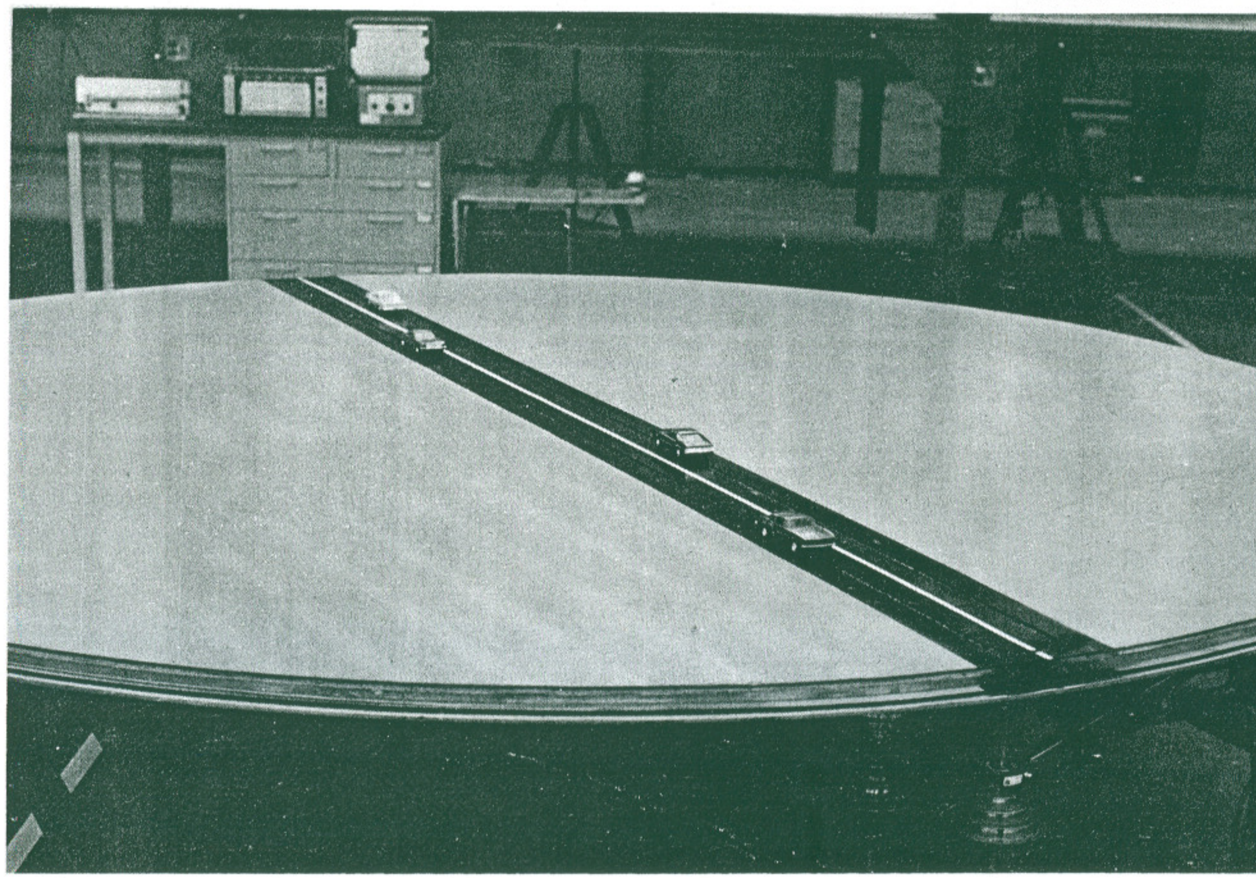


Figure 7. Highway model on removable turntable of Meteorological Wind Tunnel.

model cars, as a tracer gas. Gas samples are drawn and analyzed with the FMF's hydrocarbon analyzer. This study is to be continued.

2.5.6 Reynolds number dependence

In most fluid modeling studies of industrial smokestack emissions it is not possible to obtain exact similarity of the stack Reynolds number. Most modelers agree that exact similarity is not required. The model stack must, however, have a sufficiently large Reynolds number to ensure a turbulent effluent. There has been only a limited amount of research on just what is the minimum Reynolds number above which turbulent stack flows can be considered similar (Hewett et al., 1971).

A fluid modeling study to systematically analyze stack exit characteristics and plume rise of a neutrally buoyant effluent as a function of effluent speed to wind speed ratio and stack Reynold's number began in March 1975. The first phase of the study was nearing completion at the end of FY-75. The EPA Air Pollution Training Institute wind tunnel was used for this study. Smoke visualization and tracer-gas concentration measurements were made to determine the horizontal and vertical plume spread as well as the plume rise. A total of twenty different combinations of stack diameter, stack Reynolds number, and effluent speed to wind speed ratios were examined.

2.5.7 Two-dimensional ridge

Atmospheric flow in the lee of a two-dimensional mountain ridge is highly complex. Ground level pollutant concentrations of emissions from nearby smokestacks are quite dependent upon the stack location and height. Some basic characteristics of the turbulent cavity in the lee of a typical two-dimensional ridge were determined by laboratory analysis in the FMF Meteorological Wind Tunnel. Dispersion from stacks of various heights was also studied. The work was performed in response to a request by the EPA Office of Air Quality Planning and Standards for assistance in evaluating stack locations.

Three different two-dimensional ridge models were constructed: a 30.5 cm high Gaussian shaped ridge, a 15.2 cm high Gaussian shaped ridge, and a 30.5 cm high triangular shaped ridge. Boundary layers were developed in the Meteorological Wind Tunnel with a set of 60 cm high vortex generators and 0.6 cm high roughness slats (Figure 8). Hot-film anemometer measurements were made to determine the velocity and turbulence intensity behind each model ridge. An oil-fog smoke was released into the flow downwind of each ridge to visualize the shape and extent of the zone of recirculation (Figure 9). Longitudinal, lateral, and vertical concentration profiles were obtained for stacks located at the downwind base for each ridge. Stack heights of 0.5, 1.0, and 1.5 times the ridge height were used. The location of the maximum ground-level concentration was found to move downwind as the stack height was increased (Figure 10). A tall stack was found to produce higher concentrations far downwind than a short stack.

A report on this study was in the review stage at the close of FY-75 (Huber et al., 1975).

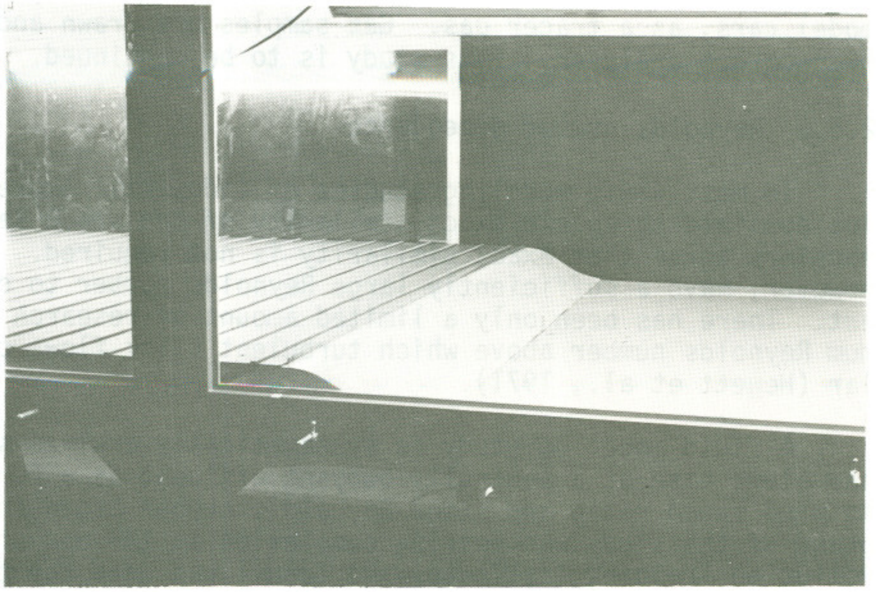


Figure 8. Two-Dimensional Gaussian Ridge installed in Meteorology Wind Tunnel downstream of Vortex Generators and Roughness Elements.

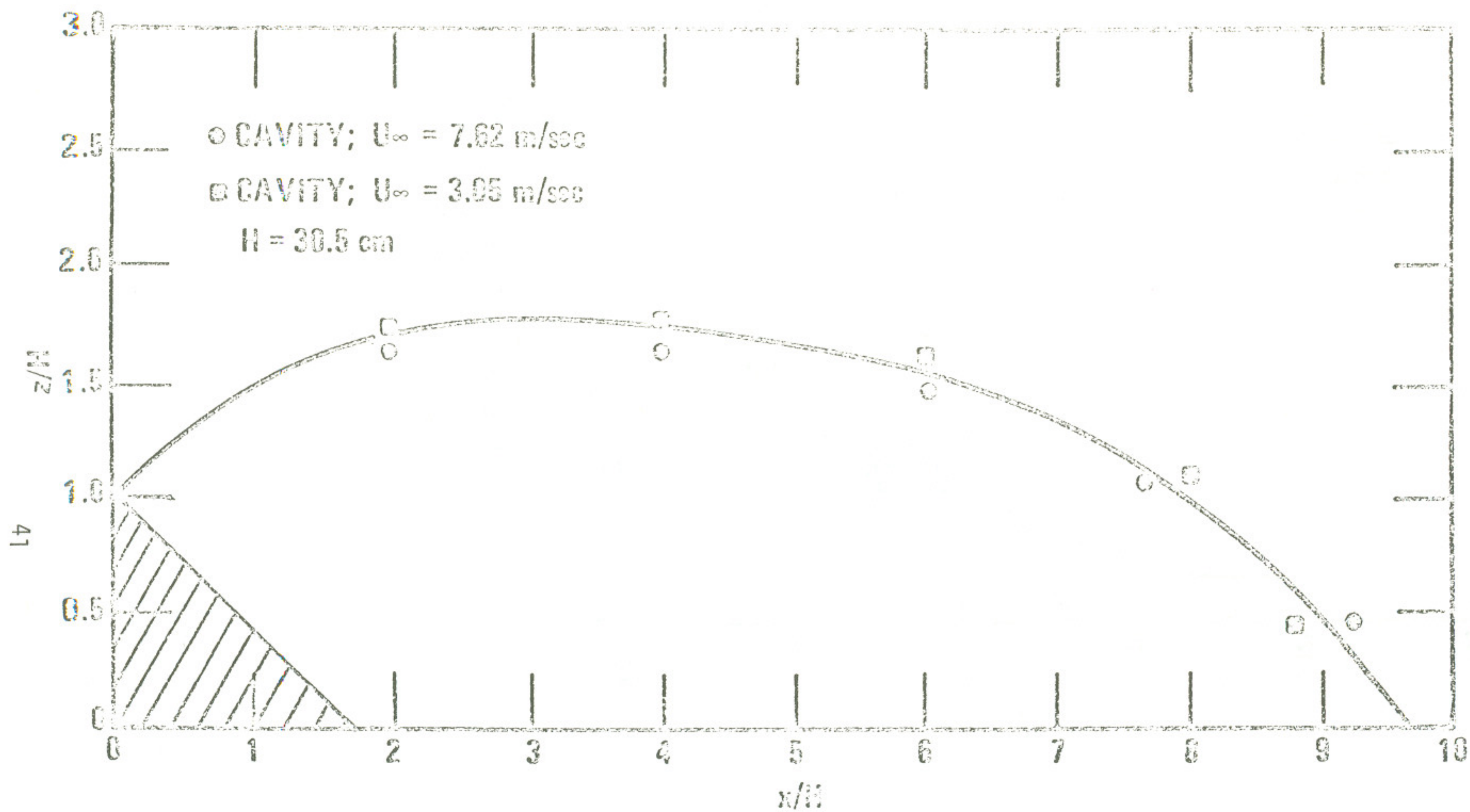


Figure 9. Cavity size in lee of 30.5-cm triangular ridge.

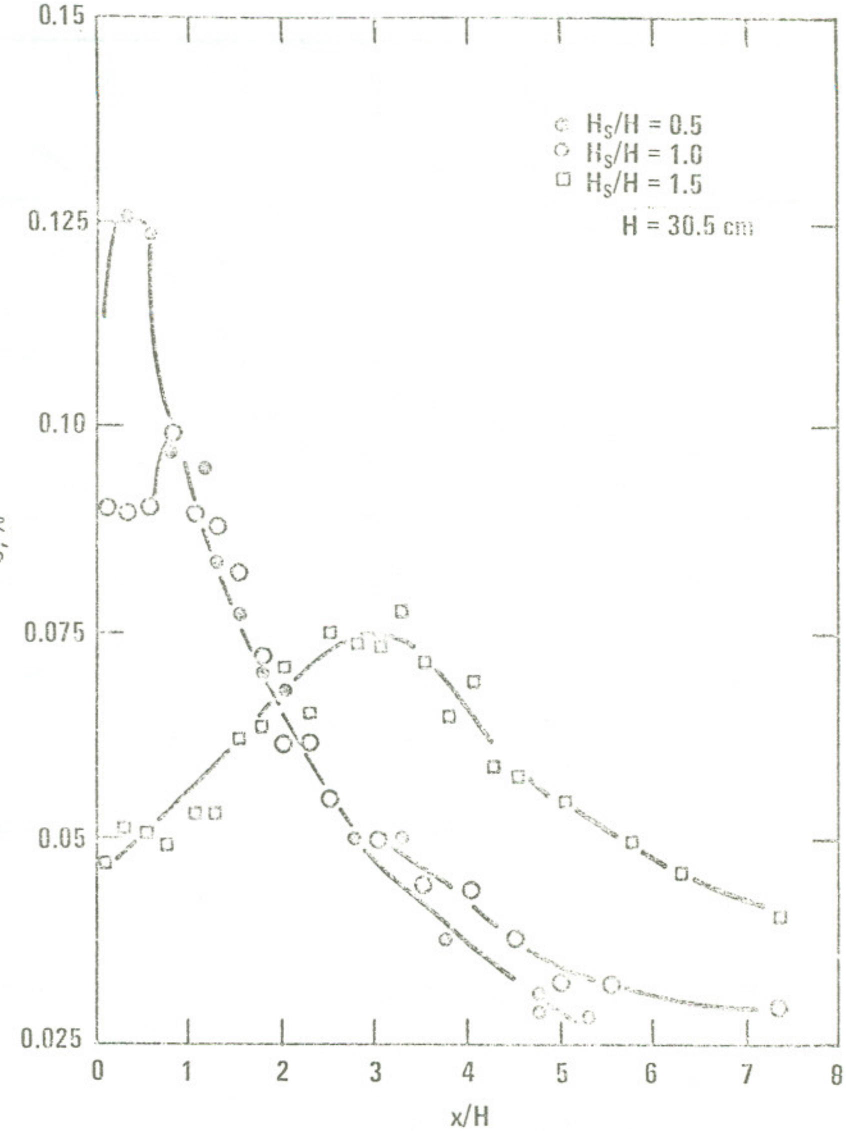


Figure 10. Ground level concentration profiles downwind from stack placed at base (x/H=2.7 from center) of 30.5-cm Gaussian ridge.

2.5.8 Two and one-half times rule

A study was conducted in the Meteorological Wind Tunnel to verify the applicability of the "2 1/2 Times Rule" for location of stacks in the vicinity of buildings. This rule states that a stack must be 2 1/2 times the height of the tallest nearby building in order to avoid serious downwash of the effluent into the building wake. It was shown that the rule is adequate for a building whose width perpendicular to the wind direction is twice its height, but that it is unnecessarily conservative for a tall thin building.

Model stacks and buildings were placed in a simulated atmospheric boundary layer in the wind tunnel. The tall thin building had a height 3 times its width. The wide building was the same height, but its width was twice its height. Smoke was used for flow visualization. A mixture of methane-in-air was emitted from the model stacks as a tracer for quantitative concentration measurements downwind of the building. The effluent buoyancy was negligible and its momentum was just sufficient to avoid downwash in the lee of the stack.

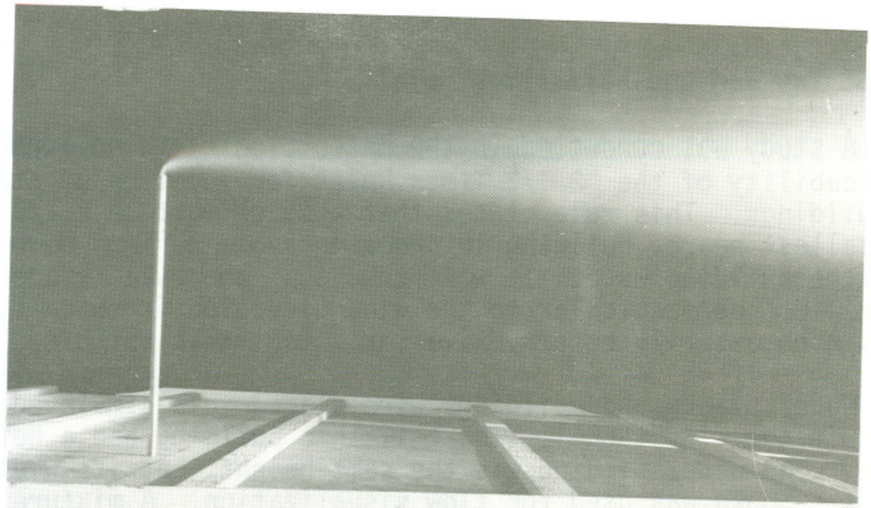
Figure 11 shows typical results of the flow visualization experiments. The stack height is 1 1/2 times the building height in all three photographs. Strong downwash of the plume is shown downwind of the wide building (b), whereas the thin building (c) shows no visible influence on the plume [compare with (a)]. Figure 12 shows similar results more quantitatively. The concentration profiles were measured with a flame ionization detector. The ordinate of the graph is elevation above ground normalized by the building height. The abscissa is the point concentration normalized by the stack concentration. These profiles were measured three building heights downwind.

Application of Brigg's (1973) proposed alternative to the 2 1/2 times rule for the thin building would result in a necessary stack height of 1 1/2 times the building height, which the data show to be adequate. The conclusions may be regarded as having a slight built-in margin of safety in the sense that the majority of plumes in the field would possess some buoyancy and a larger effluent momentum, both of which could add considerably to the effective stack height.

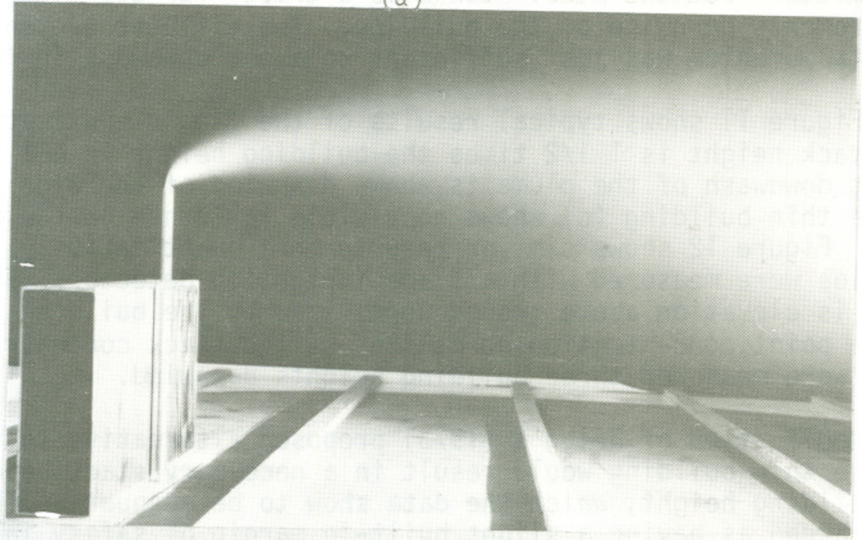
A report on this study has been cleared for publication (Snyder and Lawson, 1975).

2.5.9 Development of a colorimetric technique for concentration measurements in a wind tunnel

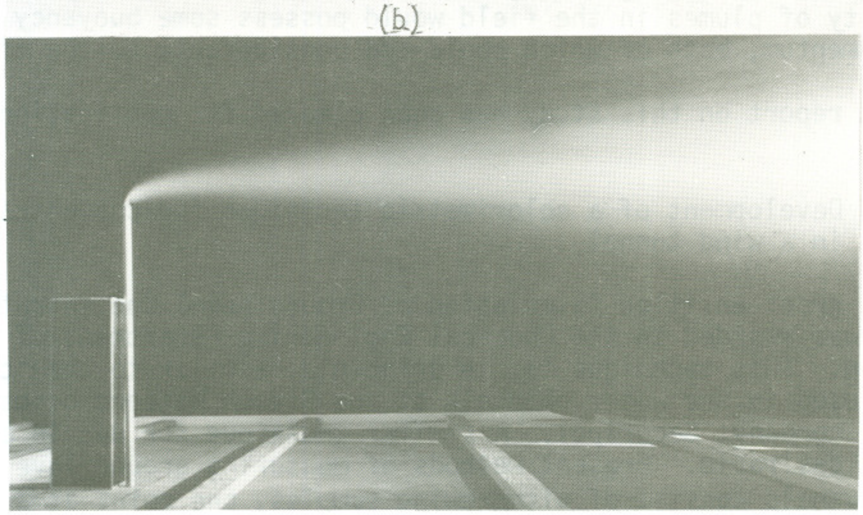
A grant entitled "Simulation of Ground Level Concentrations Using Indicator Film" was awarded to the Chemical Engineering Department of the University of Houston. This technique is, in principle, similar to the "colorimetric" technique used in the water channels of the French Meteorological Service and the French company, Securipol. A similar technique for use in a wind tunnel is highly desirable. Present methods of measuring ground level concentrations in wind tunnels consist of withdrawing samples, one point at a time, for later analysis and mapping, which is cumbersome and time-consuming. The colorimetric technique, if developed to its full potential, would result in a complete



(a)



(b)



(c)

Figure 11. Comparison of effluent behavior in the vicinity of (a) no building, (b) wide building, and (c) thin building.

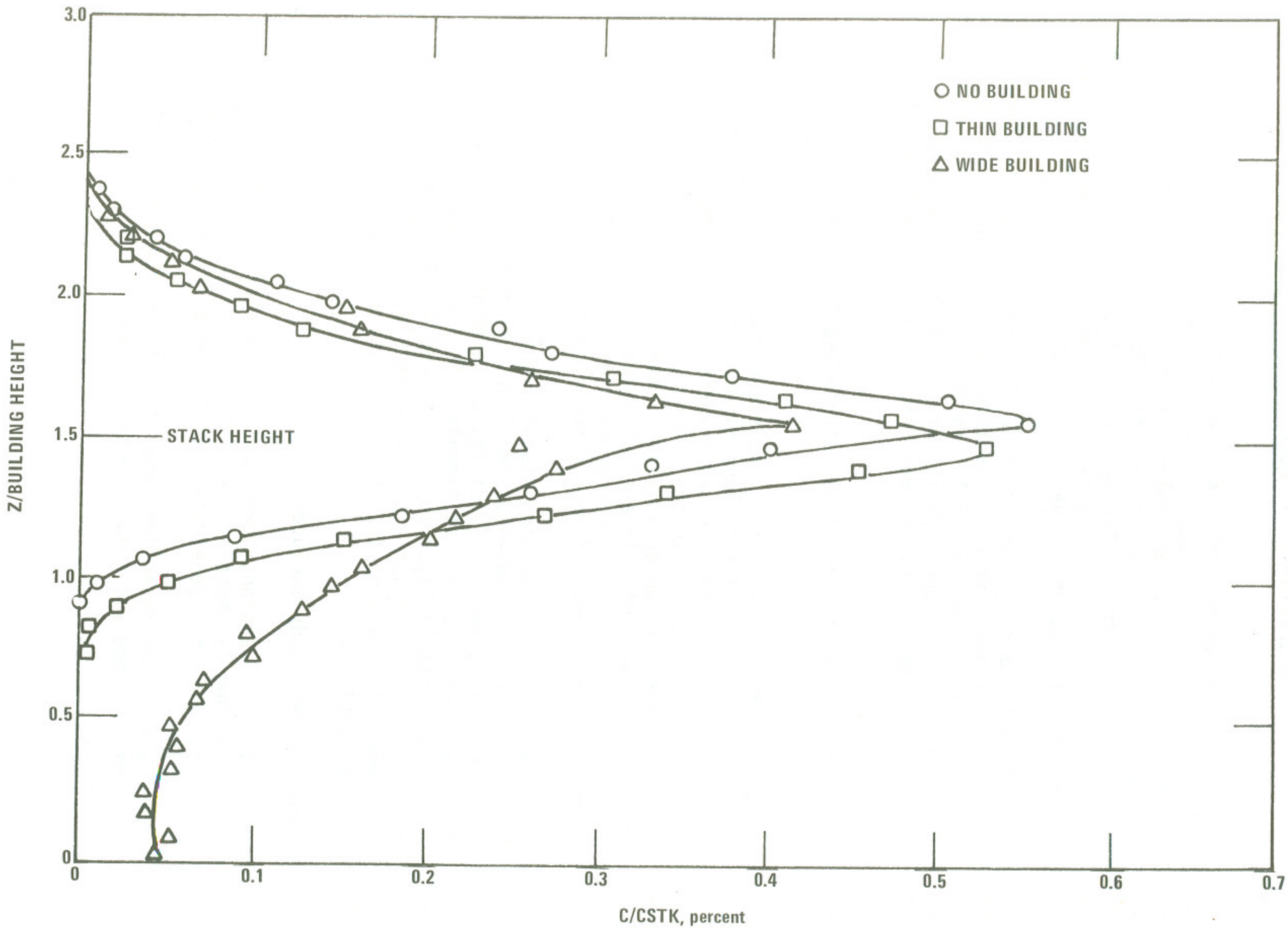


Figure 12. Influence of building on plume behavior. Stack height is 1.5 times the building height. Vertical concentration profiles taken 3 building heights downwind.

mapping of ground level concentration in an hour or so. The advantages of this technique are obvious.

A feasibility study, including preliminary experimental work, was conducted by Dr. Worley of the University of Houston. His preliminary results using ammonia as the tracer gas and an aqueous polymer film containing organic dyes and indicators for sensing the ammonia concentration looked promising. The purpose of the grant is to (1) improve the ease of application and life of the film, (2) explore other combinations of gases/films, and (3) develop quantitative correlations between film color and gas concentration.

Wind tunnel tests using a single source on a flat plate have been conducted. Three different gas/film systems have been examined, which provide three different ranges of concentration. Each gas/film system provides three colors which indicate concentration. Future work is intended to fully develop the technique for immediate application by EPA personnel in the Meteorological Wind Tunnel.

2.5.10 Studies of plume dispersion in stably stratified flow over complex terrain

Flow Research, Inc., Kent, Washington, under contract to EPA, conducted towing tank and numerical studies of the plume dispersion from an elevated source in the vicinity of complex terrain under various conditions of atmospheric stability (Liu et al., 1975). In the towing tank studies, models were inverted and towed through a salt water solution. Various density profiles were created by filling the tank with layered mixtures of salt water. The studies were conducted in much the same manner as previously described (Liu et al., 1974), with additional types of models and stratification.

Three basic types of plume dispersion studies were conducted: (1) elevated inversion over idealized terrain (dual-Gaussian-shaped mountain), (2) ground level inversion over realistic terrain (vicinity of Kennecott Smelter Works, Utah) and (3) inversion breakup over flat terrain. The inversion breakup phenomenon (growth of an unstable layer adjacent to the surface) was simulated by cooling the surface of the salt water with dry ice placed on top of aluminum channels. The temporal growth of the unstable layer was observed through the use of shadowgraph pictures.

Some highlights of the study include:

(1) For the elevated inversion, downslope winds in the lee of the ridge were not as strong as those in the linearly stratified case because the lee waves could not penetrate into the underlying neutral layer.

(2) Also for the elevated inversion case, direct impingement of pollutants on the mountain slope was evident both from visualization and probe measurements.

(3) For the realistic terrain, the plume was observed to conform closely with the underlying terrain features, i.e., the plume center line maintained nearly a constant height above the local terrain surface. Also, the plume path was strongly diverted by terrain features. The initial plume direction deviated 20° from the free stream wind direction.

(4) The capability of simulating the inversion breakup phenomena was clearly demonstrated. Before the unstable layer grew in depth to reach the plume level, the pollutants remained aloft. As soon as the top of the growing unstable layer reached the plume level, pollutants began to be entrained in the unstable layer (fumigation). As the convective motion continued to penetrate the stable layer, it stirred the entrained pollutants within the unstable layer. Finally, a well-mixed layer adjacent to the ground was established.

The numerical study consisted of the development of a numerical model using a small-Froude-number asymptotic expansion to treat strongly stratified flows over complex terrain. Additionally, some towing tank studies were conducted specifically to validate the numerical model.

The model is not a diffusion model, per se. It is a local wind-field prediction model. A tenet of the model is that when a fluid is strongly stably stratified, vertical motions are greatly inhibited, so that fluid elements tend to remain in their horizontal plane. Thus, to lowest order, the flow resembles two-dimensional (horizontal) flow around terrain contours at each level. Standard numerical procedures were used for computing the two-dimensional potential flow (irrotational) past arbitrarily shaped terrain features. Deviations from this two-dimensional theory are determined from higher order terms in a power series.

The model predicted reasonably well vertical displacements of fluid elements as they traveled around simple mountain shapes, but it obviously failed to predict the separated wake. This wake could be crudely modeled by standard techniques used in aerodynamics to compute the flow past two-dimensional bodies, but the three-dimensional nature of the boundary layer would probably have to be accounted for. The present model is simple, easy to program, and runs quickly on a computer, but it would require many modifications and improvements before it could be applied to realistic types of terrain. At the present stage of development, it is difficult to imagine the application of this model to a practically useful problem of diffusion in complex terrain under arbitrarily stably-stratified conditions.

2.5.11 Other studies

Fluid modeling facilities were also employed to conduct other studies. Gaussian modeling of effluents from the main stack of a smelter located at Glover, Missouri indicates that the plume, under stable conditions, might be low enough to cause very high concentrations of SO_2 on and near hilltops 5 to 6 km from the smelter. Higher wind, neutral conditions are also believed to pose a threat to air quality on the hills. As a result of this study, sites for monitoring downwind from the smelter will be recommended so that the air quality impact of the smelter can be better ascertained.

Another such study is of the impact of an idealized ridge on the behavior of effluents emitted from stacks downwind of the ridge. Such factors as (1) the ratio of stack height to ridge height and (2) downwind distance of the stack are considered in determining the area in which the effluent may be downwashed to ground level and the magnitude of resulting pollutant concentrations (Huber et al., 1975). Typical results are presented in Figure 13. This study will be useful in analyses concerned with the siting of sources in complex terrain and in determining the physical characteristics and emission limits of such sources.

2.6 Regional Air Pollution Study

2.6.1 Regional air pollution study (RAPS)

During fiscal year 1975, the facilities in St. Louis were brought into full operation. The major facility is the Regional Air Monitoring System (RAMS), consisting of 25 remote aerometric stations tied into a central computer facility by telephone lines. The central computer controls remote station operation, and polls all stations each minute for data acquisition. 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, and at other stations vertical temperature difference between 5 and 30 meters height, pressure, and direct and diffuse solar radiation as well as long wave total hemispheric radiation are measured. A few sites are equipped to measure three-dimensional turbulence on a demand basis.

Supplementary measurements of particulates are made at ten sites. Every third day, a 24-hour sample of total suspended particulate is obtained, and continuous measurements over either 6- or 12-hour sampling intervals are made of particulate fractionated into two size ranges; the division into small and large particles is an effective aerodynamic particle diameter of about 2 microns. Whole air samples are collected on a rotating schedule and returned to the central facility where they are analyzed for C_1 through C_{10} hydrocarbons.

The one-minute telemetered raw data are accumulated on magnetic tapes for subsequent processing. The processing consists of examining status bits that are telemetered with the raw data to ensure normal operation of the remote sampling and data acquisition systems, and comparisons of successive zero and span checks to ascertain that instrument drift is within acceptable limits. The raw data are then coverted to standard units (ppm, $m\ sec^{-1}$, etc.) and output tapes are then mailed to Research Triangle Park, N.C. so that the data may be entered into the RAPS data bank on the computer facility there.

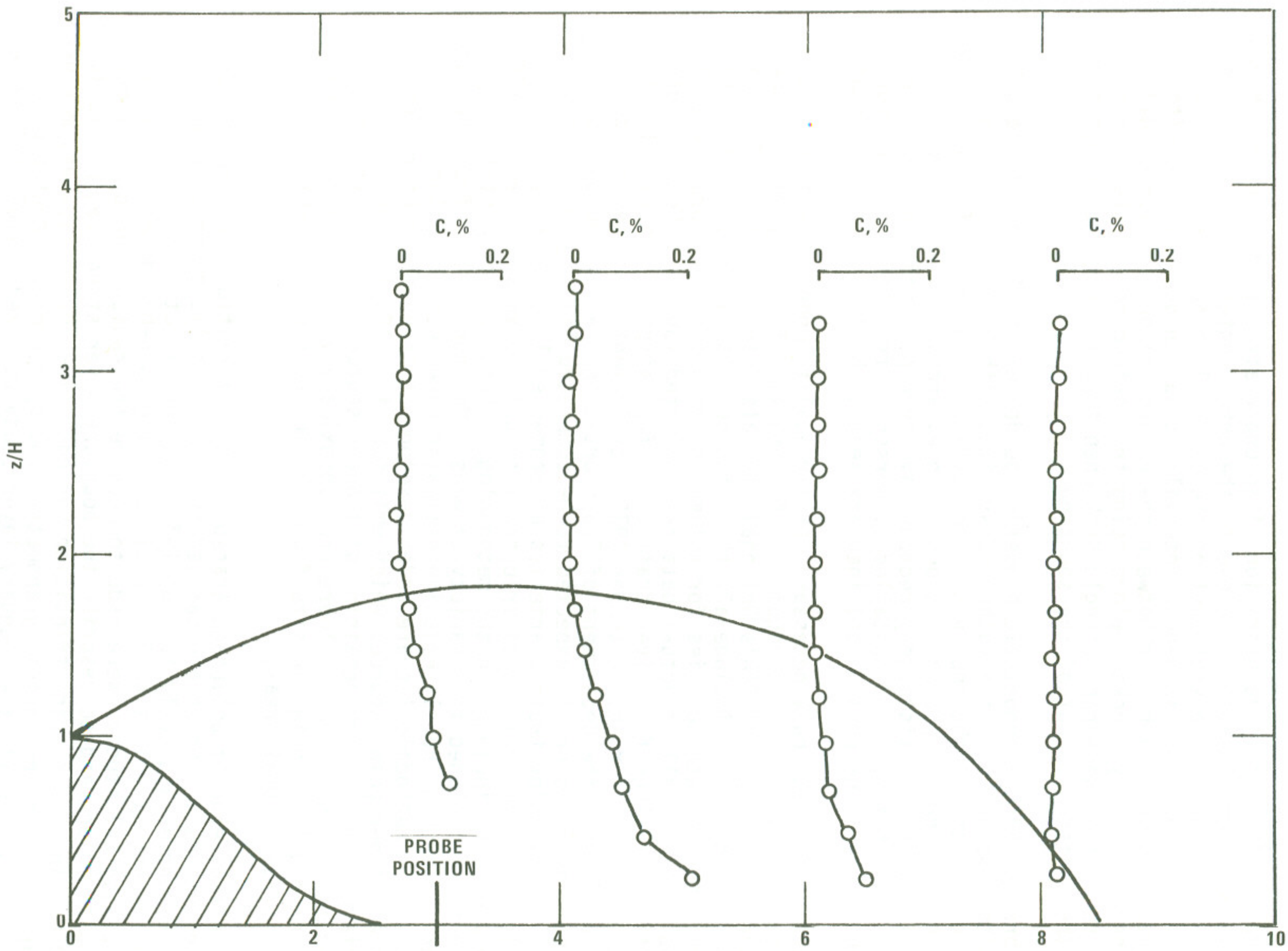


Figure 13. Ground level concentration measurements with sampling probe fixed near base (x/H = 3 from ridge center, z/H = O) of 30.5-cm Gaussian ridge for several vertical heights of stack placed at four downwind locations.

In November 1974, routine operation of an upper air sounding network began at two locations. One location is close to the urban center of St. Louis, and the other is in a rural area southwest of the city. At both locations, rawinsonde observations are made at 6-hour intervals Monday through Friday, with PIBAL observations made each hour between the rawinsonde observations. All observations are quality checked before being transcribed to computer cards. The cards are sent to Research Triangle Park when they are computer processed to obtain the finished output of the soundings.

In February 1975, a monostatic acoustic sounder was installed at the urban sounding site. Because it is a rather noisy site, with a major highway a few hundred meters to the south, the initial installation was unsatisfactory. Subsequently the sounder was placed in a deeper hole, and a more extensive baffle system was installed. Satisfactory records have been produced since late March. The sounder was fabricated and installed by personnel from the ERL Wave Propagation Laboratory. The records obtained are sent to Boulder for interpretation.

As part of the data base necessary for air quality model development, an extensive emission inventory is required. All emission inventory work is performed under the auspices of EPA's National Air Data Branch. Design of a data handling system which will include all the emission data was begun. The system will incorporate the methodologies for estimating emissions by source type, location, and time, as well as actual data from selected sources. Methodologies for estimating emissions from river traffic and from airports are expected to be available in final form by September 1975; development of these methodologies is being done by the Department of Transportation. A methodology for vehicular sources emissions is expected to be completed late in 1975. This methodology treats major traffic arteries as segmented line sources, with remaining emissions from vehicles distributed into gridded area sources. Traffic count data are to be included in the methodology. Emissions from stationary sources are to be included in a variety of ways. Monitoring data from the major SO_2 emitters to provide hourly emission estimates have been collected beginning in October 1974. Methodologies are under development to estimate hourly emissions from all other point sources which emit more than 100 tons per year of any criteria pollutant, with remaining stationary source emission estimates distributed into gridded areas. There are approximately 2000 squares making up the area source grid, ranging in size from 1 km in areas of high emission rates, to 10 km in largely rural areas.

To gain knowledge of pollutant transport, transformation, and removal processes, expeditionary studies are carried out. A major field exercise was performed in the summer and early fall of 1974 with approximately 200 investigators and support personnel utilizing 8 aircraft and 11 ground-based sampling vehicles. Meteorological studies were made to measure the radiant energy flux over the St. Louis region, and to describe the boundary layer structure, particularly during the morning and evening transition periods. The energy flux was measured using upward and downward facing pyranometers and pyrgeometers mounted on a fixed-wind aircraft, while the boundary layer study utilized a small helicopter equipped to measure temperature, dewpoint, SO_2, and light scattering coefficient to obtain vertical profiles of these elements, supported by similarly equipped vans to measure surface values of these same elements. Lidar observations of the aerosol structure were obtained both from surface and aircraft measurements. Additional measurements of the daytime boundary layer structure were accomplished by aircraft traverses across the region.

Measurements were made to assess the uptake of sulfur dioxide by vegetation. A portable tower was used to measure the near-surface profiles of wind speed, temperature, and sulfur dioxide, as well as the turbulent fluctuations of the three components of the wind.

A study of local pollutant variability was also made, using fixed point, moving point, and integrated path measurements of carbon monoxide, ozone, and ammonia. Fixed point measurements were obtained both from RAMS stations and from additional instrument installations; moving point measurements were obtained from portable instruments mounted on back packs; and long path measurements were obtained by measurements of signals transmitted by infrared lasers and reflected by retroflectors located from 0.5 to 1 km away. A tunable diode laser was used for carbon monoxide measurements, whereas a multiband CO_2 laser was used for ozone and ammonia.

Extensive measurements were made both of the pollutant plume from the whole St. Louis area, and of plumes from individual sources. Aircraft measurements of ozone, oxides of nitrogen, carbon monoxide, sulfur dioxide, and light scattering coefficient were obtained. Ground-based measurements of the overlying burdens of sulfur dioxide and, in a few cases, of nitrogen dioxide were obtained with a correlation spectrometer. Extensive aerosol measurements were made. An experimental sampling device was used to obtain short period (a few minutes) samples for particulate sulfate analysis; this device was mounted in an airplane to sample for sulfate within the plumes at various travel times. Continuous samplers which can yield a time resolution of 15-30 minutes were installed at all RAMS sites; these samplers obtain measurements of total suspended particulate. At one RAMS site, a completely equipped trailer was used to measure particle size distributions in the range from 76 Angstroms to 40 microns, with a time resolution of a few minutes.

Supporting measurements were made by personnel from EPA's Las Vegas office, utilizing two large helicopters equipped with pollutant sensors similar to those at the RAMS stations plus temperature and dew point instruments, navigational equipment to provide positioning data, and data acquisition systems to record all parameters. Most flights were spirals over or near RAMS sites to obtain vertical profile data, with a limited number of flights made to support studies made by particular investigators. Radiosonde and PIBAL observations were made on a routine schedule at two sites; one site was near the permanent urban sounding site, and the second was at Scott Field, about 30 km to the southeast. The observation schedule was like that of the (later) routine sounding network, i.e., radiosondes every six hours and PIBAL's at each intermediate hour. In addition, PIBAL observations were made as required from a large number of additional sites in support of the various studies.

In November 1974, the Las Vegas helicopters and crews returned to St. Louis to again make measurements above the RAMS sites. The only other study performed during this month was a reinstallation of the continuous samplers for total suspended particulate to collect samples for about a two-week interval.

In February 1975, a somewhat larger field exercise was carried out. The operation of the upper air sounding network was expanded to four sites with the addition of two sites in Illinois, one about 30 km northeast of the urban sounding site, the other about 30 km southeast. The schedule of observations was expanded to a full seven days per week. The Las Vegas helicopter operations were again carried out, with most flights again being soundings in the vicinity of the RAMS sites. A limited number of flights were made to support the radiant energy flux study and boundary layer studies. The radiant energy flux study again consisted of traverses at various altitudes across the region by a fixed-wind plane equipped with upward- and downward-facing sensors, to measure surface albedo and the radiant flux divergence. The boundary layer studies were first, a repeat of the measurements made with a small helicopter and instrumented vans, with emphasis on the morning and evening transition periods, and second, measurements with the NCAR aircraft to obtain turbulent flux values as a function of elevation and type of underlying surface. Another aircraft was used to make traverses to define the regional boundary layer structure, including the detailed wind field. This field exercise was not as successful as had been hoped because of the weather; conditions were changing very rapidly because of rapid movement of synoptic-scale systems, with frequent periods of precipitation and high winds.

2.6.2 Objective procedures for optimum location of air pollution observation stations

An analysis of the criteria for objective selection, i.e., that does not involve personal or subjective judgment, of the optimum sampling network does not exist at the present time. An "optimum network" is here meant in the sense of a network that is free from redundant observations, namely, data that could be derived with "sufficient accuracy" by some specified interpolation procedures from the given sampling network. Analysis of this problem appeared to be feasible in terms of the modern statistical theory of random scalar fields, and a contract was, therefore, initiated in FY-73 with Dr. C. Eugene Buell of Kaman Sciences Corporation, Colorado Springs, Colorado. At that time it appeared to be particularly important in view of the then forthcoming EPA Regional Air Pollution Study (RAPS) which required the establishment of both a large air quality sampling network and also an extensive meteorological network.

Very early in the research the exceptional subtleties and sophisticated difficulties of the optimization problem became apparent, and an unexpectedly large number of unforeseen statistical, mathematical and computational problems were uncovered. Several different approaches, even involving variations of the logical structure of the problem, were explored by the contractor in a highly innovative fashion. Because of time limitations it was finally decided to specialize the problem and to study in some detail a one-step-at-a-time add-on method of locating sampling stations. For this it is assumed to start with that there are a few existing observation points, or at least a few points at which observations will be made based on prior considerations. On the basis of this starting network of observation points, a procedure is then developed to determine the location where the statistical error of estimate, using a simple linear-type interpolation formula in terms of the observed network concentration values, would be largest. This point would then be accepted as a best location for a new observation point, and the process repeated in an iterative fashion until the required number of station locations had been determined.

Unfortunately, a fully operational and purely objective computerized program was not achieved within the scope of the contract and work was terminated in FY-75. However, a detailed account of the research has been prepared (Buell, 1975). It is hoped that this may become a major contribution towards future resolution of an exceptionally difficult and subtle problem that continues to be of major importance in defining the spatial distribution of air quality.

2.6.3 Objective analysis techniques for the regional air pollution study

Control Data Corporation, Minneapolis, Minnesota, under contract to EPA, began to develop a set of analysis techniques to provide interpolated values of wind and temperature on a fine-scale three-dimensional grid covering the RAPS area. The analysis techniques will utilize all data available from the surface Regional Air Monitoring System (RAMS) and from the PIBAL and radiosonde upper air network to objectively determine three-dimensional wind and temperature fields. A limited contract extension is being considered in FY-76 to incorporate error detection and editing algorithms into the objective analysis program.

2.6.4 RAPS intensive studies data reduction and analysis

The Meteorology Laboratory began an extensive program to reduce and analyze data collected during intensive field study periods of the RAPS program for the purpose of better characterizing various meteorological parameters in urban and rural atmospheres. The measurements, which include wind, temperature, moisture, gaseous pollutants, and aerosol backscatter, were made both at the surface and in the vertical using helicopters, mobile vans and a lidar system. The intensive study periods, which occur at various times of the year, supplement the surface RAM's (Regional Air Monitoring Stations) network and the PIBAL and radiosonde upper air network to provide the needed detailed information to further develop the meteorological portions of the air quality simulation models.

2.6.5 Observing systems for urban and regional environments

A biostatic acoustic probing system for studying temperature inversion within the planetary boundary layer (PBL) has been constructed and used to transmit sound to receivers located at distances ranging from a few to more than 10 km. The system consists, basically, of a 200 Hz acoustic transmitter, with four 60 watt amplifiers and four separate speaker enclosures, a fixed receiver station at the University Park Airport (where a micro-barograph was also located), and a second truck-mounted mobile acoustic receiver, which roved from location to location.

The system is being used in two types of studies. The first is to evaluate a scheme (Greenfield et al., 1974) for estimating temperature gradients in PBL inversions. The second study consists of an examination of the statistical properties of the fluctuations in the received acoustic signal level.

The success of the first type of study depends upon the ability of the system to resolve the "caustic", which is the minimum distance at which sound rays will return (distances less than the minimum are referred to as "the zone of silence").

Data collected during field studies on two days, July 7 and August 21, suggest that edge of the cone of silence has been observed. Additional observations are planned for the fall season, when it will be possible to much better establish the existence and the height of the inversion layer.

During the course of the experimentation with the long baseline acoustic sounder, apparently periodic fluctuations in the signal amplitude have been regularly observed. The fluctuations appear to have periods on the order of minutes, and over extended periods a sinusoidal pattern with periods varying from 15 to 30 minutes is also frequently evident. Most of these data were collected on mornings when there were clear skies overnight and winds were calm (conditions commonly associated with high pressure systems). In order to confirm a hypothesis that the fluctuations might be associated with gravity waves a microbarograph was constructed and operated. However, two sets of observations made on July 13 and August 1 failed to show obvious correlation.

3.0 AIR QUALITY AND METEOROLOGY

The Meteorology Laboratory conducted a number of studies of the relationship between air quality and meteorological parameters. The understanding of these relationships are of major concern to the Meteorology Laboratory. In the area of the effects of atmospheric pollutants on meteorological parameters, the greatest emphasis was on the examination of the effects on the atmospheric radiation field. Preparation and analysis of climatological information continued for use with air quality simulation models and as guidance for the assessment of air pollution problems.

3.1 Climatic and Air Quality Analysis

3.1.1 Empirical techniques for analyzing air quality and meteorological data

During FY-74 the potential application in air quality modeling, of so-called repro-modeling techniques, was demonstrated in a small contract with Technology Service Corporation of Santa Monica, California. "Repromodeling" is the replication of the input-output characteristics of a complex simulation model through the use of innovative multivariate regression techniques, and has the potential for great saving of computer time in the routine application of complex models. The necessary computerized regression techniques have been developed by Dr. W. S. Meisel et al. During FY-75 a larger contract effort was initiated to explore in greater depth the potential of empirical techniques for air quality and meteorological data analyses utilizing the specialized regression techniques developed at T.S.C. The work is being reported in a three volume final report under:

(a) The Role of Empirical Methods in Air Quality and Meteorological Analyses.

(b) A Feasibility Study of a Source-Oriented Empirical Air Quality Simulation Model.

(c) Short-Term Changes in Ground-Level Ozone Concentrations - An Empirical Analysis.

Part (a) will consider a variety of potential applications of the regression techniques developed to the analysis of problems of concern to the EPA. Part (b) and (c) will provide more detailed analysis of two specific problems which demonstrate the feasibility of developing a completely new approach to source-oriented air quality modeling. This is based on the empirical determination, by regression techniques, of critical "kernel" functions that occur in air quality modeling, both for inert and photochemical pollutants. In both cases the final aim is to develop a source-oriented model that would allow analysis of control strategies in terms of the emission of primary pollutants.

3.1.2 Analysis of CO and meteorological data

The historical air quality data being collected by State and local air pollution control agencies are an excellent resource for determining the effects of variations in meteorology on the observed air quality. An examination of a listing of the EPA data bank showed that the State of Maryland had an extensive network which provided hourly carbon monoxide (CO) data that were suitable for analysis. A quality control check of data for 1973 showed that data from 12 stations (five in the Baltimore area, five in the Washington area and two in the northwest part of the State) were collected in accord with federal standards and in sufficient quantity to be analyzed. The data were analyzed and compared to traffic count and meteorological data for the area. A report, "Diurnal Variations in Carbon Monoxide Concentrations, Traffic Counts and Meteorology" has been completed and is being considered for publication. The main conclusions were:

(1) The diurnal variations in CO concentrations, as seen in Figure 14 show a better month-to-month resemblance at individual stations than a station-to-station similarity in individual months. No one station is representative of a large area. (An analysis of 1973 CO data for 18 stations in New Jersey supports this finding.)

(2) The diurnal variations of concentrations, while partly correlated with traffic, cannot be predicted on the basis of traffic alone. The comparable concentrations in the middle of the day and the early morning,

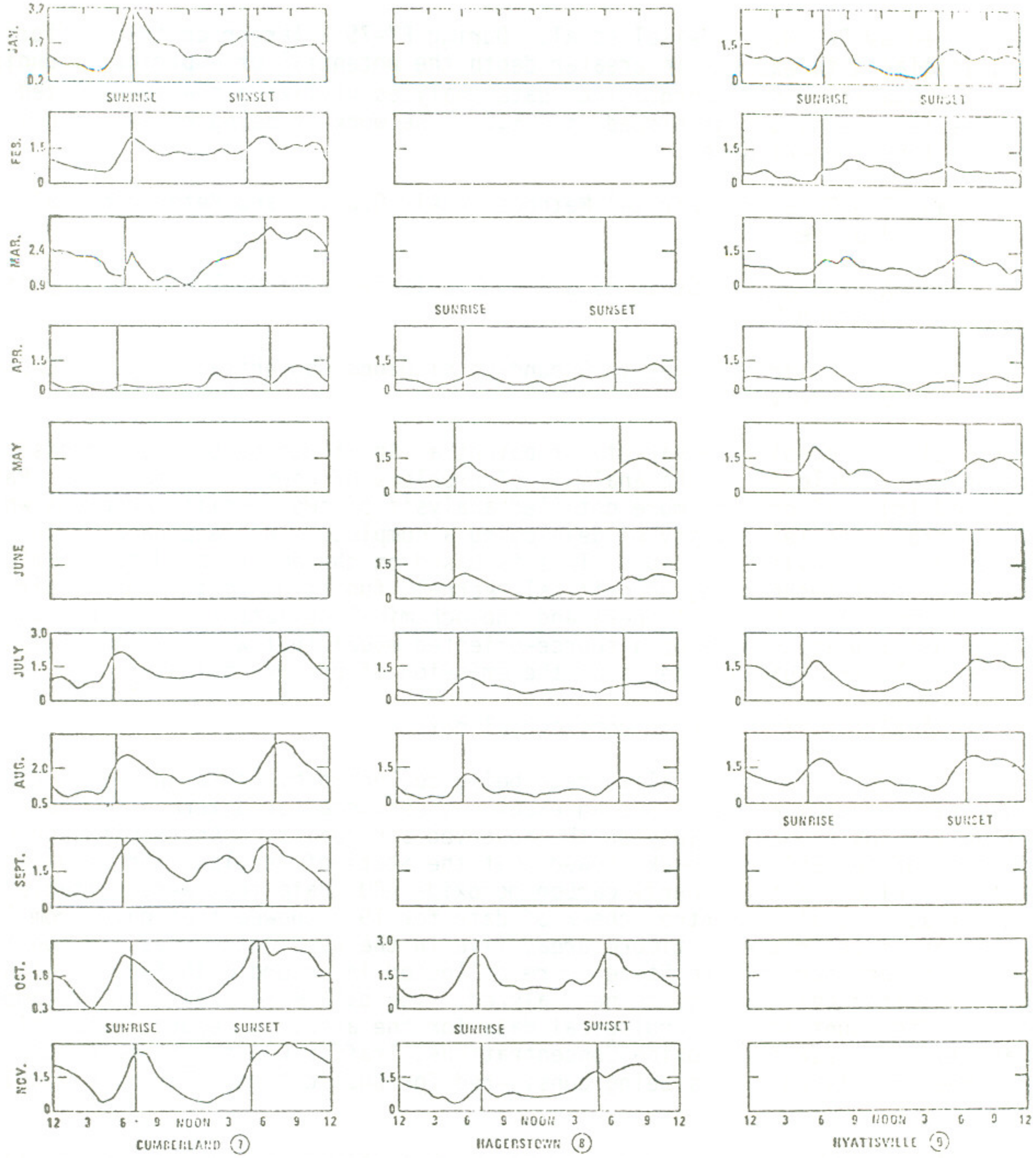


Figure 14. Diurnal variation of CO concentrations by month, Maryland stations, 1973.

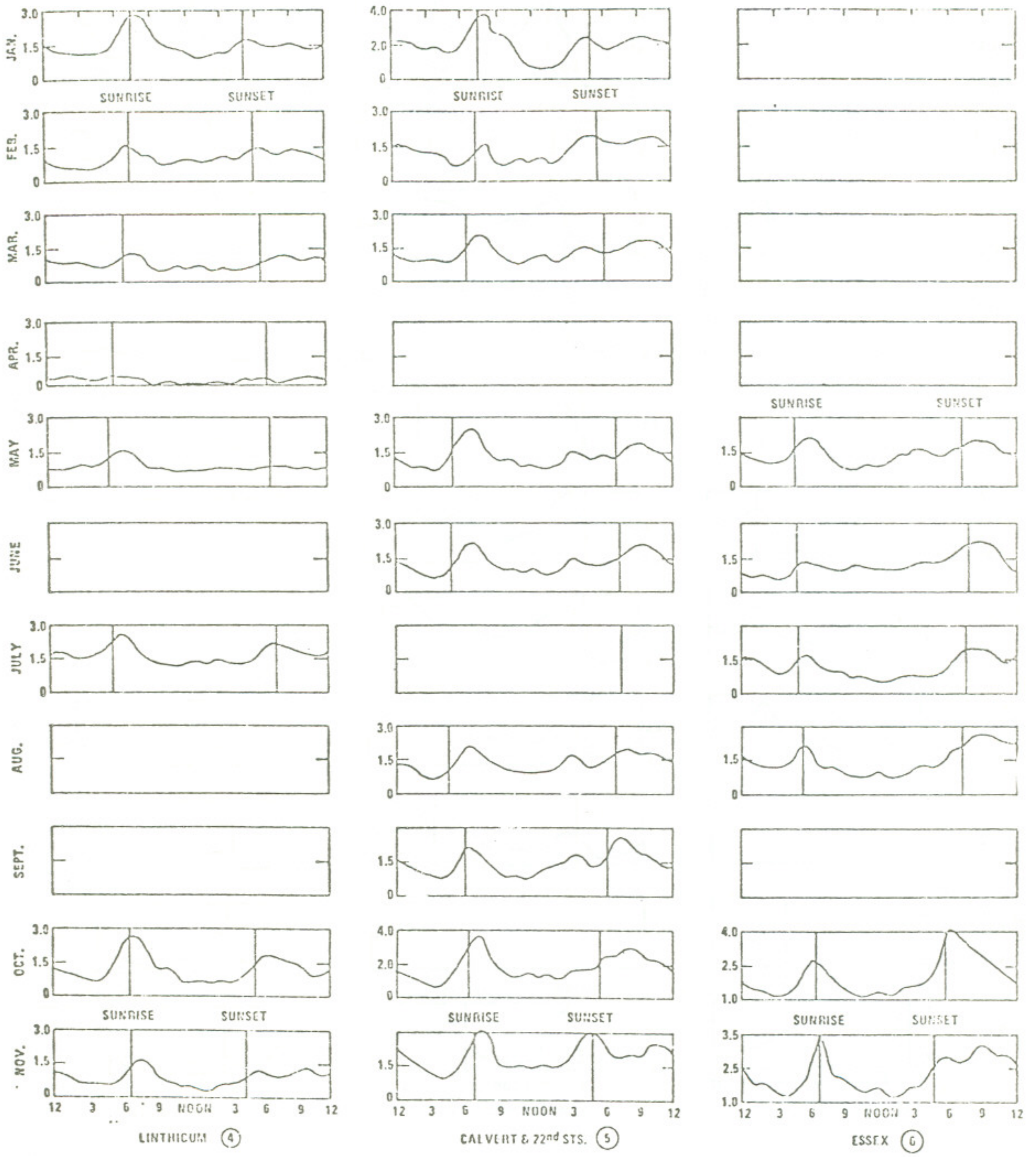


Figure 14. Continued.

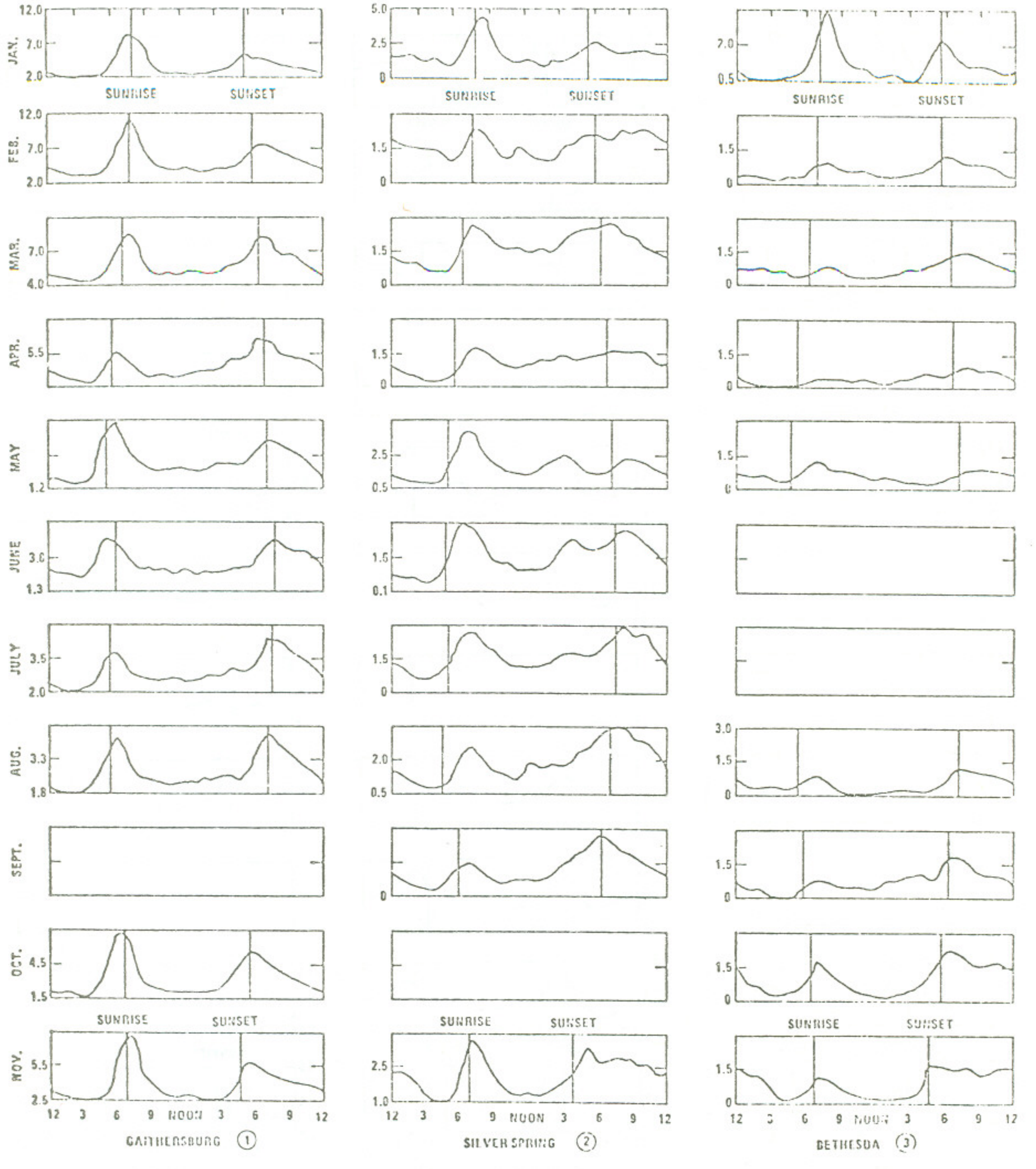


Figure 14. Continued.

when there is an order of magnitude difference in traffic flow, supports this contention.

(3) A combination of diurnal variations of traffic flow, wind speeds and mixing heights, as seen in Figure 15, correlate with the diurnal variations of concentrations, on a monthly basis.

In order to determine whether the correlation noted above can be observed with periods as short as a few hours several state and local agencies in Maryland are cooperating in quality controlling and providing CO, meteorological and traffic data.

3.1.3 Mixing heights

A report, "Nocturnal Heat Island Intensities and Relevance to Forecasts of Mixing Heights," was published (DeMarrais, 1975). The conclusions were:

(1) Nocturnal urban-rural minimum temperature differences a) vary over a wide range, b) show large day-to-day changes, and c) frequently show seasonal variations.

(2) The assumption that a constant value of urban-rural temperature differences can be used to determine daily morning mixing heights is questionable.

(3) The technique of Summers (1965) for calculating heat island intensities appears to be a possible substitute for the constant value technique because it calculates a range of values that are similar to those which are observed.

3.1.4 Global climatology

Acting as a Rapporteur for the World Meteorological Organization's Commission for Special Applications of Meteorology and Climatology, a report was prepared on the Climatological Aspects of the Composition and Pollution of the Atmosphere. This report offers some practical guidelines on the processing and use of regular surface and upper air observations as well as some special measurements in terms of their climatological influence on transport and diffusion of air pollutants. The concept of a meteorological potential for air pollution is discussed. An attempt was made to include examples of pertinent climatological data for various parts of the world but in fact the data are limited to temperate and northern latitudes of the Northern Hemisphere. There is a paucity of available meteorological studies relative to air pollution in the tropics, which, unfortunately, is where industrialization, energy consumption, and pollutant emissions are expected to increase rapidly. In addition to transport and diffusion, some attention was also devoted to climatological influences on the transformation of pollutants while they are airborne, especially the photochemical formation of oxidant. A brief summary of pertinent publications

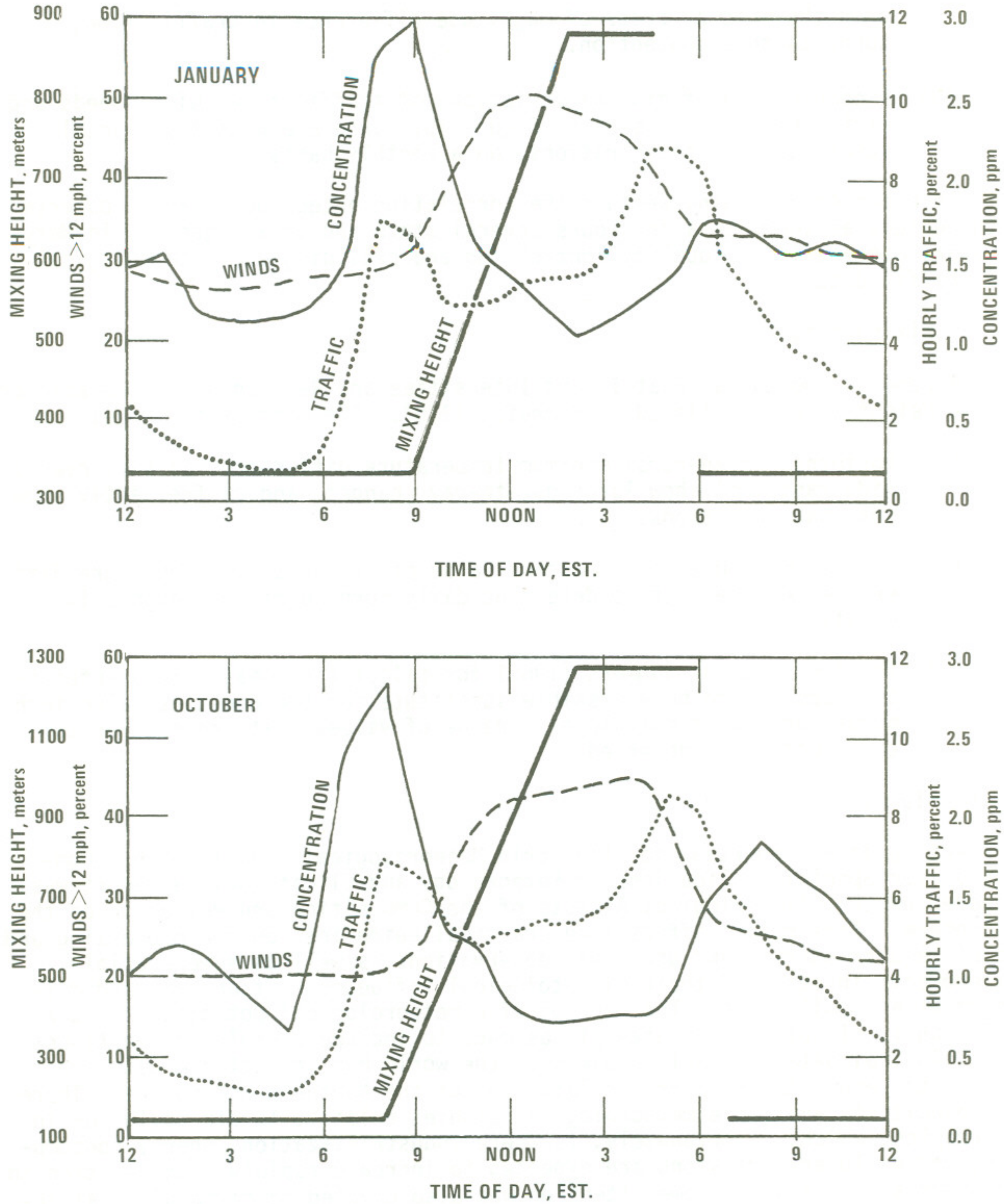


Figure 15. Diurnal variations of mixing heights, frequency of wind speeds greater than 12 mph, traffic flow and CO concentrations (hourly data plotted at hour ending time - eastern standard).

of the WMO was given.

Meteorological variables that are discussed include wind speed and direction, static stability, mixing heights, diffusion parameters, fog, precipitation, and atmospheric stagnation. Various definitions and applications of stagnation were described for different parts of the world. A brief description was given of considerations to be made in processing and summarizing measurements of air quality. The report includes almost 100 references, 17 figures, and 12 tables. Publication in the WMO's technical note series is expected during calendar year 1975.

3.1.5 Climatology of effective plume heights

The anticipated proliferation of large, coal-fired power plants throughout the United States increases the need for information on plume behavior. An important aspect of this matter is the "effective" plume height due to "plume rise" above the chimney top; e.g., because very generally ground-level concentrations vary inversely as the square of the effective plume height above ground-level. Since plume rise is highly dependent upon wind and thermal stability characteristics of the air through which the plume rises, it is important to consider such variables. Accordingly, the routine, twice daily rawinsonde observations of the National Weather Service are being used in the equations of Briggs (1970), which are in concert with his earlier extensive treatment of plume rise (Briggs, 1969), to develop a climatology of effective plume heights. Although these calculations are most appropriate to the times of the rawinsonde balloon release (about 1115 and 2315 GMT in the U.S.), interpretations are possible for other times. To enhance such interpretations the rawinsonde observations are being processed for the same stations and period of record (mostly 1960-1964) as used in the study of mixing heights and mixing layer wind speeds (Holzworth, 1972) and in the summarization of rawinsonde characteristics (Holzworth, 1974f).

In addition to wind and temperature structure, the effective plume height is also dependent on the actual chimney height (H) and the heat emission rate (Q_H) from the chimney. Values for H and Q_H are specified arbitrarily. An initial summary for this study is shown in Table 8 for H=50 m and $Q_H=10^6$ calories/sec. At New York City, annually, at about 0615 EST the effective plume height was in the range 101-250 m (all elevations are with respect to ground-level) in 87.0 percent (far right column) of the observations. Overall, the effective plume height (H_E) was within, below, and above an inversion in 31.9, 51.1, and 2.3 percent (next to last row), respectively, of the observations; there was no inversion below 3000 m in 14.6 percent of the observations. In almost all of the "within inversion" cases the calculated afternoon mixing height (H_A) was greater than the 0615 EST effective plume height (column heading $H_A/H_E \geq 1$), suggesting the fumigation type of plume during some intervening period. In fact the afternoon mixing height was usually greater than the 0615 EST effective plume height regardless of temperature profile conditions. The last row of the table gives the average effective plume height for various temperature profiles. For comparison to Table 8, Table 9 is based on the same rawinsonde observations but with H=100 m and $Q_H=10^7$ calories/sec. For the larger chimney the effective

Table 8. Percent Frequency of Effective Plume Heights (H_E) Above Ground-Level By Temperature Profile Characteristics and in Comparison to Afternoon Mixing Heights (H_A); New York, NY; Annual 1960-1964; 0615 EST Rawinsonde Release; Chimney Height = 50 m; Heat Emission = 10^6 Calories/sec.

		WITHIN INVERSION			BELOW INVERSION			ABOVE INVERSION			NO INVERSION			
H_E(m)	H_A/H_E:	≥ 1	<1	TOT	≥ 1	<1	TOT	≥ 1	<1	TOT	≥ 1	<1	TOT	TOTAL
50-100		8.0	0.7	8.8	*		*	0.2		0.2				9.0
101-250		21.3	0.5	21.8	48.7	0.5	49.2	2.1		2.1	13.6	0.2	13.8	87.0
251-500		0.9		0.9	1.7		1.7				0.6		0.6	3.2
501-750		0.2		0.2	0.1		0.1				0.1		0.1	0.5
751-1000		0.1		0.1	*		*				*		*	0.2
1001-1500		*		*										*
1501-2000														
2001-3000														
3001-4000														
4001-5000														
>5000														
TOTAL:		30.7	1.2	31.9	50.6	0.5	51.1	2.3		2.3	14.4	0.2	14.6	100.0
AVG (m):				126			153			134			157	145

*Indicates more than zero but less than 0.05.

Table 9. Percent Frequency of Effective Plume Heights (H_E) Above Ground-Level By Temperature Profile Characteristics and in Comparison to Afternoon Mixing Heights (H_A); New York, NY; Annual 1960-1964; 0615 EST Rawinsonde Balloon Release; Chimney Height = 100 m, Heat Emission Rate = 10^7 Calories/sec.

		WITHIN INVERSION			BELOW INVERSION			ABOVE INVERSION			NO INVERSION			
H_E(m)	H_A/H_E:	≥1	<1	TOT	≥1	<1	TOT	≥1	<1	TOT	≥1	<1	TOT	TOTAL
100-150														
151-250		22.3	2.6	24.8	10.1	0.6	10.6	2.1	0.2	2.3	4.1	0.2	4.4	42.1
251-500		5.9	0.3	6.3	32.2	0.5	32.7	6.9	0.4	7.3	9.8	0.2	10.0	56.3
501-750		0.2		0.2	0.7		0.7	0.1		0.1	0.2		0.2	1.3
751-1000		0.1		0.1	*		*				*		*	0.2
1001-1500														*
1501-2000														
2001-3000														
3001-4000														
4001-5000														
>5000														
TOTAL:		28.6	2.9	31.5	43.1	1.0	44.1	9.2	0.6	9.8	14.2	0.5	14.6	100.0
AVG (m):				236			291			289			288	273

*Indicates more than zero but less than 0.05.

plume heights are much greater; there are 7.0 percent fewer cases of the effective plume height below the inversion layer, and 7.5 percent more cases of the effective plume height above the inversion top.

Summarizations similar to Tables 8 and 9 for other rawinsonde stations and additional prescribed input variables are being prepared by the National Climatic Center. These data will provide the basis for a climatological study of effective plume height for the United States.

3.1.6 Air quality and meteorological trends

The impact of meteorological conditions on analyses of air quality trends is significant. This is especially important in analyses of changes in air quality associated with the 1973-74 energy crisis and in analyses of long-range air quality trends for the purpose of attaining and maintaining air quality standards.

Because of the shortage of low sulfur fuel oils during the 1973-74 winter, EPA granted New York and New Jersey selected variances from their State Implementation Plans. Figure 16 shows the changes in average concentrations of SO_2 which occurred between the two winters, 1972-73 and 1973-74 (Environmental Protection Agency, 1974). The large concentration increases in parts of New Jersey and Staten Island are attributable to the existence of a sizeable number of local and frequently upwind point sources. The smaller sector in New York containing large decreases in SO_2 is attributed to residential fuel saving during the energy crisis.

Meteorological conditions during this period have been examined in addition to air quality and emissions data because, over a single season meteorological anomalies can have a pronounced effect on air quality levels. It was found that wind speed and temperature are the two variables that probably affect the SO_2 levels. Adjustment for meteorological differences between the two years is based on a determination of the variation of SO_2 concentration relative to both wind speed and temperature during the two years. The average winter concentrations during the 1973-74 winter are adjusted to account for the meteorological differences. Generally, the 1973-74 winter season was milder and had lower observed wind speed than the previous winter. It has been concluded that the 1973-74 winter season may have been more conducive to higher overall SO_2 concentration due to existing meteorological conditions, but an increase in SO_2 concentrations could be clearly discerned even after accounting for meteorological variations. This analysis clearly implicates fuel quality and use as major factors in observed changes in SO_2 levels.

Another analysis of meteorological and air quality trends considered the impact of the 1973-74 energy shortage on ambient air quality for Metropolitan Boston. One objective of this study is to obtain a clearer understanding of the impact and potential impact of the energy shortage on air quality levels throughout the region by isolating the relative effects of factors such as meteorology, population/industrial growth, energy conservation measures and source variances on ambient SO_2 and TSP concentrations. The dispersion modeling analysis indicates that the energy shortage is responsible for average

Figure 16. Percent change in average concentration: winter season 1973-74 compared with winter season 1972-73.

+20

concentration levels lower than those projected to occur if historical fuel use trends had continued during the winter of 1973-74. This is a consequence of the impact of conservation measures being greater than the opposing effects from growth and the implementation of variances. The modeling further indicates that if variances had been fully implemented, SO_2 levels would have deteriorated significantly across the AQCR in spite of conservation effects (see Figures 17 and 18). Variations in meteorological conditions are found to have little overall impact on variations in pollutant concentrations. TSP concentrations in the AQCR are largely unaffected by the energy shortage itself.

A broad-scale study concerned with the relationship between meteorological and air quality trends is in progress. The purpose of this effort is to evaluate meteorological trends on a time-scale comparable with air quality trends. In addition, the potential for routinely filtering out the effects of meteorological variations from observed air quality trends is being examined. The meteorological data have been selected from NOAA Weather Service Stations most representative of the Standard Metropolitan Statistical Areas under study. Quarterly and annual averages have been computed for both sets of data for the period 1970 through 1974. The following parameters are included in the study: wind speed, temperature, rainfall amount, raindays (.01 inch or more), total suspended particulates, and sulfur dioxide. Seasonal variations and period trends of the six parameters will be compared both graphically and through 2-variable statistical correlation computations. The results of the study will be discussed qualitatively in the 1974 air quality trends report.

3.1.7 Air quality statistical analyses

A Symposium on Statistical Aspects of Air Quality Data, supported by the Meteorology Laboratory and cosponsored with the Triangle Universities Consortium on Air Pollution, was conducted in November 1972. Fifteen papers were presented by foreign and domestic statisticians, meteorologists, chemists, and engineers. The Consortium provided a 266 page, edited, camera-ready copy of the proceedings this year. This document was reproduced (Kornreich, 1974) and distributed by the Meteorology Laboratory.

Richard I. Pollack of the Lawrence Livermore Laboratory attended the above symposium. He drew on these 15 papers and other data in his analysis of air pollutant concentration data and the frequency distributions used to describe such data. His resulting doctoral dissertation identifies the nature of the frequency distributions for both reactive and inert pollutants, for both point and area sources, and to some extent for different types of atmospheric conditions, using a substantially non-empirical approach. Because of the valuable information presented in his dissertation, Dr. Pollack and the Lawrence Livermore Laboratory gave their kind permission to the Meteorology Laboratory to publish it (Pollack, 1975) for wider distribution.

Air pollutant concentrations can be predicted on the basis of mathematical models of physical and chemical processes or on the basis of past analyses of concentration as a function of meteorologic variables such as wind speed, wind

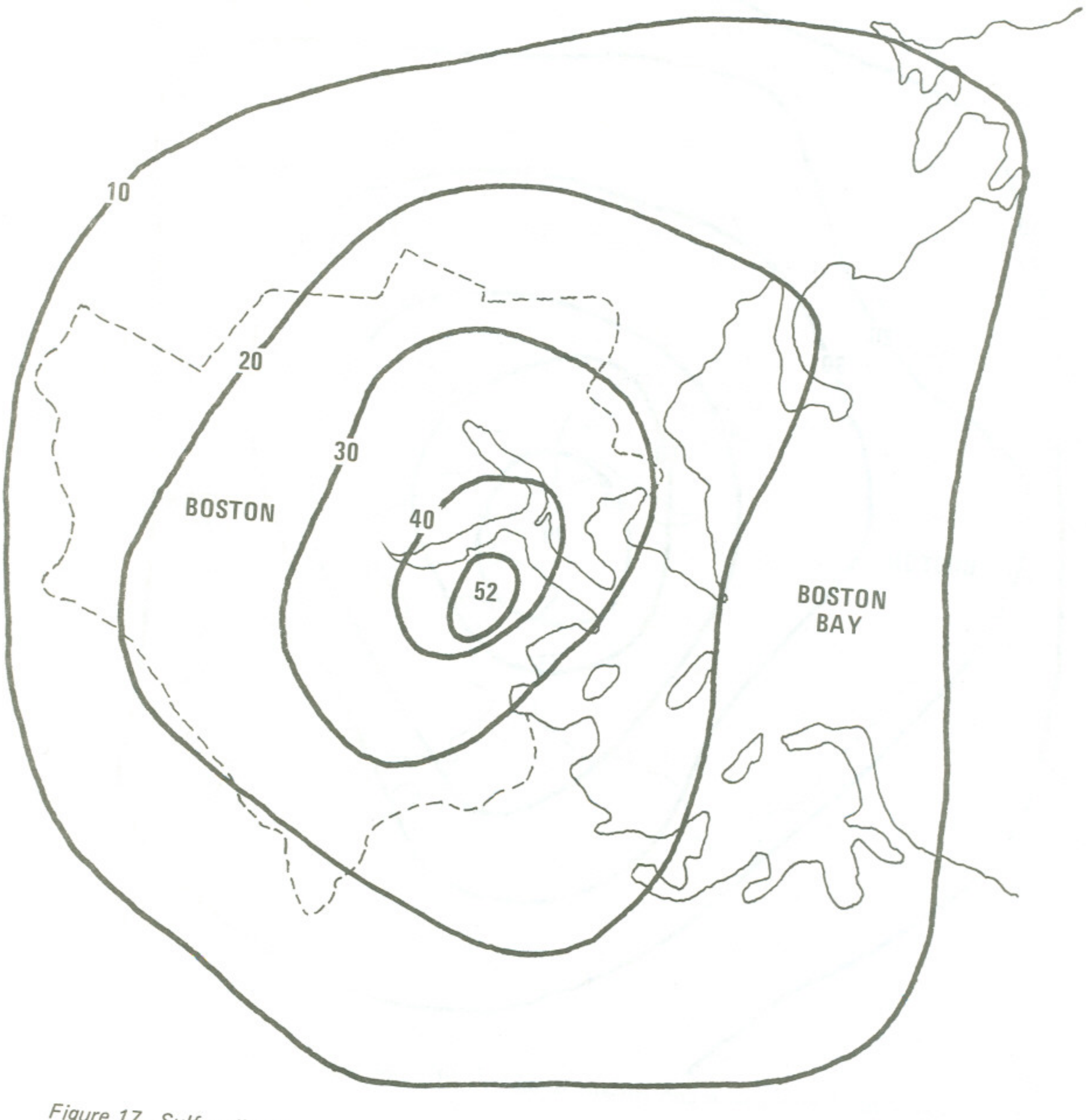


Figure 17. Sulfur dioxide concentrations (μg/m3) 1973 first quarter - simulation 1.

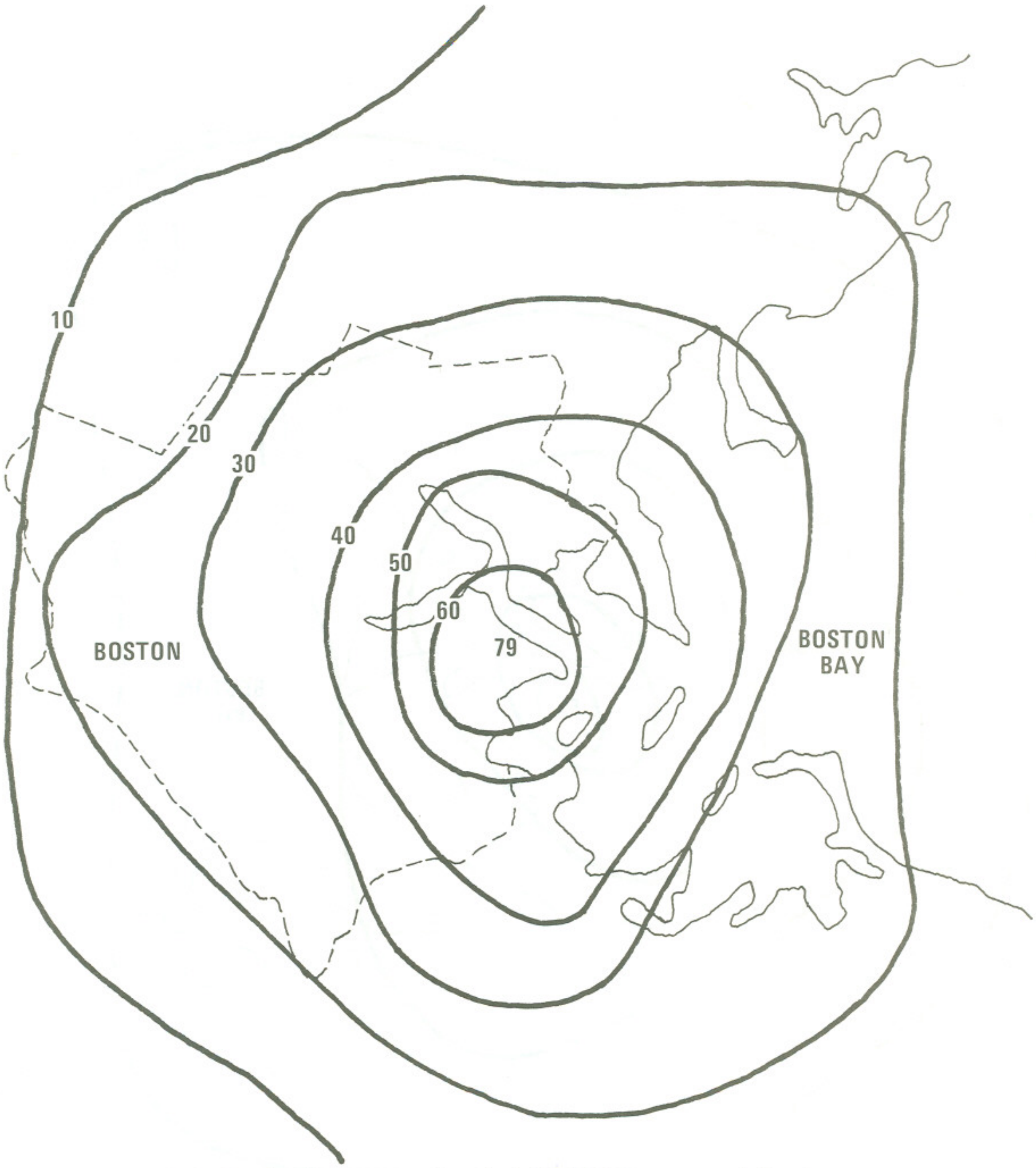


Figure 18. Sulfur dioxide concentrations ($\mu g/m^3$) 1974 first quarter full variance.

direction, sunlight intensity, etc. This latter type of analysis is currently being used to analyze oxidant concentrations in Riverside, California, as a function of wind direction and other meteorologic variables.

3.1.8 Fairbanks, Alaska, Heat Island

Under a grant to the University of Alaska, Professor Sue Ann Bowling has been investigating the properties of this sub-arctic, urban heat island. Heat islands are known to be at their strongest under nighttime conditions of low wind speed, clear skies and strong ground inversions away from the city. Fairbanks is noted for these conditions, especially in winter, so it is quite a good location for studying the phenomenon. In Fairbanks, as in few other cities, the effects of solar energy on the heat island can be eliminated. The long winter nights, with negligible solar heating in the daytime, are highly favorable for heat island development. The data obtained will ultimately help in the construction of computerized models of air pollution.

Since November 1974, an instrumented automobile has made a number of journeys through the area, measuring temperatures and sometimes ground inversion strengths along its course. Thermographs have been recording temperatures downtown, in suburban areas, and as far away from human activity as they can be located and still stay in the Fairbanks basin. At intervals, five to ten people, each equippedwith a small anemometer, a wind vane, and a thermometer, were scattered through the area to measure how the wind varies. Attempts to measure temperatures off the ground with a fixed-wing airplane were unsuccessful, as the plane was unable to fly low enough. But a helicopter has twice been successfully used to measure temperatures 100 m or so off the ground. Aerial photography is helping to determine how different regions vary in the amount of sunlight they absorb.

Although data will be gathered for another year, it has already been learned that the Fairbanks heat island is stronger than previously thought. Measurements made in ice fog conditions 10 years ago suggested a heat island of 6°C (11°F) - about what would be expected for a town the size of Fairbanks. Measurements under ice fog conditions this year gave heat island intensities of 2°-10°C (4°-18°F) and measurements under clear skies ranged from 5° to more than 12°C (9°to 22°F). When conditions were most favorable (clear skies and low wind speeds at night with snow cover) the heat island was always 10°C (18°F) or more. Even when skies were cloudy or the ice fog very dense, Fairbanks was about 3°C warmer than its surroundings. Although the daytime heat island was no longer measurable by mid-March, the nighttime temperature contrast remained about the same until well into the season of snow melt. Later in the spring and summer the heat island disappeared during the daylight hours, but at times it still exceeded 6 C at night.

The strength of the ground inversion between 0.5 and 2 m is very dependent on traffic density. A single car will destroy the inversion in its exhaust plume, and the inversion strength and 2-m temperature both change dramatically when a main road is crossed.

Since the heat island is due in part to direct heat input from human activity, the heat island study includes a survey of fuel/energy use in the Fairbanks area over the last 10 years. Data for the pre-1965 period were collected during our previous ice fog studies in the early 60's. The only conclusion which can be drawn from these data at the present time is that there has been a dramatic increase in rural/suburban electricity use (peak winter generation has increased by a factor of 5 in 10 years), and, at the same time, residential use of coal has dropped by almost two orders of magnitude.

Work for the next year will concentrate more on determining the vertical structure of the heat island. Helicopter measurements cannot be carried out below 100 m, and telephone wires and power lines make it difficult to make measurements more than 3 m up from a moving vehicle. Temperature measurements will be attempted by lifting the thermistor probe with a small balloon and possibly hanging the probe out from a building roof on a pole. This will not completely close the gap between surface and helicopter measurements, but it will help. More data will be collected on the fuel/energy inputs to the Fairbanks area, and additional wind measurements are planned.

3.2 Atmospheric Effects

3.2.1 Atmospheric turbidity

No major changes have been made in that part of the turbidity network supported by ML. Details of the network were presented in previous annual reports.

Changes in calibration of the sunphotometers used in the network continue to be the largest problem in the program. Over 50 instruments were recalibrated this past year with many of these showing relatively large changes in their calibration factors. A partial solution will be scheduled annual recalibrations, but more time and manpower will be required to accomplish this.

In addition to recalibrations, calibration services were provided for various cooperators including a group of new stations to be located in Venezuela, Colombia, El Salvador, Paraguay, Nicaragua, Guatemala, Ethiopia and Afghanistan.

Regular intercomparisons of a group of reference sunphotometers continues as part of the turbidity program. Included in the group of reference instruments this year were several that have been modified to provide a 1 1/2 degree limiting angle of view in contrast to 3 and 7 degrees in the two other types of reference instruments. The reason for the smaller view angle was to lessen the effects from the varying brightness of the solar aureole. No systematic differences were detected between the modified and unmodified instruments even under conditions of very high turbidity. It is possible that the random errors in the instrument are larger than any differences that may result from the different viewing angles. From the intercomparison work with the reference instruments along with occasional Langley-type calibrations, the sensitivity of the primary standard (DA-3) appears to be the same as when it was originally determined in 1971. Details of the calibration and intercomparison procedures are contained in Flowers et al. (1974).

The six years of turbidity data from Raleigh are being examined in an attempt to explain the causes for turbidity changes. Reverse trajectories and synoptic weather patterns are being used to examine turbidity levels and changes during special case periods. The cases consist of 4 or more successive days when frequent turbidity measurements were made and during which time there were large changes in turbidity. The results of the case studies are not yet available but summaries of the complete Raleigh record made preparatory to the case studies have yielded other interesting features.

Figure 19 presents plots of: the monthly average turbidity, the 12-month running mean of the monthly average turbidity, and the frequency of occurrence of daily average turbidity values equal to or less than 0.040. The running mean shows a relatively large increase of turbidity with time from a level of about 0.130 to about 0.160. Translating this into the vertical transmission of solar radiation at 500 nm wavelength gives a change from 63.5 to 59.2 percent. The running means are dominated by the high summer values, and therefore reflect trends in the summer time turbidity. The frequency curve shows a steady drop in the number of days with low turbidity. With the exception of two days in October 1972 and one day in April 1970, all of the days with average turbidity less than or equal to 0.040 were in the months from November through March. Thus at Raleigh, since 1969, summertime turbidities have gradually increased and there are now fewer days with clean air in winter. This apparent trend to higher turbidity at Raleigh is consistent with similar trends analyzed for Meridian, Mississippi and Oak Ridge, Tennessee and presented in last year's report.

3.2.2 Urban model of radiative effects of pollutants

The Meteorology Laboratory continued its grant support of Purdue University during FY-1975. January 1975 marked the end of a three-year research grant, which focused on the development of a time-dependent numerical model of urban wind, temperature and pollutant structure. During the first two years of the grant, a one-dimensional numerical model was developed. During the last year, an extension of the model to two dimensions (vertical cross section) was largely completed. The unsteady two-dimensional transport model was developed with emphasis on the importance of solar and terrestrial radiation to alterations of the meteorological and pollutant distribution over a city. The model can be used to investigate the effects of surface properties and flow field changes, as well as the influence of artificial heat and air pollutant sources on the temperature and pollutant concentrations in the urban planetary boundary layer. The gaseous and particulate pollutants as well as the natural constituents in the atmosphere are considered to absorb, emit, and scatter radiation. The air-soil interface temperature within the urban area is predicted from an energy balance in which the variation of surface albedo and thermal emittance, soil diffusivity and thermal conductivity, rate of water evaporation, and artificial heat sources are taken into account. The modification by the urban environment

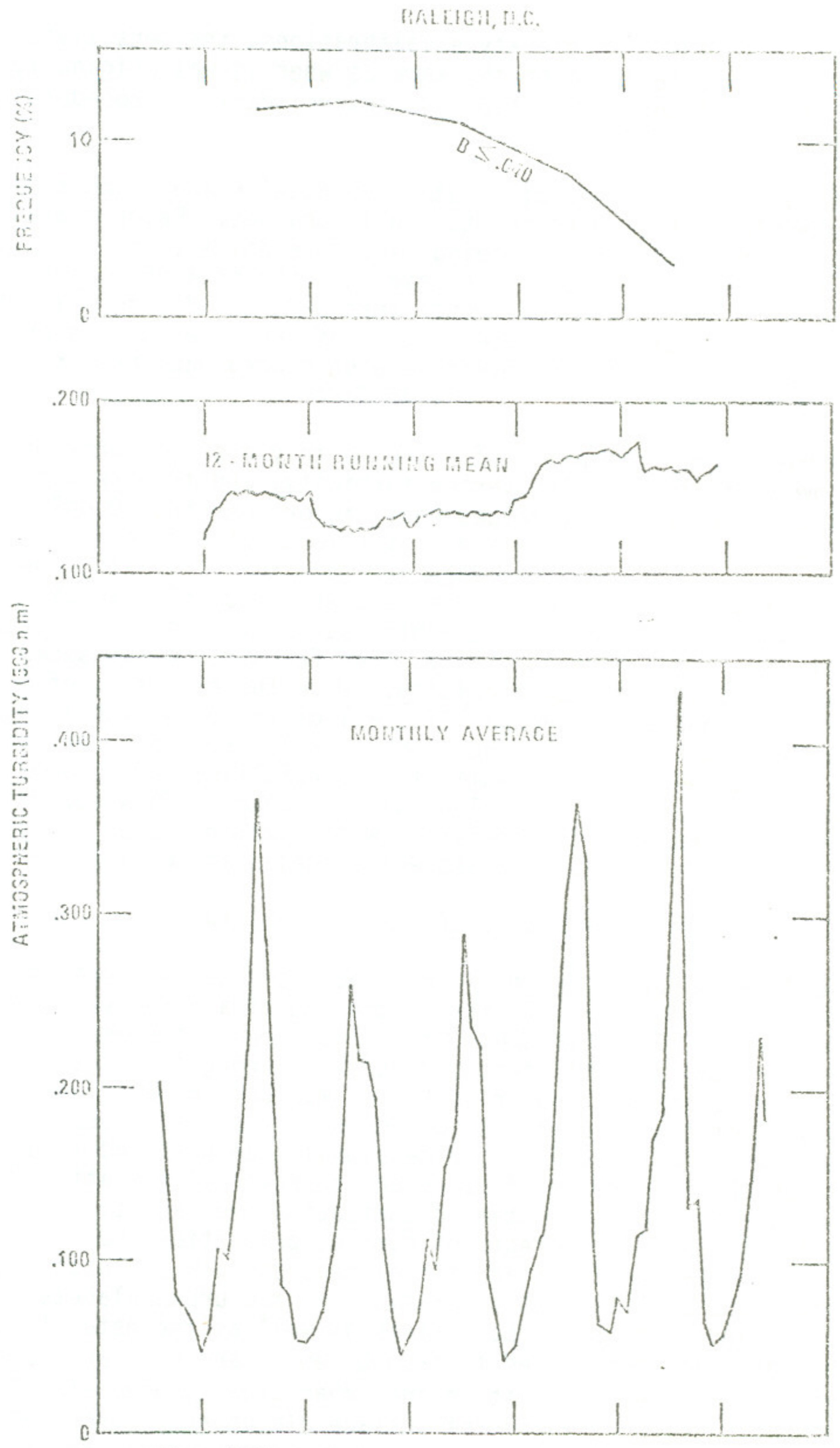


Figure 19. Raleigh, N.C., July 1969–June 1975: average monthly turbidity, 12-month running mean of average monthly turbidity, and frequency of occurrence of daily average turbidities (B ≤ 0.040).

of the flow field, temperature, water vapor and pollutant concentration distributions can be studied by numerically solving the governing equations. A final report covering results from the full three years of the grant is in preparation.

In January 1975 a new two-year grant was begun with Purdue University to continue development and application of their two dimensional model. Objectives are: (1) to improve the way turbulence and radiative transfer are accounted for in the model and to incorporate these changes into the existing two-dimensional transport model and in the numerical algorithm, (2) to conduct a series of numerical simulations of the thermal structure and pollutant concentration profiles in the urban boundary layer along with various sensitivity analyses, and (3) to compare the results to available experimental data for the purpose of confirming and improving the model. The major thrust of the research will be the numerical simulations and sensitivity studies of the effects of radiative participation of pollutants on energy balance, thermal structure and dispersion in the planetary urban boundary layer.

3.2.3 Relation between circumsolar sky brightness and atmospheric aerosols

The final report has been received on this grant work conducted by Drs. Glen Shaw and Charles Deehr at the University of Alaska. The study utilized field measurements and theoretical considerations of the brightness of the solar aureole to characterize the atmospheric aerosol, specifically the particle size distribution. Several special instruments were developed to measure the scattered radiation from the sun's aureole and other parts of the sky and the spectral intensity of the directly transmitted solar radiation. Measurements with this equipment were made in Barrow and Fairbanks, Alaska and in Kenya, Africa. The Kenyan measurements are described in Shaw (1975) along with a discussion of the analysis techniques.

The observations were used to derive the aerosol scattering phase functions which were then compared with values of the phase function computed with various assumed particle size distributions. It was found that the observations could be described by a Junge power law size distribution with clean air yielding a power law exponent of (ν = 2.5 to 3.0). One instance of an incursion of forest fire smoke yielded an exponent of (ν = 4.0).

The utility of the aureole measurement appears to be in characterizing the atmospheric aerosol, particularly in clean environments. The spectral sunphotometer appears to be more accurate and have greater precision than the instrument used in the turbidity program. In addition, the Shaw sunphotometer provides intensity measurements at six wavelengths rather than two as is the case for the turbidity program sunphotometer. However, the Shaw sunphotometer may be limited to observatories staffed with specially trained scientists or technicians since the accuracy of the measurements requires careful observations and frequent instrument calibrations.

3.2.4 Urban meteorological measurements

During FY-1975 the University of Wyoming continued its field experiments in the St. Louis area under a research grant. Expeditions were made to St. Louis during July-August 1974 and February 1975. The 1974 field operations provided opportunities for studying the kinematics of the general mesoscale air motion over the urban area, as well as for investigating the temporal and spatial variations of the temperature, pressure and moisture in the urban environment.

During July-August 1974, the University of Wyoming employed an airborne Doppler navigation system to measure mesoscale wind fields over the urban area. Preliminary analyses suggest that mesoscale wind components show some relationship to the anomalous thermal patterns of the mixing layer and during light wind situations there is evidence of a convergent flow into the urban area.

Initial studies of the characteristics of the downwind urban plume suggest that the lateral boundaries of the plume are well-defined in terms of Aitken nucleus concentrations, potential temperature, and specific humidity at distances of 55 kilometers downwind from the center of the urban area. The downwind reductions in Aitken nucleus concentrations and corresponding increases in cloud condensation nucleus concentrations suggest a particle size transformation to larger sizes, possibly through coagulation, at distances beyond 50 kilometers 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 land use features and provide critical components of the energy budgets of the earth's surface and the lower atmosphere. (Spangler and Dirks, 1974; Dirks, 1974.)

The initial stages of preferentially growing cumulus over the metropolitan area can be partially explained in the association of these clouds with the urban temperature and moisture anomalies; complex wind circulations, favoring localized regions of convergence, are also offered as explanations.

During the period February 4-10, 1975, experiments were conducted which examined the kinematics of the mesoscale air motion over the urban area and investigated the temporal and spatial variations of the temperature, moisture, and particulates in the urban-influenced environment. In particular, these experiments were designed to evaluate the transferability of findings from summer studies -- mesoscale airflow, mixing layer doming, anomaly fields of temperature and moisture, aerosol patterns, urban plume -- to the winter season.

The University of Wyoming's instrumented Queen-Air aircraft, a mobile radiosonde truck, and a mobile meteorological station were employed in the study. Seven people participated in the field work. Inclement weather conditions limited actual field operations to three days during the February 4-10 period -- a total of 12 aircraft hours were flown on station.

Preliminary results suggest that such features as temperature and moisture anomalies, and mixing layer doming, may be less prominent during winter than summer; however, the less than optimum weather conditions, particularly following a period of widespread precipitation, greatly restrict the generalization of these results. Weather conditions also precluded an evaluation of urban influences during periods of snow cover.

3.3 High Surface Ozone Problem

3.3.1 Ozone trajectories

Work has continued in connection with an effort by EPA Region IV to help the State of Florida determine the source of unexplained high concentrations of ozone. With the assistance of the Office of the Director, ARL, trajectories were obtained which purport to show the paths traveled by air that arrives at various sampling sites during sampling periods of interest. Some ozone is produced locally, but there is convincing evidence that at times ozone is transported in from places outside of Florida. At present an effort is being made to summarize the numerous plots of trajectories now available.

At the request of the Monitoring and Data Analysis Division a special briefing was given on the results of the Florida trajectory study. The information presented was needed for planning another ozone study to the north and west of the Gulf of Mexico.

A paper was prepared which analyzed air pollution monitoring results in Great Britain (Lee et al., 1974). The study showed that wind direction was the most important factor in the particulate concentration levels. During stagnation conditions or when the wind was predominantly from an easterly or southern direction, i.e., from the northern European continent, particulate levels were highest. However, when the wind was predominantly from a westerly direction, i.e., the Atlantic Ocean, particulate levels were lowest. Particle sizes were sufficiently small to account for the long range transport.

A paper was completed with the title, "Ozone Levels in the Vicinity of 33 Cities". It has been submitted to the Journal of the Air Pollution Control Association. (Fankhauser 1975) The 50th and 90th percentile concentration were plotted on maps to show regional distribution. On the map of the 50th percentile concentrations there appears to be a band of higher concentrations diagonally across the country from Rochester, N.Y., to El Paso, Texas, whereas on the 99th percentile range the industrialized areas showed the higher values more consistently. The highest concentrations were to the north from Milwaukee eastward across to Rochester, with slightly lesser concentrations to the south along the Mississippi River and to the Texas Gulf Coast, with higher values again along the immediate Gulf Coast. Florida was low on both the 50th and 90th percentile ranges. Numerous occasions of high ozone concentrations occurred when wind directions were apparently from areas with low concentrations of the known precursors. Ozone from thunderstorms was considered, but determined to be much less important than that transported from long distances.

3.3.2 Ozone background profiles for air quality simulation models

This grant work is being pursued under the direction of Professor Kenneth P. MacKay of San Jose State University. Observations from the Mt. Sutro TV Tower in San Francisco began on June 24, 1974. Measurements of three-dimensional wind components, temperature, and pressure were obtained at six levels between about 250 m and 500 m MSL and ozone measurements at four levels.

Figure 20 shows the cumulative frequency distributions of ozone hourly average concentrations at each of the four measurement levels for the period June 24 through September 24, 1974. This distribution shows that the ozone concentrations at those elevations most consistently within the elevated inversion layer (levels 3, 5, and 6) recorded higher ozone concentrations than the level located within the marine layer. The 80 ppb National Air Quality Standard is exceeded during about 15% of the hours at levels 5 and 6. While this figure shows similar distribution at levels 5 and 6 for concentrations above about 35 ppb, similar graphs show that during August and September, when most of the data were taken, level 5 had consistently higher ozone concentrations than level 6.

The breaks in the log-normal cumulative frequency distribution at about 35 ppb at level 6 and 25 ppb at level 5 indicate that the distribution comes from sampling of a heterogeneous population. Analysis is underway to determine the properties of the distributions of the two populations by methods described by Hald (1952). It is possible that these two populations represent days of high versus low ozone concentration within the inversion layer and/or periods representing elevated (stratospheric?) versus surface ozone sources.

Figures 21 through 23 represent the diurnal variation of the September 1974 monthly hourly average values of ozone concentration, temperature, and vertical velocity at each measurement level. Figure 24 shows the monthly average diurnal variation of the hodographs of the horizontal wind. While the patterns for July and August are similar, more consistently valid O_3 data were recorded during September.

Figure 21 shows that the average monthly value of ozone at 473 m is 80 ppb at 1500 PST, that the ozone concentrations within the inversion layer (levels 3, 5, and 6) are higher than those within the marine layer (level 1) for most of the day, and that there is a secondary ozone maximum occurring near 2100 PST.

High ozone concentrations within the west coast inversion layer have been measured before, but always by methods such as ozonesondes or instrumented aircraft which could not give continuous measurements. These data show that the average afternoon ozone concentrations at about 400 and 500 m above sea level are consistently at or near the 80 ppb one-hour average National Ambient Air

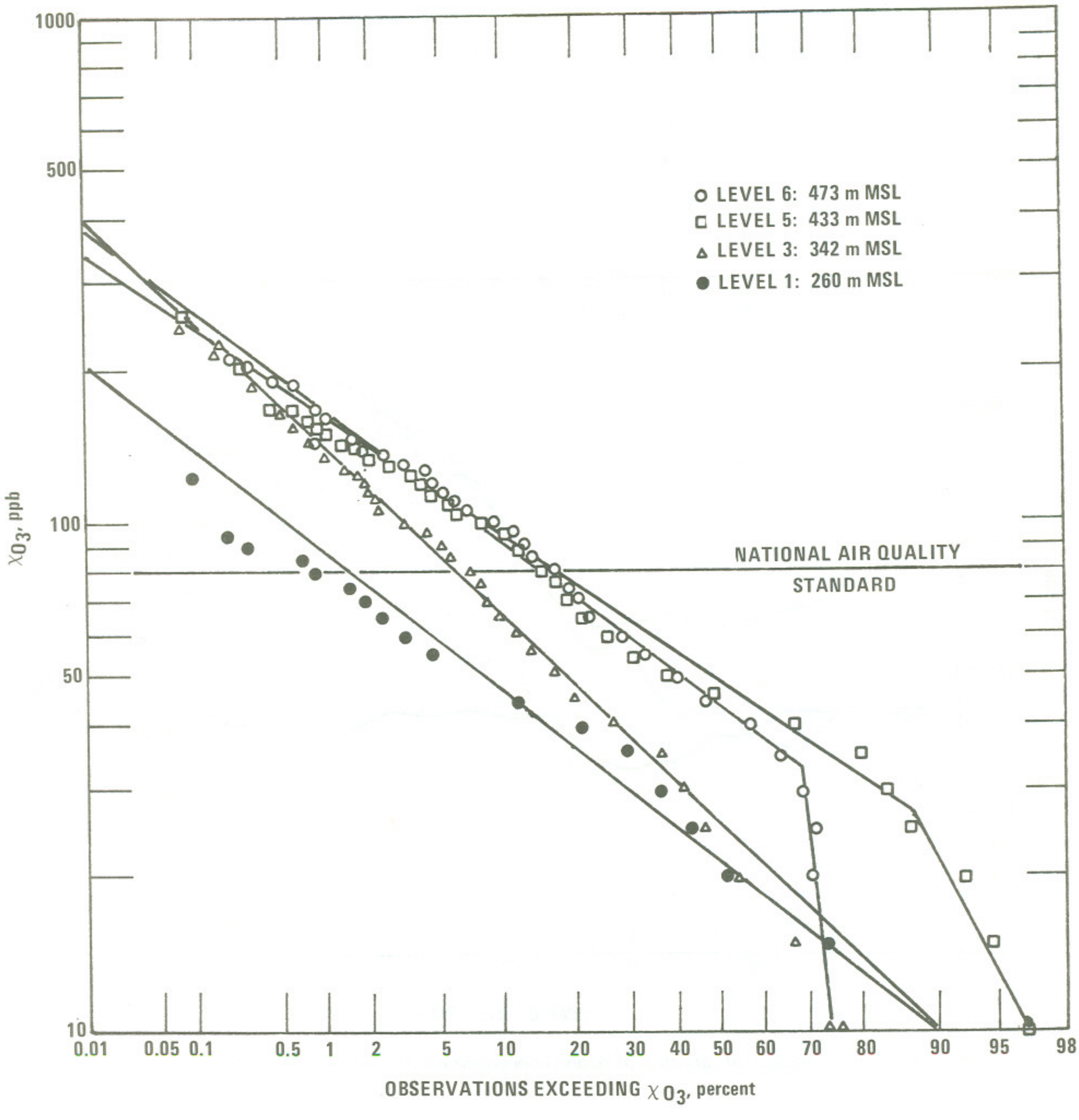


Figure 20. Cumulative frequency distribution of ozone concentrations, Mt. Sutro Tower, June 24 - September 24, 1974.

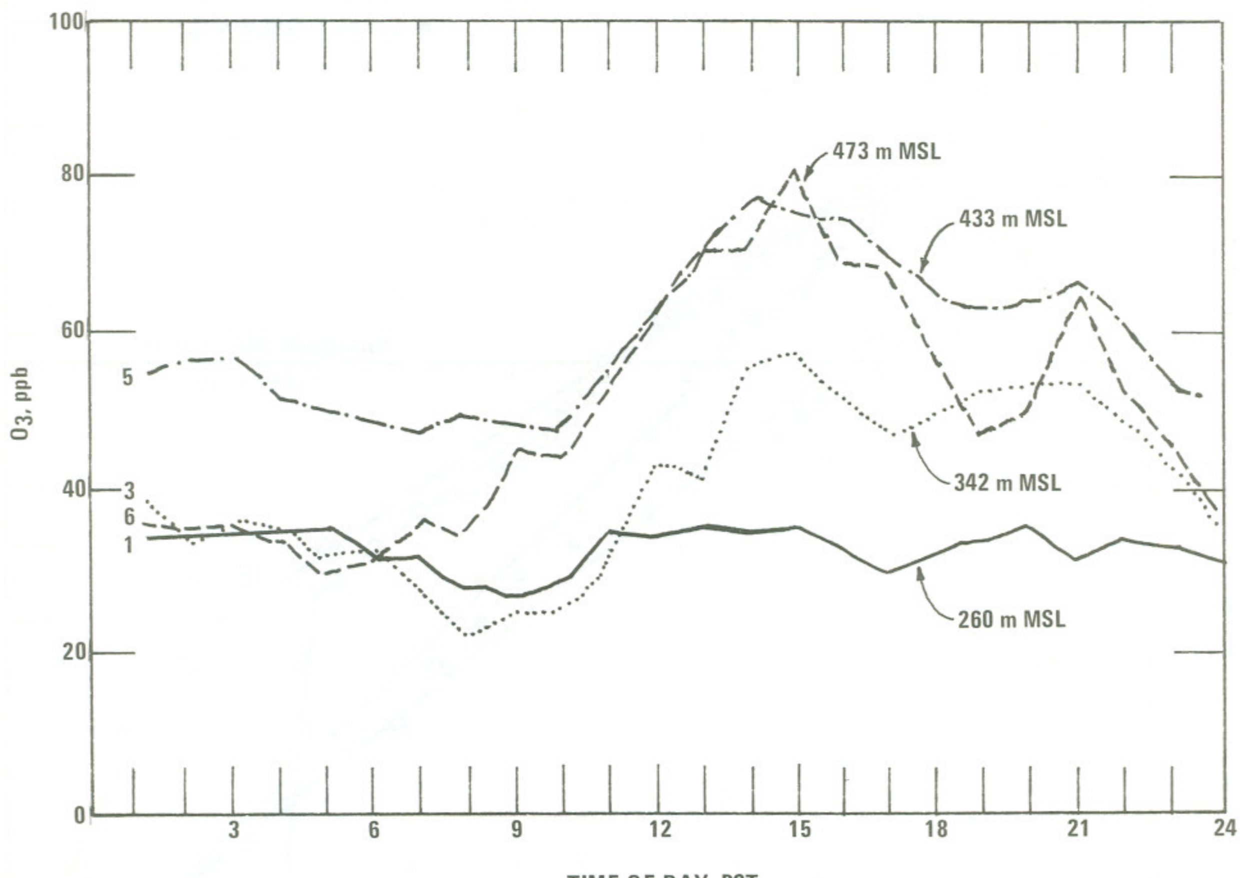


Figure 21. Average diurnal variation of ozone concentration, Mt. Sutro Tower, September, 1974.

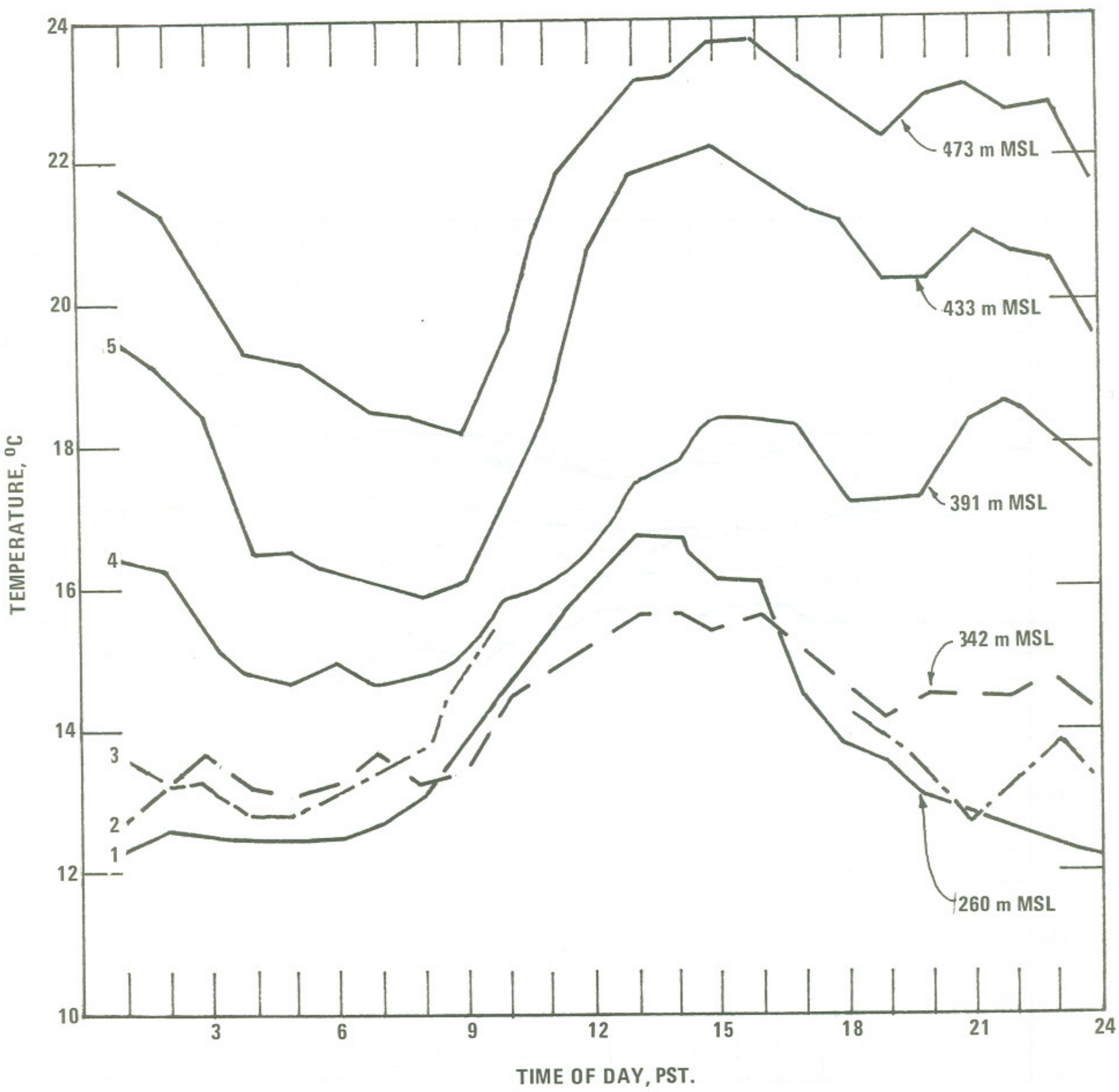


Figure 22. Average diurnal variation of temperature, Mt. Sutro Tower, September, 1974 (mid-day level 2 data, 300 m MSL, unreliable; surface at 254 m MSL).

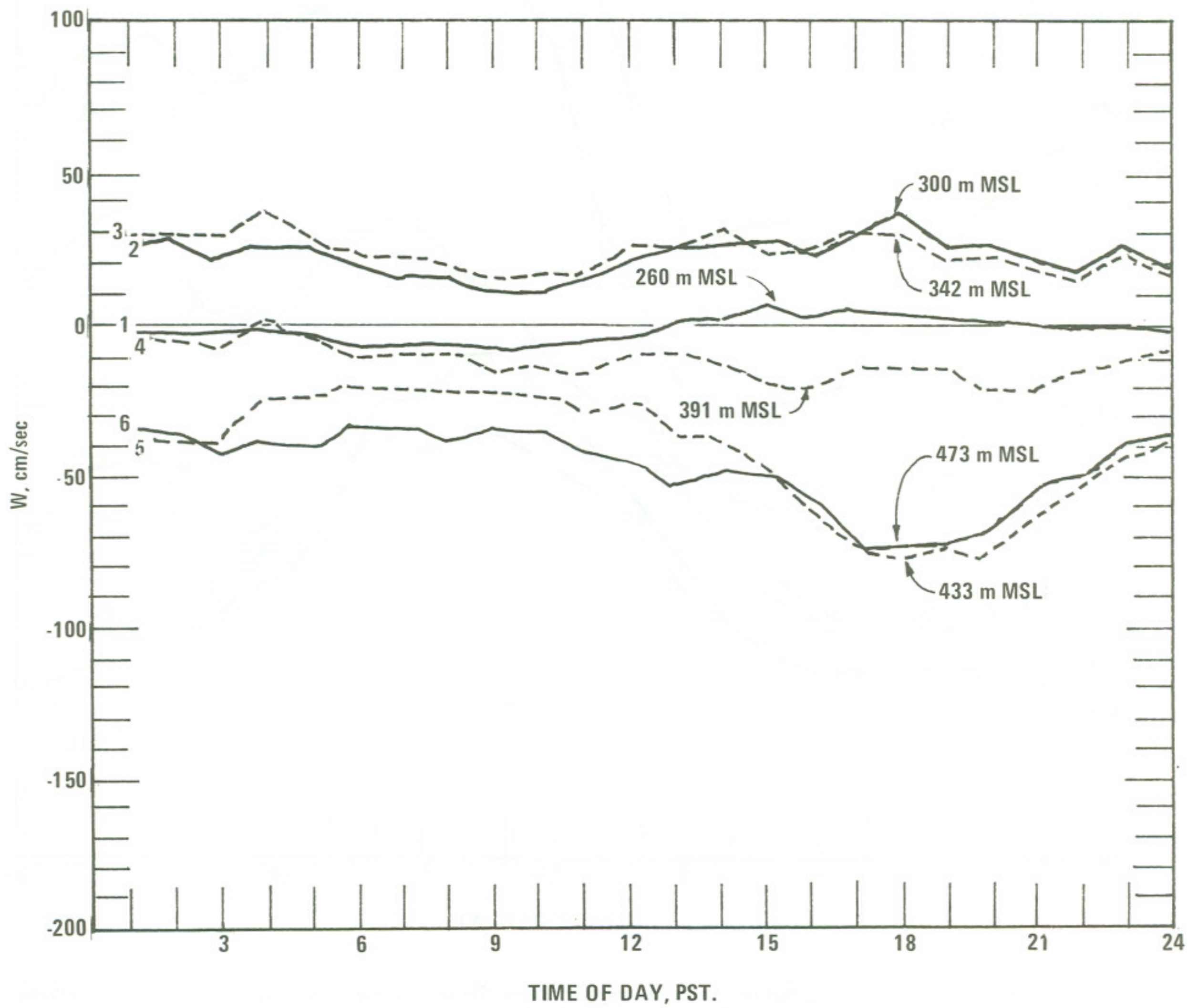


Figure 23. Average diurnal variation of vertical velocity, Mt. Sutro Tower, September, 1974.

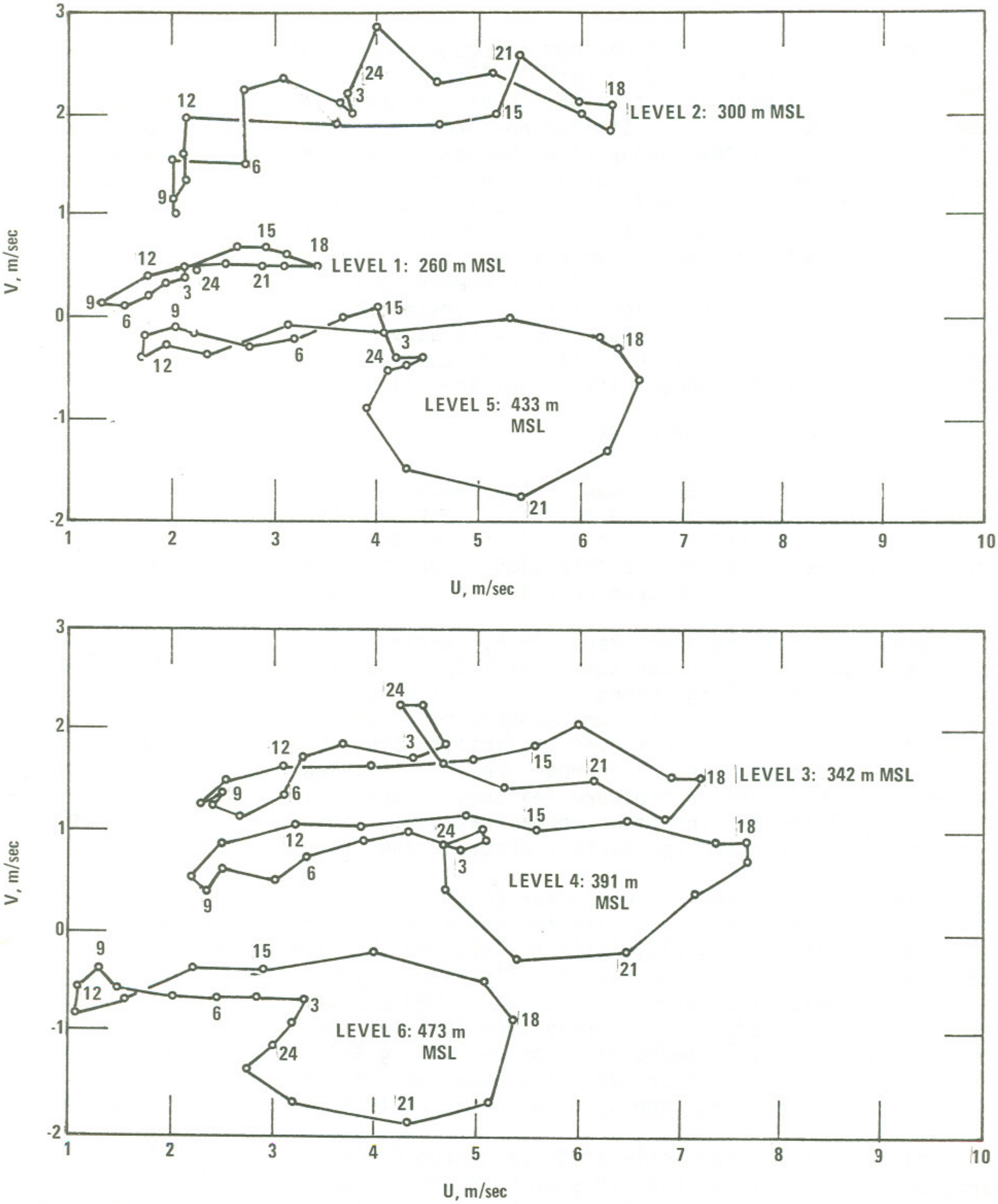


Figure 24. Average horizontal wind hodographs, Mt. Sutro Tower, September, 1974.

Quality Standard (NAAQS).

The secondary nocturnal maximum in ozone concentration shown in Figure 21 is similar to those reported by Perl (1965) in Arosa Switzerland (see Reiter, 1971, p. 149) and by Teichert (1955) in Berlin measured on an 80 m tower (see Geiger, 1965, p. 134). Similar nocturnal maxima have been explained in mountainous areas by the transport of ozone-rich air in downslope winds (Perl) or by wind increases producing subsidence (Teichert, 1955). The location of the Mt. Sutro Tower and the fact that the nocturnal maximum concentration is an average condition negates these explanations. Simultaneous warming (Fig. 22), maximum downward vertical velocities (Fig. 23), and a northerly wind component (Fig. 24) indicate that this phenomenon is related to an as yet unexplained pattern in the behavior of the inversion layer. It does appear that the ozone source for this nocturnal peak is above the top of the tower. Further analysis, including interpretation of completed power spectra of winds, temperature and ozone concentrations may shed light on this behavior.

3.3.3 Urban-rural oxidant studies

Over the past few years studies to assess the extent and cause of high oxidant concentrations observed in rural areas have been carried out. Due to the need to improve the technical basis for oxidant control strategies, the studies have focused on the contribution of urban oxidant precursor emissions and the role of long range transport and chemical transformations.

Meteorological analyses (Bach, 1975; Martinez, 1975) of a limited field study which took place in the summer of 1973 and covered non-urban portions of four mideast states (Ohio, Pennsylvania, West Virginia, and Maryland) indicate that high pressure areas, maximum temperatures above 60°F, abundant sunshine, low wind velocities, and low-level instability are usually associated with high ozone concentrations in nonurban areas. Also, lower mixing heights and high water vapor mixing ratios are features of the mixing layer which are statistically related to high ozone concentrations. Figure 25 illustrates the relationship between average surface pressure and ozone concentration.

Meteorology Research, Inc., under contract to EPA, has analyzed three-dimensional aircraft sampling data for ozone and meteorological variables obtained over the Los Angeles Basin in 1972 and 1973 (Blumenthal et al., 1974). The data have been evaluated specifically in relation to the feasibility of long-range transport of ozone and ozone-related pollutants downwind of the Los Angeles Basin. In addition to trajectory analyses showing the transport of ozone and precursors eastward with the prevailing daytime-summer wind flow, flux calculations (see Figure 26) have been used to demonstrate the magnitude of transfer of ozone from the western to the eastern portions of the Basin.

Analyses of a large scale study conducted during the summer of 1974 over parts of the Midwest and East (Research Triangle Institute, 1975) have been completed. The study utilized ground-based and aircraft monitoring of ozone, ozone precursors, and meteorological variables. The area covered by the ground monitoring network is shown in Figure 27. A summary of the ground monitoring

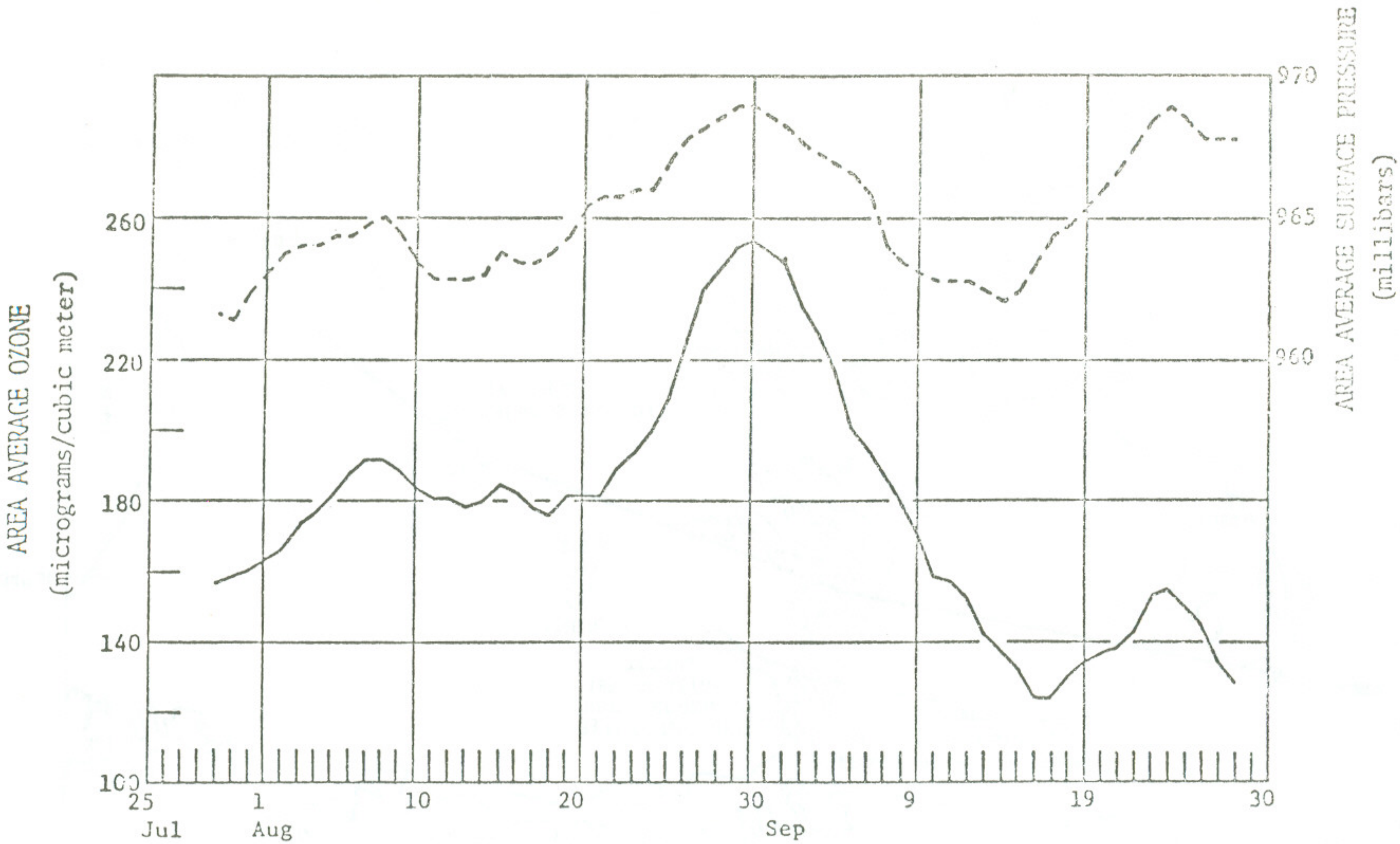


Figure 25. Smoothed variations of area average daily ozone - surface pressure, 1973 time sequence.

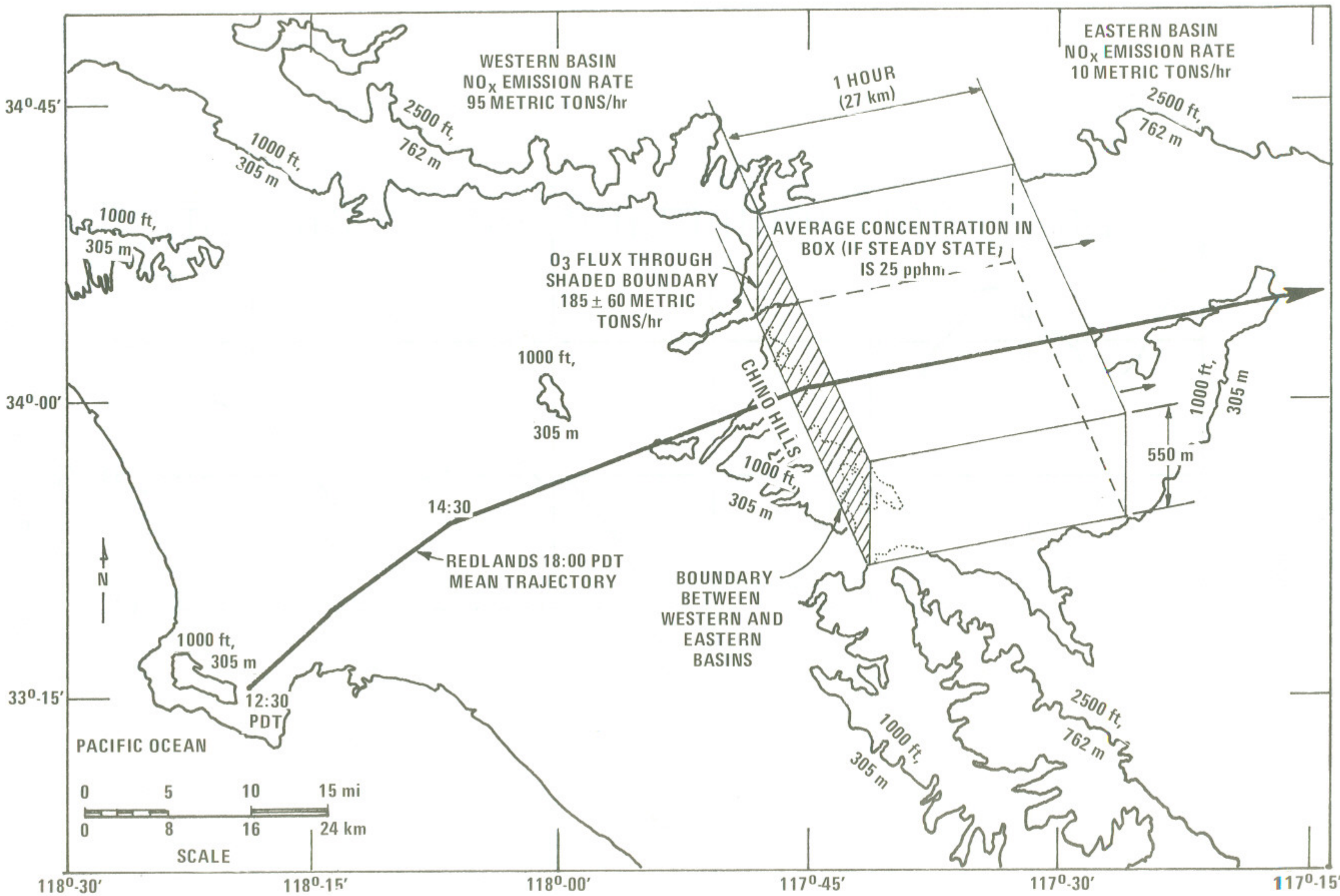


Figure 26. Estimated ozone flux from western to eastern basin, July 25, 1973, 1700 PDT.

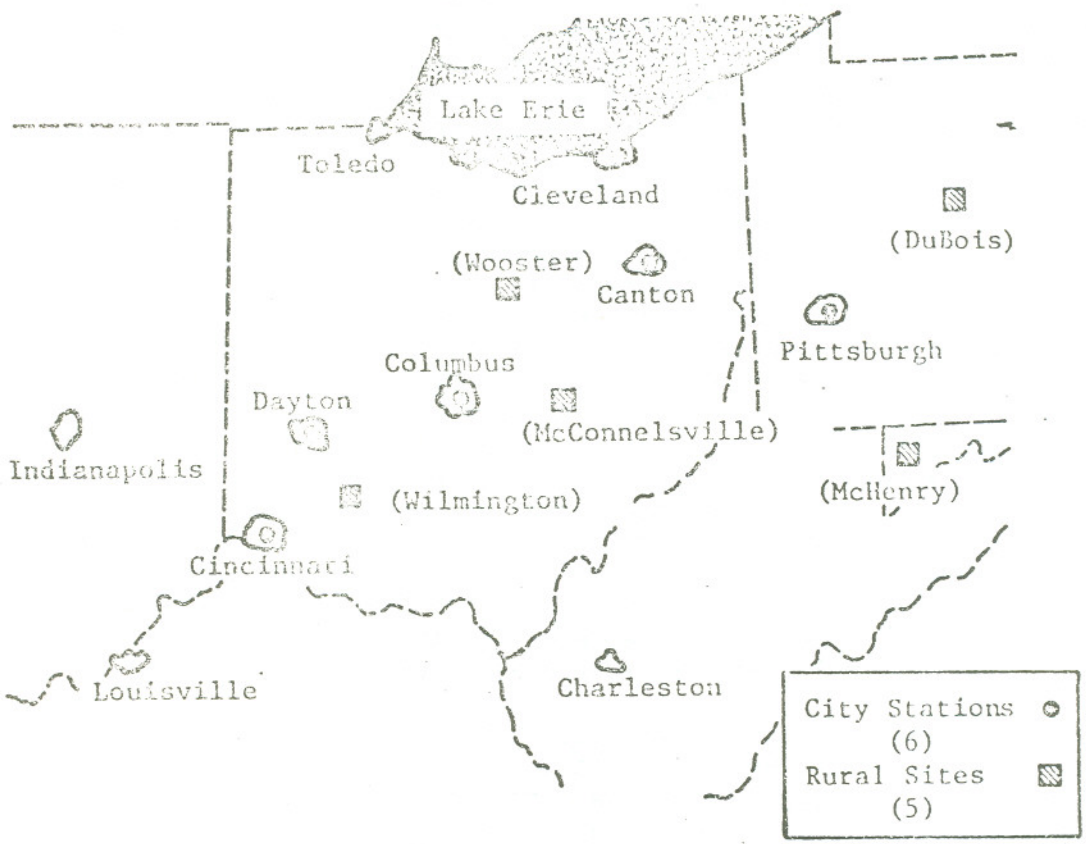


Figure 27. Location of fixed ground stations.

results is shown in Table 10. The following observations and conclusions are based on data collected during this study: (1) concentrations of photochemical oxidants are generally higher at isolated rural sites than at urban sites; (2) the near surface concentration of ozone may equal or exceed the air quality standard of 160 $\mu g/m^3$ hourly average over large areas (2.3×10^5 square kilometers or more) when the center of a high pressure cell moves over the region of interest; (3) transport of ozone precursors from urban areas to isolated areas under appropriate meteorological conditions is apparent; (4) an urban influence on ozone concentrations is discernible for 50 to 80 kilometers downwind of a city; (5) the observed high rural ozone concentrations cannot be explained in terms of air flow from a specific point source or a single-urban-industrial area sourc ; (6) the control of hydrocarbons in any individual city will reduce but not necessarily prevent the occurrence of high rural ozone concentrations in excess of the air quality standards.

Plans have been finalized for conducting additional field studies during the summer of 1975. These studies will attempt to answer relevant questions not previously resolved. Two large scale studies will be conducted concurrently, one from the Upper Great Plains eastward to the Appalachians, and the other along the Western Gulf Coast (between Corpus Christi, Little Rock, and Mobile). Ground-level and aircraft ozone sampling will be included in these studies. The main purpose of the Great Plains Study is to follow the development of high ozone concentrations in high pressure systems as they enter unpolluted from Western Canada and progress southeastward across the United States. Concerted efforts will be made to assess the relative contribution of natural and man-made sources to the development of high oxidant concentrations. The Gulf Coast Study will be exploratory, with the main purpose being to examine the distributions and probable causes of ozone concentrations over a wide area characterized by large petro-chemical source activities. Figure 28 indicates the general areas covered by the two 1975 studies and the ground locations that have been selected for ground-based monitoring.

In order to further understand the nature of the urban/rural oxidant problem, a contract with Stanford Research Institute has been let. The contractor will analyze data from the above noted field studies (and other data sources) on the temporal/spatial variation of oxidant levels. Synoptic and smaller scale meteorological variables will be considered. An assessment of the role of stratospheric ozone intrusions will be included. The ultimate goal of the study is to ascertain the feasibility of identifying large geographic areas for possible application of uniform oxidant control strategies. If feasible, a procedure for determining the boundaries of such areas will be recommended.

4.0 Technical Support

4.1 Regional support

Six of the ten EPA Regional Offices have NOAA meteorologists assigned. These offices are located in Boston, Philadelphia, Atlanta, Denver, San Francisco

Table 10. Summary of Ozone Data
Above NAAQS By Station
(June 14 - August 31, 1974)

Station	Maximum hourly average concentration ($\mu g/m^3$)	99^{th} percentile ($\mu g/m^3$)	Days exceeding standard (%)1/	Hours above standard (number)	Hours above standard (%)
Wilmington, Ohio*	370	260	58	259	14.9
McConnelsville, Ohio*	330	240	56	239	13.3
Wooster, Ohio*	330	260	55	262	14.0
McHenry, Maryland*	330	270	43	262	13.0
DuBois, Pennsylvania*	400	310	54	341	20.5
Canton, Ohio**	280	230	44	148	8.0
Cincinnati, Ohio**	360	220	20	54	3.5
Cleveland, Ohio**	270	200	26	51	3.0
Columbus, Ohio**	340	220	27	113	5.8
Dayton, Ohio**	260	220	35	114	7.2
Pittsburgh, Pennsylvania**	300	230	37	106	6.5

*Rural stations

**Urban stations

1/Based on data available from each station

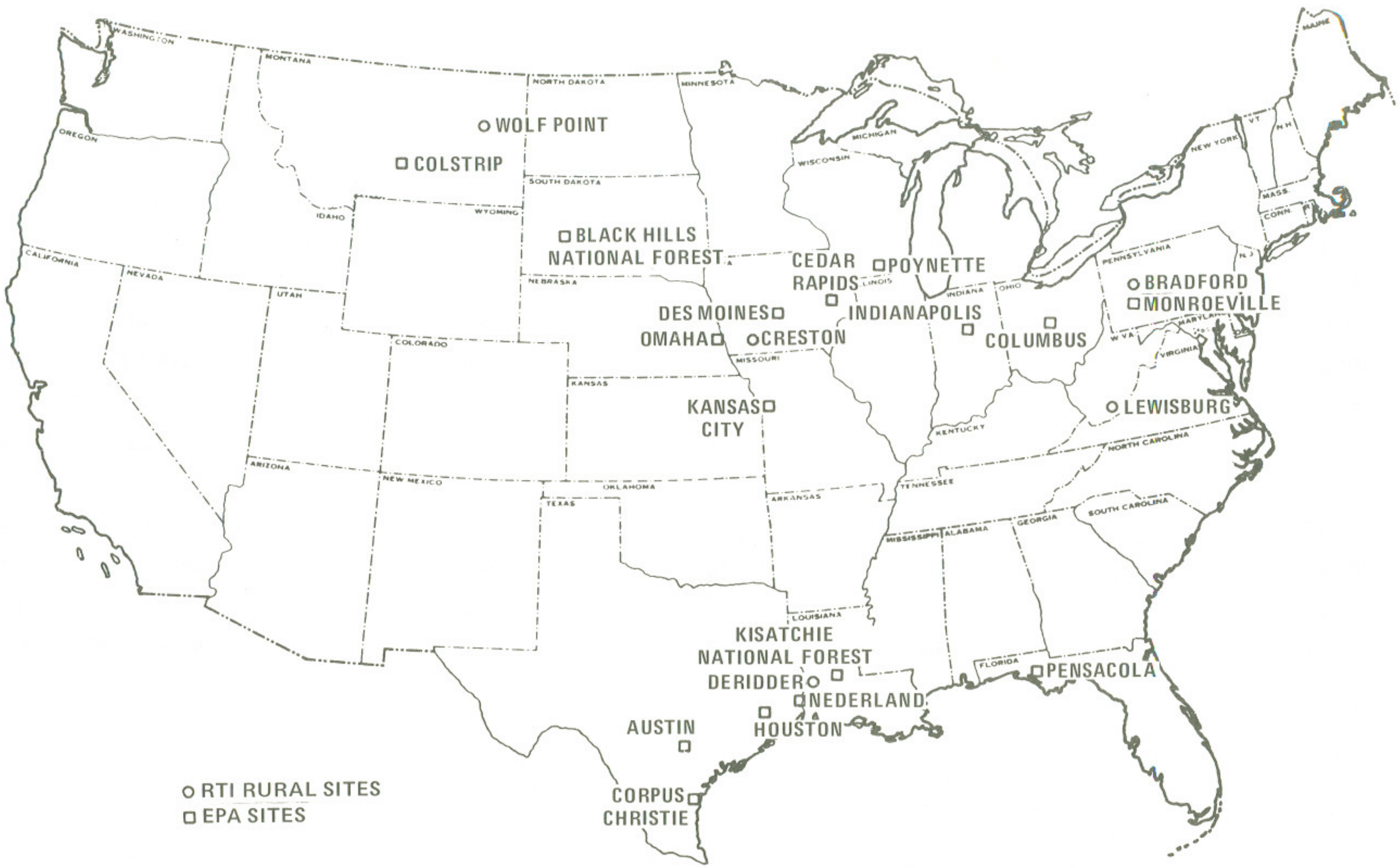


Figure 28. Site locations for ground station network.

and Seattle.

All of the Regional Meteorologists have some responsibilities that are similar. All supply meteorological technical assistance to State and local air pollution control agencies, review environmental impact statements, assist with monitoring site selection, are involved with the development of transportation control plans, serve as expert witnesses in legal proceedings, and are available to participate in the operation of emergency control centers for episode and accident response. All Regional Meteorologists have problems associated with large pollution sources with tall stacks, and the fuel crisis has placed an added burden as power stations everywhere are being studied for possible usage of more coal with a higher sulfur content. Given below are highlights of the activities in each Region to which a NOAA meteorologist is assigned.

4.1.1 Region I-Boston, MA.

The Meteorologist EPA Region I has engaged in the following activities:

(1) Pioneered in the application of transportation control plans. Boston was specifically selected to develop and test the feasibility of certain vehicular strategies. Under a tight deadline imposed by a Federal Court Order, Region I prepared a 1600-page document (EPA Region I, Boston, MA) demonstrating the presence of a carbon monoxide and oxidant problem. For the preparation of this report the Regional Meteorologist (a) assisted in the preparation of traffic, meteorological and other data for the APRAC model, (b) analyzed the highest reported CO concentrations and showed that CO violations were not the result of exceptional meteorological events, (c) performed a similar analysis for oxidants, and (d) devised a method for establishing the impact of the Summer and Callahan under-water vehicle tunnels on CO concentrations in East Boston and prepared a special report on this impact. Further, as a result of the transportation pollution problem, the Regional Meteorologist has completed a study of air particle trajectories on days with ozone violations and analyzed observed ozone concentrations, isolating effects of temperature, wind and sunshine.

(2) Served as the Regional representative for EPA's summer study of oxidants in the Northeastern United States. This has required the supervision of the logistics for operation of radiosonde facilities located on the MIT campus.

(3) Developed a computer model depicting the impact of open-dump burning for the State of Maine Department of Environmental Protection.

(4) Activated the Regional Environmental Operations Control Center to deal with a potential spill of hydrogen cyanide, which was prevented by action at the scene.

(5) Participated in several press interviews about acid rain, a subject

of particular interest in this Region.

(6) Investigated modeling of sea-breeze fumigation in the vicinity of a coal-burning power plant.

4.1.2 Region III-Philadelphia, PA

Three studies of particular interest, described briefly below, were conducted by the NOAA meteorologist assigned to Region III.

(1) SO_2 Diffusion Model for Selected Areas in Allegheny County, PA

The study calculated, by means of diffusion modeling techniques, maximum three-hour, 24-hour, and annual ground level SO_2 concentration in the vicinity of selected groups of large industrial sources, using projected emission rates. The sources are located along the Monongahela, Allegheny, and Ohio Rivers in Allegheny County and comprise coal-fired power plants, steel mills, and coke works. It is expected that from these efforts EPA will be able to evaluate regulations to achieve primary and secondary Air Quality Standards for SO_2.

The contractor conducting the study is the H. E. Cramer Company, Inc. A report has been published (Cramer et al., 1975).

(2) Simulation of SO_2 Diffusion in the Area of Clairton, PA

The study is expected to develop, by means of atmospheric simulation modeling, the maximum three and twenty-four hour average ground level SO_2 concentrations caused by stack emissions from sources located near the Monongahela River in the Clairton area of Allegheny County, PA. Qualitative and quantitative studies of the plumes are being made in a wind tunnel for both neutrally stable flow and flow with a ground inversion. From the efforts it is expected that EPA will be able to evaluate placement of ambient monitors and regulations designed to achieve primary and secondary Air Quality Standards for SO_2. The study is being conducted under contract by the Calspan Corporation.

(3) Particulate Study for the Southwest Pennsylvania Intrastate Air Quality Control Region

This is a three-phase program. Phase I is a feasibility study to see if a meaningful improvement in emissions data can be generated within budget limits. Phase II is an upgrading of the emissions inventory including stack tests as necessary, an analysis of ambient particulate data for model verification and as an independent check on sources of particulate, and generation of an advanced particulate model for the local-area--including particulate size distribution and terrain effects on the wind field. Phase III is an evaluation of various candidate strategies for particulate control using the model and data generated in Phase II.

The contractor for this study is the H. E. Cramer Company.

4.1.3 Region IV-Atlanta, GA

The Meteorologist assigned to EPA Region IV:

(1) Served as Joint Project Officer during 1974 for Air Quality Maintenance Areas (AQMA's). AQMA proposals were written for Tennessee and Florida.

(2) Served as Project Officer on Indirect Source Review Program.

(3) Presented a seminar at Georgia Tech University on National Air Pollutants.

(4) Appeared as an expert witness for the North Carolina Department of Natural and Economic Resources in regard to the State's denial of a permit for the operation of an uncontrolled grain dryer.

(5) Made ready for operational use in Region IV the Rough Terrain Model (C8M3D). It will be used for evaluating AQMA's with rough terrain.

4.1.4 Region VIII-Denver, CO

The Meteorologist assigned to EPA Region VIII:

(1) Assisted Regional Office personnel with the development of proposed regulations on sulfur dioxide and particulate controls for large sources. These sources included Kennecott Copper Corporation, Anaconda Copper Corporation, Anaconda Aluminum Corporation, American Smelter and Refinery Company, and U.S. Steel. This effort required application of atmospheric dispersion models to complex situations. Brief reports were written for each source and statements were made in public hearings. Work similar to the above was also performed for new source reviews and reviews of environmental impact statements.

(2) Devoted a significant amount of time to providing meteorological assistance to Region VIII Energy Office on studies related to environmental impact of energy development in the Rocky Mountain Prairie Region. The Regional Meteorologist was a contributing author to the report describing this program (Atmospheric Aspects Work Group 1974).

(3) Assisted with preparation of proposal requests, and contract monitoring, for contracts dealing with meteorological and air quality data acquisition in the Northern Great Plains Resources Program (NGPRP), and other energy development related projects. Prepared a request for proposal dealing with the application of large scale atmospheric diffusion modeling to NGPRP area for the purpose of studying the environmental impact of several coal conversion facilities proposed there. The contract will be funded during FY-76 and the Regional Meteorologist will be Project Officer on this study.

(4) Co-authored and presented a paper at the First Conference on Regional and Mesoscale Modeling, Analysis, and Prediction, Las Vegas, Nevada, May 6-9, 1975 (Henderson and Joseph, 1975).

4.1.5 Region IX-San Francisco, CA

The Meteorologist assigned to EPA Region IX:

(1) Assisted in the preparation of regulations for the control of sulfur oxides from 8 copper smelters in Arizona and Nevada. This work has included (a) the analysis of data collected at special EPA monitoring stations placed in the vicinity of each source to determine the appropriate air quality levels on which to base emission limits, (b) the calculation of emission limits based on air quality and individual smelter configurations, (c) the calculation of emission limits required for application of SCS using partial permanent control and based on specific smelter configurations, (d) a field study of SO_2 levels in an area where 2 smelters share the same air space, (e) the analysis of results of diffusion modeling of each smelter (both C8M3D and PT models were used), and (f) the preparation of technical documents in support of the regulations.

(2) Assisted in the review of new source permits including the application of PT model results to determine the air quality effects.

(3) Reviewed the air quality portions of several Environmental Impact Statements (EIS's) and worked with contractors and other Federal agencies in the design of data collection and analysis for air quality assessments, and in the improvement of draft reports.

(4) Participated in several task group efforts to better understand and define the Los Angeles air quality problem. (a) A review of the Los Angeles County "smog chamber model" resulted from the efforts of one group and a review paper was prepared by three task group members (Hopper, Mueller and Souten, 1975) and presented at the APCD meeting in June 1975. (b) One task group was devoted to the design of an intensive measurement network to collect data to be used in an SAI model verification study.

(5) Hosted seminar on photochemical oxidant modeling in October. The seminar was attended by about 50 representatives from Government agencies and private industry. Presentations were made by both model developers and users on the current status of model development.

(6) Participated in seminar presented by both model developers and users on the current status of model development.

(7) Assisted in review of several research proposals.

(8) Provided assistance in the preparation of several contracts for air quality studies.

(9) Provided technical assistance to Nevada Highway Department in large scale air quality study of Las Vegas and Reno areas.

4.1.6 Region X-Seattle, WA

The Meteorologist assigned to EPA Region X:

(1) Estimated by application of dispersion modeling the impact of growth-generated particulate emissions in the Auburn, Washington area on the air quality in the Kent-Auburn Valley and on Seattle and Tacoma in 1990.

(2) Developed regional air pollution models for the Longview-Kelso, Portland-Vancouver area using four formulations: (a) normal Gaussian plume, (b) a Gaussian plume following curvilinear winds, (c) a grid solution of the conservation of mass equation, and (d) a statistical relationship between long-term and short-term air quality. The EPA models CDM (Climatological Dispersion Models) and PTMPT were modified and used for the Gaussian plume models. CDM was modified for curvilinear winds by developing joint probability frequency wind roses. Area sources were added to PTMPT. The GRID model was developed for this program. The statistical model was based on Larsen's work.

Computerized emissions data bases were developed for the years 1972, 1973, and projected for 1975 and 1985. Each model was tested with the same emission data base and appropriate meteorological data. Sensitivity analysis and calibration were performed using the 1973 data base and model validation was performed using the 1972 data.

The GRID model and the Statistical model were used to project regional particulate and SO_2 annual and maximum 24-hour concentrations for the 1975 and 1985 time period. Additional model applications to air quality maintenance planning and an evaluation of the existing air quality and meteorological monitoring network were also considered. Contract support for this project was provided by Xonics, Inc. A final report is expected in September 1975.

(3) Developed the groundwork for a study that will determine, through the application of a set of diffusion models, the ground level ambient concentrations that will occur as a consequence of current sulfur dioxide emissions from a smelter in Ruston, Washington. The model predictions will be compared to applicable local, State and National ambient air quality standards. For those standards which are not expected to be attained with the current, approximately 51%, permanent degree of emissions control at the smelter, a determination will be made, through application of the diffusion models, of the actual

level of permanent control necessary to attain the standards.

Additionally, this study will examine the past performance of the smelter supplementary control system (SCS), and a determination will be made whether or not the local, State and National standards can be reliably maintained with 51% or 70% permanent control together with practice of SCS.

The results of this study will allow Region X EPA, the State of Washington, and the Puget Sound Air Pollution Control Authority to isolate the environmental consequence of several options on the control strategy for the smelter. Contract support for this project is being provided by the H.E. Cramer Co. A final report is due in January 1976.

(4) Started a project for applying the APRAC-1A Model, which will proceed as follows:

First, the frequency distributions of 1-hour and overlapping 8-hour average CO concentrations for each year and for each station for which data are available will be calculated. These frequency distributions will then be compared with emphasis on discerning differences arising from station siting and from climatological factors. The process will be repeated using data normalized for wind speed to minimize climatological differences.

Second, for Seattle, both July 1971 to July 1972, and the 1974 CO emission inventories will be generated. For Spokane, both July 1971 to July 1972, and April 1973 to April 1974, CO emission inventories will be generated. In this task, EPA will provide traffic count data, typical facility speed and volume data and emission factors; EPA will also provide county-wide, bulk CO emission inventory data. High resolution emission inventory simulations will be made for the central metropolitan areas using APRAC methodology while extra-urban emissions will be taken from the county inventories.

Third, using the analysis of concentration data, those days with poorest air quality will be identified and the accompanying traffic and meteorological conditions (surface and upper air) for both Seattle and Spokane defined. These worse-case days will be randomly split into two subsets.

Using data from one subset the APRAC model will be used to predict air quality at the Seattle and Spokane 1973-1974 monitoring sites, and evaluate and calibrate the model accordingly. The second data subset will be used to assess model performance.

Finally, for worst-case traffic and meteorological conditions, the model will be used to simulate the two-dimensional CO distribution for Seattle and Spokane in 1971-1972, for Spokane in 1973-1974, and for Seattle in 1974. The magnitude and extent of the CO problem areas will be determined. Contract support for the project is being provided by the Stanford Research Institute. A final report is expected by December 1975.

(5) Served as Secretary to the Pacific Northwest River Basins Commission-

Meteorological Committee.

4.2 General Assistance

4.2.1 Panel studies of acute health effects of air pollution

Meteorological support was furnished to the ongoing Community Health Surveillance Systems (CHESS) operating in New York City and Los Angeles. Results from a study concerned with the effect of sulfur oxide air pollution on cardiopulmonary symptoms in New York City (Goldberg et al. 1974) revealed a significant effect of ambient air temperature.

A study of cardiopulmonary symptoms in adults during 1970-1971 involved over 500 elderly persons residing in or near New York City who were well, or who reported cardiopulmonary symptoms. Participants were grouped into those previously diagnosed by a physician as being well (without a history of cardiopulmonary 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 of symptom status. Decreasing temperatures induced or aggravated symptoms in all but heart disease panelists, who reported worsening of symptoms with elevations in temperature. Elevated levels of sulfur dioxide, total suspended particulates, and especially suspended sulfates were linked to symptom exacerbations. However, within temperature-specific ranges, suspended sulfates exhibited the strongest and most consistent association with symptom aggravation.

A follow-up study, 1971-1972, in New York City (Stebbings and Hayes, 1975) confirmed the earlier finding that increased temperatures aggravated cardiopulmonary symptoms in heart disease panelists, but clear and consistent relationships of temperature to symptoms in the well, lung disease, or combined heart and lung disease panelists were not apparent. Daily minimum temperature was found to be most useful, whereas maximum temperature was only slightly less significant. No strong or clear relationships of symptoms with values of daily maximum and average relative humidity were detected.

The requirement for meteorological data was also revealed during the health studies of asthma. A 6-month study of 211 asthmatics residing in Great Salt Lake Basin, Utah, indicated excess asthma attack rates could be attributed to both colder days and air pollution, with air temperature unquestionably the most consistent determinant, asthma frequency increasing as temperature decreased. When a statistical temperature-specific risk model (Finklea et al. 1974a) was employed to separate pollutant effects from temperature, it was found specific pollutants, total suspended particulates and suspended sulfates, caused significant asthma attacks on days with minimum temperatures above 30°F. 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 total suspended particulates and suspended sulfates in a low minimum temperature range, 30° to 50°F, and different thresholds appeared in a higher minimum temperature range, greater than 50°F.

A comparable 32-week study of 148 asthmatics in the New York City area (Finklea et al. 1974b) was also conducted. In contrast to Utah, no direct temperature effect was found. However, temperature-dependent thresholds of total suspended particulate and suspended sulfate concentrations were evident as in Utah.

4.2.2 Development of a daily mortality model for air pollution districts in the United States

Meteorological data, particularly maximum and minimum temperatures, will be used from 172 first order, second order and cooperative selected stations representing regions from which daily mortality data are available for inclusion in multiple regression analyses to establish the contribution of each variable to mortality in the presence of all the others. For each region, this method provides a predictive equation giving the percent change in the dependent variable, for each unit of change in any given independent variable. Results from previous mortality studies (Buechley et al. 1973), (Buechley et al. 1972) indicate air temperature is a highly significant variable when taken as a seasonal temperature cycle, extreme heat wave or as shifts from warm to cold periods.

4.2.3 Nationwide survey of children living near primary non-ferrous smelters

Excessive absorption of heavy metals has been documented among children living near non-ferrous metal smelters in El Paso, Texas, Kellogg, Idaho, Tacoma, Washington, and Helena, Montana, as well as in Australia, Canada, Britain, Italy, Chile and Finland. Inhalation and ingestion of metallic particulates in air and dustfall by the smelters appear to account for the increased absorption, and there is evidence in the case of those smelters discharging lead to suggest subclinical damage to the nervous system of exposed children.

In support of this study, upper-air wind roses for the 300-meter level were computed for 32 smelter sites in the United States. These diagrams give a rough estimate of the upwind-downwind orientation of populations relative to smelter stacks.

4.2.4 Interagency liaison

A meeting of the U.S. Department of the Interior Ad Hoc Group on Cataloging Meteorological Data was attended on August 28, 1974. Subsequently, contact by correspondence has been maintained with this group. EPA has offered to answer questions about its data-handling facilities, but concurs that the focal point for knowledge about meteorological data services should be the National Climatic Center, Asheville, N.C.

Membership has been maintained in the Subcommittee for Air Quality Meteorological Services, which meets regularly every two months. A draft of a Federal Plan for meteorological services was prepared for this Subcommittee.

4.2.5 Emergency response

Two meteorologists and two technicians are organized into a team that is prepared to respond to accident emergencies. However, there were no accidents that required response during the fiscal year. Nevertheless, quick response of a semi-emergency nature was given when two other meteorologists on two separate occasions during October made trips aboard ship into the Gulf of Mexico to assist with monitoring possible high concentrations of hydrochloric acid in the effluent of a seaborne incinerator which burned a mixture of waste material made up of chlorinated hydrocarbons. The incinerator temperature was set for at least 1200°C and the ratio of burning was such that almost 500 lbs of HCL would be emitted each minute. However, there was no visible plume. The meteorologist made meteorological observations and advised how the monitoring ship (the Oregon II, provided by NOAA) should be positioned with respect to the incinerator ship (the Vulcanus). Most of the time no HCL was detectable, but on one occasion 1.2 ppm were measured. Since industrial hygiene standards allow a concentration of 5 ppm for an 8-hour period, the measured levels were not considered especially serious.

A paper has been prepared (Humphrey, 1975) for the Fourth International Symposium on Transport of Hazardous Cargoes by Sea and Inland Waterways under the auspices of the U.S. Department of Transportation, U.S. Coast Guard--technical assistance provided by the National Academy of Sciences Committee on Hazardous Materials. This meeting was originally scheduled for April 1975, but was postponed to October 26-30. It was also moved from New Orleans to Jacksonville, Florida. The paper is addressed to non-meteorologists and draws on experience gained during four previous chlorine barge accidents in order to explain the role of a meteorologist and to develop suggestions for future emergencies.

4.2.6 Special support

A meteorologist has served as a member of EPA work groups that have prepared comprehensive documents on specific pollutants. A document on chromium has been completed; (National Environmental Research Center, 1974a) a similar document on nitrogen oxides is in preparation. Also input was provided on a review of 1974 research support with reference to critical and hazardous pollutants (National Environmental Research Center, 1974b).

4.2.7 Energy Supply and Environmental Coordination Act (ESECA)

The Energy Supply and Environmental Coordination Act (ESECA) makes it possible to require the conversion of power plants and other large fuel burning sources from oil/gas to coal. However, this conversion can only be allowed if certain environmental conditions are met. One condition is that emission limits (primary standard conditions) must be set which assure that primary National

Ambient Air Quality Standards (NAAQS) will be met. Another condition is that monitoring of the air quality impact of the plant must be conducted to insure that NAAQS are not exceeded. Guidelines for both requirements were prepared.

The guidelines for specifying primary standard conditions (Environmental Protection Agency, 1975a) discusses (1) the importance of source and site characteristics, dispersion climatology, existing air quality, and the growth of other sources in the vicinity of the fuel burning installation; (2) the types of atmospheric simulation models which are available for estimating the increases in annual and 24-hour average concentrations caused by a switch to coal; (3) the procedure for selection of emission limits which will insure that primary NAAQS are maintained; (4) procedures for revising primary standard conditions. Primary standard conditions have been estimated for the approximately 90 power plants that are considered to be candidates for fuel conversion under ESECA.

The guidelines on monitoring requirements (Environmental Protection Agency, 1975b) considers (1) sources and pollutants for which monitoring is required, (2) measurement techniques (3) reporting schedules and (4) general procedures. The use of dispersion models in network design is also discussed.

4.2.8 Supplementary control systems and tall stacks

NOAA meteorologists continue to be deeply involved in all aspects of the development and evaluation of Supplementary Control Systems and Tall Stacks. These are crucial areas of air pollution control which are closely tied to energy/environmental issues. Interagency debate and review at the highest levels of government are routine.

Guidelines for Evaluating Supplementary Control Systems (Environmental Protection Agency, 1975d) have been prepared under the guidance of NOAA meteorologists and partly under contract to the H.E. Cramer Company, Inc. These guidelines provide general guidance for control agencies on one area of responsibility with respect to Supplementary Control Systems (SCS). This responsibility is the evaluation of SCS applications on a case-by-case basis to determine whether there is adequate justification for an SCS and whether the proposed SCS provides a feasible means of attaining and maintaining National Ambient Air Quality Standards (NAAQS). The document describes the circumstances under which a source may apply for permission to use SCS, the manner in which the source must apply, the steps to be taken in the development of an SCS, and a detailed description of the technical aspects of an SCS. Considerable attention is given to the meteorological aspects of Supplementary Control Systems.

A contract has been initiated with Environmental Research and Technology, Inc., to conduct a case study demonstration of the application of a reliability analysis technique to the development, analysis, and upgrading of an SCS. The case study demonstration shall also serve as an example of the "background study" described in the above noted guidelines.

NOAA meteorologists have also been involved in evaluating the effectiveness of tall stacks for achieving acceptable levels of air quality and in defining a tall stack policy for EPA. Battelle (Pacific Northwest Laboratories) under contract to EPA is assessing the capabilities and effects of tall stacks. The goal is a critical review of the advantages and disadvantages of tall stacks for achieving acceptable SO_2 concentrations at ground level and for minimizing environmental problems associated with total atmospheric loading of sulfate concentrations from elevated sources.

A major consideration in the development of EPA's tall stack policy has been the definition of a stack height which constitutes good engineering practice (GEP). This is in contrast to a tall stack whose sole purpose is to increase dispersion of pollutants. In some cases it will be necessary to calculate the emission control requirements of a source based on its calculated impact with a GEP stack. An engineering rule of thumb states that to avoid wakes, eddies, and downwash a stack should be 2.5 times the height of surrounding structures. Also it has been found through an analysis of historical data on plant characteristics that stack heights equal to approximately 2.5 times associated building heights are typical for coal-fired installations. Thus the use of the "2.5 times rule" for GEP stack height has been accepted as reasonable.

4.2.9 Environmental impact statement review

Approximately 30 environmental impact statements were reviewed during FY-1975. These are summarized below.

A.	Nuclear fuel projects	
	1. Power plants	18
	2. Fuel storage stations	1
B.	Fossil fuel projects	
	1. Power plants	3
	2. Refineries	1
	3. Gas transmission stations	1
C.	Guidelines	
	1. Air transportation	2
	2. Highway transportation	2
	3. Nuclear projects	1
D.	Other	
	1. Incineration of herbicides at sea	1
	2. Concorde supersonic aircraft	1
	3. Modular closed-system housing	1

4.3 Monitoring

4.3.1 Kellogg, Idaho, lead study

Advice was given during two conferences with representatives from EPA Region X, pertaining to the locations of monitoring stations in the vicinity of a lead smelter located at Kellogg, Idaho. Some previously measured concentrations were compared with wind directions in an attempt to find a source-receptor relationship, but results were inconclusive, possibly because of lead contamination in the surface layer of dust throughout the area. Recommendations were given for locating monitoring instruments for a continuation of this environmental study.

4.3.2 Monitoring guidelines

Guidelines were prepared or updated to assist air pollution control agencies in complying with various regulatory requirements involving ambient air monitoring. NOAA meteorologists had an active role in assessing meteorological requirements and in providing judgments on source-receptor relationships important to network design and physical placement of pollutant monitors.

The principal guideline on network design and instrument siting (Environmental Protection Agency, 1975c), provides the necessary guidance and assistance in establishing, modifying, and/or maintaining general purpose monitoring networks.

One supplement to this guideline which is in preparation is concerned with monitoring in the vicinity of large point sources. Point source monitoring presents a unique and very important monitoring situation which cannot be treated adequately in a general monitoring guideline. Also, specific guidance is needed because of proposed regulatory changes which will place greater emphasis on monitoring around large sources. This supplement specifically considers the meteorological factors which are relevant to site selection around a point source.

Another supplement (Ludwig and Kealoha, 1975) is being prepared for CO monitoring. That supplement is necessitated largely due to the unique nature of large concentration gradients for that pollutant. Unique factors related to monitoring for other criteria pollutants will be examined through further contractual and in-house efforts and further guidance issued as necessary.

5.0 INTERNATIONAL AFFAIRS

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

The Proceedings of the 5th Meeting of the NATO/CCMS Expert Panel on Air

Pollution Modeling, held June 1974 at Roskilde, Denmark, was published as NATO/CCMS Air Pollution Report No. 35, August 1974. This was the last meeting within the framework of the NATO/CCMS Pilot Study on Air Pollution, conducted from 1970 to 1974 under the chairmanship of the U.S.A. As a result of this first pilot study the Governments of the NATO member countries recommended continuation of the modeling activities and exchange of information on modeling. Based on this the Federal Republic of Germany proposed initiation of another pilot study, and the F.R.G. will be the new pilot country (with the U.S.A. as a co-pilot). The former meetings of the Expert Panel on Modeling will be continued under the new title "International Technical Meetings on Air Pollution Modeling and its Applications." The first of such meetings (6th International Technical Meeting) was held at Battelle Institute, e.V, Frankfurt, F.R.G. on 24-26 Sept. 1976, and the Proceedings have since been published (NATO/CCMS, 1975). Dr. Dieter Jost of the Umweltbundesamt, Berlin, acted as Chairman and Mr. K.L. Calder (U.S.A.) as Co-chairman.

5.2 Visiting scientists

Mr. Knut E. Grønskei of the Norwegian Institute for Air Research, Kjeller, Norway, returned to the U.S.A. in June 1974, for a six-month visit in the Meteor- logy and Assessment Division, while holding a NATO/Committee on the Challenges of Modern Society (CCMS) Fellowship. During this period he prepared a comprehensive report (Grønskei, 1975) relating to the current and future needs for air quality simulation models, covering their use for environmental impact studies, development of control strategies, land use and transportation planning, comprehensive planning, air pollution episodes, and research on atmospheric processes.

Dr. Frank Pasquill, until recently the Head of the Boundary Layer Research Branch of the Meteorological Office, U.K., and an international authority on atmospheric turbulence and diffusion, spent several months in the U.S.A. during fiscal year 1975. This was under the support of the Meteorology and Assessment Division and its research grants, both with Pennsylvania State University (Select Research Group in Air Pollution Meteorology) and North Carolina State University (Department of Geosciences). At both universities he was a Visiting Professor of Meteorology and gave extensive lectures on atmospheric turbulence and diffusion. During his stay in North Carolina his lectures were attended by many NOAA meteorologists directly concerned with air quality modeling. In addition, he also consulted at both places on a variety of topics of major current interest to modelers. While in Raleigh, N.C., this included extensive discussion relating to the 2nd-order closure schemes for modeling atmospheric turbulence, e.g., the work being conducted by Dr. W.S. Lewellen under contract (Aeronautical Research Associates of Princeton, Inc.) that is discussed elsewhere in this report. Other topics included crosswind dispersion and the properties of turbulence, wind direction fluctuation statistics over long sampling times, "local similarity" treatment of vertical spread from a ground source, representations of dispersion in terms of distance or time, and modeling for elevated sources. Dr. Pasquill authored a report on these miscellaneous topics (Pasquill, 1975). It is anticipated that Dr. Pasquill will continue these extremely valuable services in fiscal year 76 and provide expert consultation regarding the updating of the atmospheric dispersion parameter system that he originated in 1958, and that has since been adopted worldwide as a basis for air pollution concentration predictions.

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7.0 METEOROLOGY LABORATORY STAFF
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