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Fiscal Year 1967 Summary Report of Meteorology Program Support to the National Center for Air Pollution Control U. S. Public Health Service

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U.S. DEPARTMENT OF COMMERCE / ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION

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FISCAL YEAR 1967 SUMMARY REPORT of METEOROLOGY PROGRAM SUPPORT to the NATIONAL CENTER for AIR POLLUTION CONTROL U. S. PUBLIC HEALTH SERVICE

AIR RESOURCES LABORATORY
TECHNICAL MEMORANDUM NO. 4

CINCINNATI, OHIO
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PREFACE

Communication between individuals or groups is a difficult activity. This is especially true of communications about new problems and new research, since much must be left unsaid and many questions unanswered. Nevertheless, periodic summaries of work performed constitute a valuable information source as well as a management "how goes it" tool.

The work reported herein is funded by the Public Health Service and is accomplished under agreement between the Public Health Service and the Environmental Science Services Administration, dated July 27, 1966.

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to the
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The following brief summaries of research and other meteorological activities attempt to convey the present status of a variety of projects being conducted by the Air Resources Cincinnati Laboratory for the National Center for Air Pollution.

Key Words: Air pollution potential forecasting, dispersion models, urban heat island, atmospheric transport, air pollution climatology, turbidity, radon, abatement, long-range tracer studies, and tetroons.

1.0 HIGHLIGHTS

Arrangements were completed for the transfer of the Air Pollution Potential Forecast Program to the Weather Bureau's National Meteorological Center, which will provide, routinely, forecasts of air pollution potential for the contiguous United States.

Analyses of tracer experiments (within the planetary boundary layer) from the St. Louis Dispersion Study indicated the following: (1) during the daytime, both horizontal and vertical dispersion over the urban area at distances to 10 mi from low-level sources is similar to that observed over open country; (2) during the nighttime, vertical dispersion over the urban area is much greater than that observed over the adjacent rural area, a finding that supports the concept of the "heat island" effect often producing a slightly unstable layer of air over the central city at night.

A computer-soluble mathematical Dispersion Model was developed to provide a calculation of the diurnal variation of emissions from space heating and to determine values of plume centerline trajectory and dispersion parameters at positions along the trajectory.

Preliminary investigations of the Urban Heat Island in the Cincinnati area indicate that during nocturnal hours, when clear, light wind conditions persist, an unstable mixed layer of air, about 200 to 300 ft thick, prevails over the center city area while a strong inversion usually exists at the surface in the adjacent rural areas. Downwind of the central-city area, a less stable layer of air overlies the surface-based inversion layer that resides in the rural region. This layer aloft has been identified as an extension of the unstable mixed layer of air from over the downtown region.

Analyses of radar-tracked Constant Volume Balloons (Tetroons) offer statistical evidence for the existence of longitudinal roll-vortices (helices) as major elements in mesoscale circulations in the planetary boundary layer. These helices have been shown to represent an efficient mechanism for the downward transport of momentum.

Sampling and chemical analysis techniques for three inert halogenated gases have been perfected for a gaseous tracer system to obtain dispersion data over relatively long travel distances. Extended-Range Tracer Experiments utilizing sulfur hexafluoride (SF_6) and fluorescent particles simultaneously have been carried out successfully to distances of 115 km.

An Air Pollution Climatology has been prepared for selected locations in the United States; this climatology consists of data on (1) mixing depth, (2) transport wind speed, and (3) pollution potential.

Atmospheric Turbidity is a measure of the mass aerosol content of the atmosphere. Analysis of turbidity network data has indicated that the atmospheric transmission of total solar radiation decreases as turbidity increases. Indicated increases in turbidity over the past several decades may be responsible for a decrease in observed worldwide temperatures, with attendant climate modification effects.

Measurements of Natural Radioactivity (Radon) in an urban-rural environment have shown this technique to be an inexpensive and helpful means of assessing mesoscale vertical mixing rates and dilution in the lower atmosphere. A study has suggested that an urban area does not act effectively as either a source or a sink for radon.

Meteorological support was provided to three Abatement Programs. These consist of (1) identification of pollutant sources in an Illinois city, (2) calculation of sulfur dioxide transport between New York City and New Jersey, and (3) determination of the extent and nature of visibility restrictions at a Midwest air terminal.

2.0 NATIONAL AIR POLLUTION POTENTIAL RESEARCH AND ADVISORY SERVICE

Arrangements were completed for the transfer of the Air Pollution Potential Forecast Program (Miller and Niemeyer, 1963) from the Air Resources Cincinnati Laboratory to the Weather Bureau's National Meteorological Center in Suitland, Maryland. This marked the culmination of a successful 7-year research and development effort to forecast air pollution potential. The Weather Bureau will now provide routine forecasts of air pollution potential conditions for the contiguous United States.

Since August 1960, 83 episodes of high air pollution potential have been forecast; many of these episodes were related to severe local pollution conditions (e.g., the Thanksgiving Week Episode in 1966, which affected many of the metropolitan areas along the East Coast). During the past year 11 episodes of high air pollution potential were forecast (fig. 1)—seven in the East, and four in the West.

Beginning on April 4, 1967, computer data provided by the National Meteorological Center were made available to all Weather Bureau stations on National Teletype Service C. These data are disseminated after the Air Pollution Potential Forecast, which is issued at 1200 EST (1700 GMT). This teletype message includes today's and tomorrow's values of the mixing depth and transport wind speed, for each of the radiosonde stations in the contiguous United States. (Miller, 1967)

The method of calculating today's mixing depth utilizes the morning (1200 GMT) radiosonde sounding and the forecast maximum temperature for that day. This method of calculation has provided reliable values of mixing depth for cases when the air mass over a given station does not undergo any marked changes in thermodynamic structure. During periods of cold air advection, however, this technique underestimates the mixing depth. Recent studies to determine a correction for cases of cold air advection suggest that the forecast maximum temperature can be corrected by a factor based on 850-mb temperature differences between the 1200 GMT and following 0000 GMT soundings. This correction technique is undergoing further analysis.

Comparison of 12- and 36-hr forecasts of transport wind speed with observed wind speed values indicates poor correlation. In an attempt to improve the forecast of transport wind speed, replacement of the barotropic forecast of wind speed with the Primitive Equation Model forecast is being studied.

3.0 LOCAL FORECASTING RESEARCH

3.1 Cincinnati, Ohio

In 1962 the Public Health Service established the Continuous Air Monitoring Program (CAMP) to study several gaseous pollutants of economic and biologic significance in selected major cities. To enhance the interpretation of these sampling data, a receptor-oriented diffusion model was formulated. The model considers the spatial variation of sources and utilizes only routinely available meteorological parameters.

Although the model was initially verified by Cincinnati CAMP data, the analytical relationship between observed pollutant levels and the meteorological and source parameters is adaptable to any location within a given city. The model has been used advantageously to calculate concentrations of sulfur dioxide (SO_2), oxides of nitrogen (NO_x), and hydrocarbons at the CAMP site, and SO_2 concentrations at the Kettering Institute in Cincinnati. It has also been tested on CAMP data in Washington, D. C., and Philadelphia, Pennsylvania.

Since the summer of 1965, the model has been applied as an objective aid in an experimental program to forecast pollutant concentrations at the Cincinnati CAMP station. Early results indicated that a major problem was the inability to forecast the meteorological parameters for the model. Development of techniques to obtain a more accurate forecast of these elements (surface wind speed and direction and the lapse rate within the planetary boundary layer) was added to the objectives of the project.

Other efforts have been made to develop semi-objective aids to forecast the following parameters in the planetary boundary layer: (a) lapse rate; (b) surface wind speed; and (c) wind direction for the period near sunrise. The technique for predicting the build-up of the nocturnal inversion requires knowledge of the geostrophic wind, net radiation, temperature advection, and the thermal properties of the ground. These parameters are related quantitatively to the lapse rate through an adaption of the energy-balance equation for the surface of the earth. A graphical presentation of the technique is shown in figure 2. Given the wind speed, V, at the top of the planetary boundary layer and the total net radiation integrated from the time of sunset, the temperature gradient can be determined. This diagram was constructed for no advective temperature change ($\Delta T = 0$)[1], a depth into the ground of diurnal cooling, h, of 25 cm, and a value of the density-specific heat of the ground, $\rho_g C_g$, of 0.56 cal cm^{-3} T^{-1}. The same diagram can be used to determine the temperature gradient when the advective change is not zero by increasing (warm air advection) or decreasing the net radiation value on the abscissa by the magnitude $\rho_g C_g h \Delta T/2$. To determine the temperature gradient when the values of h and $\rho_g C_g$ are different from those used in figure 2, it is necessary to construct another set of curves. A paper, "A Method for Estimating the Lapse Rate in the Rural Planetary Boundary Layer During Nocturnal Hours" was presented at the Conference on Physical Processes in the Lower Atmosphere, March 20-22, 1967, at the University of Michigan, and is being prepared for publication.

An aid to forecasting the surface wind speed and direction during the period near sunrise was developed from a statistical analysis of the wind and temperature profiles of the 1200 GMT Dayton, Ohio, soundings. Five years of data, 1958 through 1962, were used. The statistics of wind variation at the surface from that at 700 mb were determined as a function of wind speed and stability class. This technique has shown promise and it will be tested this coming year.

Forecasts of pollutant concentrations for the Cincinnati CAMP station, using the receptor-oriented diffusion model (Clarke, 1964), were made on a test basis from June 1966 through January 1967. Values of the meteorological parameters used in the model (wind speed and direction and atmosphere stability class or mixing height) were forecast each workday morning by 1100 EST, to be valid for the periods 1400-1600 EST today and for 0600-0800 EST tomorrow. For the afternoon period the meteorological forecasts were based on (1) techniques

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[1] ΔT is defined as the advective temperature change at 900 mb from the previous 0000 GMT to the 1200 GMT soundings.

developed through the Air Pollution Potential Advisory for forecasting the top of the mixing layer and the average wind speed through the mixing layer and (2) a technique to calculate the surface wind direction and speed during the mid-afternoon convective period from knowledge of the height of the convective layer and the average geostrophic wind in that layer.

The forecast meteorological parameters in the diffusion model predict pollutant concentrations for the Cincinnati CAMP station. The results for oxides of nitrogen for the summer of 1966 are given in figure 3. The results for the fall and winter season are not yet available, since a revised inventory of pollutant sources was obtained late in the reporting period. Forecast values of oxides of nitrogen and sulfur dioxide will be calculated in Fiscal Year 1968. A report will be written to describe the diffusion model, the semi-objective aids to forecasting the meteorological input data, and verification of the forecast.

3.2 St. Louis, Missouri

In response to a request by local officials, an air pollution meteorologist was assigned to St. Louis on January 1, 1966. The primary objectives of this position were (1) to devise techniques for forecasting air pollution potential and air pollutant concentrations over the St. Louis Metropolitan Area and (2) to provide technical assistance to officials of local air pollution control and public health agencies.

In support of the latter objective, liaison was maintained with local air pollution officials through weekly visits and by attendance at meetings of the Interstate Air Pollution Study and the local Air Pollution Control Association. Meteorological assistance was furnished upon request, including lectures to air pollution inspectors and suggestions on location of air monitoring equipment.

In developing techniques for predicting air pollution concentrations for St. Louis, an urban diffusion model was tested daily, beginning in May 1966. By use of observed values of meteorological parameters, calculations of average SO_2 concentrations for the periods 0600-0800 CST and 1400-1600 CST were validated at the St. Louis CAMP station.

The diffusion model requires only a desk calculator to compute concentrations. It is receptor-oriented and considers the spacial variations of sources over a city. For a detailed description of this model, refer to Clarke (1964).

In application of the diffusion model to the city, St. Louis was divided into twelve 30^{o} sectors extending outward from the CAMP station. Each sector was further divided into four areas according to radial distance from the receptor. Based on an average building height of 45.7 m (150 ft) in the vicinity of the receptor, provision was made for enhanced vertical dispersion caused by the city. A source height of 30 m was assumed for all SO_x.

The input SO_x emission inventory[2] was based on data collected during the Interstate Air Pollution Study. Emission rates were given in pounds per summer day and pounds per winter day for individual grid squares, 5000 ft on a side. The grid squares were combined to produce the SO_x emission rates for each area of each 30^{o} sector and then multiplied by appropriate diurnal factors to obtain the emission rates for the two periods, 0600-0800 CST and 1400-1600 CST.

The desired meteorological parameters include surface wind speed and direction, stability, mixing depth, temperature, and heating degree days. Two sites were used for wind measurements. The first was the Weather Bureau site at Lambert Field, where the sensor (Cardion system) was mounted at a height of 20 feet; this station is located 13 mi northwest

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[2] R. Venezia and G. Ozolins, Interstate Air Pollution Study, St. Louis, Phase II, Project II, Project Report, Vol. II, PHS-DAP, Cincinnati, Ohio, May 1966.

of downtown St. Louis. The second source of wind data was the KMOX-TV tower located approximately 4000 ft north of the CAMP station. This tower is instrumented with anemometers at three levels: 127, 250, and 459 ft above street level. With wind speeds over 5 kt both sites yielded essentially the same readings; at lower speeds the winds measured at the tower were considered to be most indicative of the wind field near the receptor.

The stability was determined by the method described by Turner (1964), in which solar altitude and cloud cover are used to determine a net radiation index.

The top of the mixing layer is the height at which the dry adiabatic extension of the surface temperature intersects the observed vertical temperature profile. If no morning urban-rural temperature difference was apparent or if the maximum temperature did not occur in the afternoon, the mixing depth was assumed to be at the base of any inversion shown on the temperature sounding. If no inversion was present, the mixing depth was assumed to be high enough not to affect the calculations.

The morning mixing depth was calculated from an analysis of the St. Louis urban-rural temperature difference and the 1200 GMT radiosonde sounding at either Columbia, Missouri, or Peoria, Illinois, whichever sounding was subjectively determined as most representative of the air mass over St. Louis. The afternoon mixing depth was obtained by applying the St. Louis afternoon maximum temperature to the same sounding.

Heating degree days were determined from the morning minimum and the afternoon maximum temperature at Lambert Field. The number of degree days was then multiplied by the winter SO_x emission rate per heating degree day and added to the summer base-level emission rate. When no heating degree days existed, only the summer base-level emission rate was used in the calculations.

When all of the parameters had been determined, the calculations were performed. Computed concentration in micrograms per cubic meter ($\mu g\ m^{-3}$) were converted to parts per hundred million (pphm). Table 1 lists the results of testing the diffusion model for both the morning and afternoon weekday periods for 12 months. The correlation coefficients obtained for observed and calculated SO_2 concentrations are given for each month; the number of cases used to calculate each coefficient is indicated in parentheses.

Because of consistent overcalculations for the summer season, the SO_x emission inventory was arbitrarily reduced by excluding space-heating emissions. The concentrations for the heating season were then recalculated using only the summer base-level SO_x emission rate from the inventory. The net effect of the exclusion of space-heating emissions was an increase in accuracy, an apparent indication either that the SO_x emission inventory is incorrect or that the model did not provide for adequate dispersion of pollutants. Actually, both factors appear to contribute to the high calculated values.

Considering the alternative that the differences were due to an excessive SO_x emission inventory, the National Coal Association has established that home heating with coal in the St. Louis area decreased approximately 50% since the emission inventory was made in 1963. In addition, the installation of industrial controls and the passing of local air pollution ordinances probably contributed to a decrease in SO_x emissions. On the other hand, the diffusion model could give erroneous values since during periods of relatively low mixing depths, SO_x emissions from tall stacks probably remain trapped in the stable air aloft, but were included in the calculated concentrations because a source height of 30 m was assumed for all emissions. Further analysis of the data is planned.

3.3 Philadelphia, Pennsylvania

An air pollution meteorologist and a technician were assigned to the Weather Bureau Airport Station at Philadelphia to conduct research, leading to the establishment of an operational air pollution forecasting service, by (1) development of mathematical relationships that describe the concentrations of air pollutants for varying time periods and (2) development of techniques for improving the forecast of meteorological parameters used in the models. Also, they provide technical assistance to governmental agencies engaged in air pollution research or control in the Philadelphia area. After preliminary meetings with

state and city officials, it was decided that priority be given to the development of a technique to predict local air pollution potential; the forecast was to be made available in the morning of a given day, and valid for a 24-hr period from the time of issuance.

Initial attempts to correlate 24-hr values of particulate matter concentrations, measured at the CAMP stations, to synoptic features depicted on the Weather Bureau's Daily Weather Map proved unsuccessful.

An alternative procedure was then employed using multiple regression analysis and an "air pollution index" (API) developed by Green (1966). A "least-squares" plane was fitted to data arrayed so that the API based on 24-hr air quality data (SO_2 and COH) was a dependent function of the 24-hr mean wind speed and the morning (1200 GMT) mixing depth. This technique yielded critical values of 750 m for a mixing depth and 6.4 mph for wind speed; values equal to or less than these would define a day of high air pollution potential. Tests on historical air quality data indicated that the technique was workable and might be worth further evaluation.

An experimental forecast program was established for the 5 months from October 1966 through February 1967; daily forecasts were available at 0930 EST. During this period the Laboratory of Environmental Health, City of Philadelphia, specified 34 days as having poor air quality; 29 of those days specified met the established meteorological criteria considered necessary for high air pollution potential days. For these 29 days, high air pollution potential was correctly forecast 96% of the time. The utility of this forecast of local air pollution potential is easily demonstrated when one notes that a National Air Pollution Advisory was in effect over Philadelphia on only 4 of these days. Incorporation of this technique into Weather Bureau forecasting methods for Philadelphia is being studied.

Next it was decided to investigate the possibility of forecasting a numeric value of the air pollution potential index (API). Using the 7094 computer at the Weather Bureau's National Meteorological Center, a model was formulated in which the 24-hr API was a function of the afternoon mixing depth, the 24-hr mean wind speed, the mean temperature, and the morning-to-afternoon change in the mixing depth. Initially, this model yielded a correlation coefficient of 0.810, significant at the 1% probability level. To test this model, all available SO_2 and COH data for the year 1965 (24-hr averages) were obtained from the Philadelphia CAMP station. The API was determined from air quality data, and by use of the model and observed meteorological data, the API was calculated for comparison with air quality data. The correlation coefficient (R) = 0.749 obtained was quite reasonable, although the model tended to undercalculate the API value.

Next, forecast (rather than observed) meteorological parameters were used in the model, except for the afternoon mixing depth. Again most of the API values predicted by the model were lower than the observed values determined from air quality data.

Since some degree of success had been obtained with the statistical development (linear stepwise multiple regression) of the prediction model for the API, it was decided to examine a procedure for the prediction of the Soiling Index (COH). This parameter as a measure of air pollution was suggested by air pollution control personnel of Philadelphia. Because it was difficult to define a specific source strength for the COH parameter, the following analytical technique was applied: the distribution of COH was examined for a 2-yr period, excluding days with precipitation, weekends, and holidays; the top 5% of occurrences were identified (this 95th percentile level (COH > 3.00) was deemed critical by the Laboratory of Environmental Health of the City of Philadelphia); the data were arrayed into two groups -- days with high COH values (> 3.0) and days with low (< 3.0) COH values.

The numeric value of the discriminant function, D, was determined from afternoon mixing depth and 24-hr mean wind speed data to yield:

(a) values of D greater than 0.0 are indicative of days on which potential for pollution is high (COH > 3.00);

(b) values of D less than 0.0 define days during which COH $\leq$ 3.0 (95% value of the distribution).

The function D has the capability of including other descriptive meteorological variables such as temperature, degree days, etc. The technique is completely machine-compatible, and forecasts of D-values have been made locally in real time, although not verified because of lack of observed pollutant data. When the meteorological conditions do not specify high air pollution potential (COH > 3.00), this procedure determines the expected 24-hr average COH value in terms of the 24-hr mean wind speed, the afternoon mixing depth, degree days, and the change in mixing depths from morning to afternoon. An initial evaluation indicates that this technique looks promising.

One aspect of the current research program is development of techniques for improving the prediction of meteorological parameters affecting air pollution potential. A project was initiated to forecast the 24-hr mean surface wind speed, the forecast value to be available by 0900 EST. An objective technique was developed by use of a simple linear regression:

$$U_{24} = K + K'U' \quad ,$$

where

U_{24} = 24-hr mean surface wind speed in mph, beginning at 0900 E,

U' = preceding average surface wind speed determined from 00-09E based on observations, and

K and K' = regression constants.

A separate equation was developed for each month. The standard errors of estimate by month ranged between 1.1 and 2.2 mph; these values are based on historical data and operational forecasts and they are equally good for independent data.

To be of significant value, such a technique should be extended to include a forecast of tomorrow's 24-hr mean surface wind speed, today. Such a technique has been developed and is currently being tested. For the month of June the standard error of these forecasts was 2.1 mph. Because of a need for short-period forecast (e.g., morning or afternoon) an effort is being made to develop methods of predicting the temporal distribution of wind speeds within the 36-hr period.

Since no temperature soundings are available for Philadelphia, it was necessary to devise a technique for estimating the morning and afternoon mixing depths. For a period of 2 months, soundings for Washington, D. C. (DCA), Pittsburgh (PIT), and New York (JFK) were plotted and the mixing depths (morning and afternoon) were calculated for each station. These values were analyzed with respect to the height of the haze layer over Philadelphia, reported by outbound aircraft pilots. This analysis suggested that the mixing depth calculated from JFK was most representative of the mixing depth for Philadelphia.

3.4 New York, N. Y.

From the spring of 1963 to January 1, 1967, an air pollution meteorologist was assigned to the Weather Bureau Office in New York City. His primary activities were devoted to research and to the development and validation of urban dispersion models to provide a basis for forecasting air pollution in the New York Metropolitan Area. In addition he provided consultative services to the New York City Department of Air Pollution Control, particularly during critical air pollution situations.

An effort was made to adapt the analytical diffusion model of Miller and Holzworth (1967) to calculate morning and afternoon sulfur dioxide (SO_2) concentrations, which were compared with values measured at the New York City Air Pollution Laboratory in Manhattan. An SO_2 emission inventory for 1-sq-mi areas was made available by New York University. For application to the model, 30% of the emissions were assumed constant throughout the year and the remainder was treated as a function of degree-day values. The average emission rate was determined for sectors emanating from the New York Pollution Laboratory and centered on each

of the eight primary wind-direction sectors. In addition to the emission rate, the input parameters used in the model were mixing depth, wind speed, and city size -- the latter varying with wind direction.

Calculated and measured concentrations of SO_2 were compared for the 5-yr period, 1962-1966. The correlation coefficients varied irregularly from quite good ($r = .81$) to poor ($r = -.11$). One reason for some of the poor correlation was thought to be unreliable SO_2 emission data. A comparison of the observed monthly frequencies of SO_2 concentrations for 1965 with those measured during 1960-1964 indicated significantly higher concentrations in 1965 than could be accounted for by meteorological conditions. In addition there were times when the SO_2 measurements and the model calculations did not seem to reflect meteorological conditions. Another difficulty arose in determining the wind field. It was felt that at certain times the contribution of SO_2 concentrations from sources upwind of metropolitan New York City may have a significant effect on the concentrations in Manhattan. Finally, the model itself may not be sufficiently comprehensive to account for all the complexities in New York City.

During the first half of the year further calculations and validations of the analytical diffusion model were carried out and possible refinements in the model were investigated. Also, the receptor-oriented urban diffusion model of Clarke (1964) was tested on additional data. This model is similar to the Miller-Holzworth model except that each sector is divided into four consecutive upwind areas, in which uniform emission rates are assumed for each (a total of 32 areas for all eight directions); also, a larger variation of the coefficient value (standard deviation of vertical concentration, σ_z), which is dependent upon solar radiation, wind speed, and cloudiness, is utilized. In the past, calculated concentrations from this model were similar to those obtained from the Miller-Holzworth model.

For comparison of calculated with observed SO_2 concentrations, categories of concentrations were based on historical data. The range of concentration values in each category was selected to be at least 7 pphm SO_2 and to include at least 10% of all observations. In the comparisons some overlapping of adjacent categories was permitted.

The number of categories for the Manhattan Pollution Laboratory data ranged from four in summer to seven in January. In addition to the usual correlation coefficients for observed and calculated concentrations, the skill scores, S, were computed for the comparisons by categories using

$$S = \frac{R - E}{T - E} \quad ,$$

where R = total number of calculations in correct categories,

T = total number of all calculations, and

E = total number of calculations expected correct based on historical data.

For the analytic (Miller-Holzworth) model the average correlation coefficients, r, and skill scores, S, for July 1965 through June 1966 were as follows:

	r	S
0700-1000 EST	0.56	0.60
1200-1600 EST	0.57	0.60

with the range of monthly r's from -0.11 to 0.81 and for the S's from 0.38 to 0.92.

For Clarke's receptor-oriented model the average correlation coefficients, r, and skill scores, S, for September 1965 through May 1966 were as follows:

	r	S
0700-1000 EST	0.64	0.55
1200-1600 EST	0.53	0.63

with the range of monthly r's from 0.31 to 0.79 and for the S's from 0.29 to 0.77.

Throughout the extensive air pollution incident that affected New York City during Thanksgiving week of 1966 the air pollution meteorologist provided special briefings on the weather situation as requested by city officials. News media also were provided weather information. The termination of this pollution incident after passage of a cold front was accurately forecast.

On January 1, 1967, the position of the air pollution meteorologist in New York City was transferred to the Weather Bureau.

4.0 URBAN STUDIES

4.1 St. Louis Dispersion Study

A 2-yr experimental program was conducted in St. Louis, beginning in the spring of 1963, to assess the diffusion of tracer material (zinc cadmium sulfide) over an urban area, and to relate that diffusion to measured meteorological parameters. A meteorological network, consisting of three outlying sites and a television tower in downtown St. Louis, was instrumented to provide climatological information on airflow and temperature patterns as well as useful weather information for conducting tracer experiments. This network was supplemented during experiments by single-theodolite observations of winds aloft, measurements of wind near the surface made at the tracer dissemination site, transponder-equipped tetroons released into the tracer cloud, and free or tethered radiosonde ascents made from downtown St. Louis. Forty-two tracer experiments were conducted in seven series during this study. Disseminations from either of two pre-selected sites were generally of 1-hr duration. Measurements of total and sequential dosages were obtained from analysis of tracer concentrations measured on three nearly circular arcs at distances out to 10 mi from the dissemination sites. During nine of the experiments tracer measurements were obtained at several heights along the tether of a balloon flown at a single location.

An analysis of the individual experiments has been completed; dispersion parameters were obtained for 32 of the 42 experiments. For each of these experiments, statistical estimates of the cross-wind integrated concentration, CIC, were obtained for the three sampling arcs. Analyses of dispersion in the vertical and of the mean transport wind, $\bar{u}$, differed in daytime and evening experiments. For the daytime experiments, estimates of $\bar{u}$ were usually obtained from the mean tetroon trajectories and less regularly from the television tower, pilot-balloon wind profiles, or sequential sampler measurements of the rate of travel of the tracer clouds. Derived estimates of the vertical spread of the tracer cloud, σ_z, were then computed from the continuity equation, assuming a Gaussian distribution of tracer material in the vertical and $\bar{u}$ constant with height. For the evening experiments a simple model was devised, based on the assumption of a power law wind profile and a uniformly mixed tracer cloud of depth, h, increasing linearly with time. The development of a more complex model was not thought to be justified in view of the limitations of the data. Coefficients for the wind profiles were computed from the television tower or pilot-balloon wind profiles. Estimates of h and $\bar{u}$ were calculated from the continuity equation, assuming $\bar{u}$ to be the mean wind through depth h.

A preliminary analysis of the tracer experiments in conjunction with meteorological parameters was published by Pooler (1966). These results indicate that horizontal dispersion over an urban area does not differ greatly from that observed over open country, except for a much greater initial spreading of the tracer plume. Vertical dispersion during the daytime

does not appear to differ greatly from that observed over open country. However, vertical dispersion over an urban area during the evening appears to be much greater than that observed over open country. The limited results obtained suggest the formation of a slightly unstable layer as the air flows over the city.

More detailed analyses of the results of the tracer experiments with respect to meteorological parameters are being performed to determine how well dispersion over urban areas can be described or predicted. Utilizing meteorological data in the St. Louis area, plots of σ_y versus travel distance, x, and versus travel time, t (defined as $x/\bar{u}$), were categorized according to a) the extreme, the third highest, and fifth highest ranges of wind direction fluctuations over the tracer dissemination period, b) a modified "Smith and Singer gustiness class" scheme (Singer and Smith, 1953), and c) the "Pasquill-Turner stability class" scheme (Turner, 1964). Ranges of wind direction fluctuations are being used to estimate the standard deviation of the wind direction fluctuation, σ_ϑ. The third and fifth highest ranges of direction, as well as the extreme ranges, were computed since it was believed that these lower ranges would provide more consistent estimates of σ_ϑ than would the more extreme ranges. This technique compares the range of the wind direction fluctuation with gustiness. Cloud cover information for use with the Pasquill-Turner method was obtained from records of the hourly observations at the Weather Bureau Station at Lambert Field, west of downtown St. Louis.

Correlograms of σ_y versus x and t were plotted as functions of meteorological parameters; this yielded a large scatter of points. Correlation of diffusion parameters with meteorology was poorest for the close-in sampling arcs. Bimodal or multimodal cross-wind distributions occurred yielding a non-Gaussian distribution of σ_y values. In general little difference in correlation between meteorology and calculated diffusion parameters was observed for any of the meteorological stations. Comments on these results are reserved until a more detailed analysis of the data is made.

Plots of the vertical dispersion parameter (σ_z) and axial (i.e., peak on each arc) surface concentration, $(\chi/Q)_p$ for daytime and nighttime releases, versus travel distance and versus travel time were also categorized by the forementioned methods, for each of the meteorological stations. These plots generally disclosed a large scatter, with limited distribution for the close-in arcs, and very wide distribution for neutral stability conditions. Little difference was found when different meteorological stations were used. Differences in distribution between travel distance and travel time were also noted. Again, further discussion will be delayed until the effects of stability parameters and wind speed on the data distribution are determined.

Estimates of vertical stability were obtained from the vertical temperature and wind gradient data obtained on the tower and by radiosonde. Computations of temperature lapse rates, gradient Richardson numbers, and bulk Richardson numbers were made for the lower atmosphere. Estimates of afternoon mixing depths were made from the analysis of radiosonde ascents; these data will be used in the analysis of the vertical dispersion spread and its relation to $(\chi/Q)_p$ plots.

Utilizing tetroon, pibal, tower, and surface wind data, mean wind speeds ($\bar{u}$) over the interval of tracer dissemination were computed for comparison with the computed mean wind speeds determined from an analysis of the tracer data. Preliminary evaluation of the meteorological measurements indicated that the sensors at the periphery network stations and at the lowest level on the tower underestimate the mean wind speed in the layer for both daytime and evening. The wind sensor at the upper level of the tower appears to give the most representative measure of the mean wind speed affecting the tracer plume in the daytime, even though it overestimates the mean wind for the evening cases. Aerovanes were used at the peripheral sites and on the tower.

Estimates of σ_ϑ are being made from the analog wind direction traces to allow comparisons with the computed ranges of the wind fluctuations and to assist in analysis of the dispersion data. One technique assumes that the distributions of wind direction versus time are either Gaussian or are a summation of Gaussian distributions. Calculations were made using the edges of the wind traces (absolute direction range) rather than the usually "painted" central portions. Statistical comparisons of these estimates of σ_ϑ with ranges of wind direction fluctuations recorded at a peripheral station and by the lower and upper sensors on the downtown television tower indicated a linear relationship in each instance. The results are

presented in Table 2. As indicated, the third highest range appears to give the most reliable estimate of σ_y. These results are compatible with those of other investigations that have related wind direction range to σ_θ, to yield a fluctuation constant of about 6.

The nine experiments with measurements of tracer concentration at various elevations above a single location were analyzed in detail. For two of the experiments, dosage increased with height; for both instances, considerable vertical wind shear existed.

4.2 Urban Diffusion Modelling

In principle, accurate forecasts of atmospheric pollutant concentration require an accurate assessment of meteorological parameters as well as pollutant source strength values. Efforts are being made to develop and validate urban diffusion models that will provide accurate forecasts of pollutant concentrations, which in turn can serve as a basis for optimum air quality meanagement through the following applications: (1) for planning and zoning to assess the impact on air quality from changes in fuel usage or composition by industrial or domestic sources, and from proposed new sources or the removal of old ones; (2) for estimating the spatial extent of critical concentrations of important pollutants in a community; (3) for research and survey purposes to provide a basis for the strategic location of air sampling equipment and to aid in the interpretation of air quality data; (4) for evaluating the effects of control procedures designed to prevent the occurrence of critical concentrations; and (5) for determining relative cost-benefit data with respect to potential abatement and/or control measures.

The diffusion model used for the St. Louis metropolitan area calculates SO_2 concentrations for 24-hr periods by 2-hr increments at a 19 by 17 rectangular array of receptor points, orthogonally spaced every 5000 ft. This model uses source strengths from an inventory of SO_2 emissions for 1200 area sources (a 30 x 40 array) and for 62 "point" sources. A trajectory approximating the path of the pollutant plume is calculated for each 2 hr for each source (or group of sources in the case of area sources). The contribution to the concentration from each source is calculated for all receptor points affected by each pollutant plume. Calculations are made by electronic computer.

A method was devised to determine the diurnal variation of emissions from space heating sources for use in the model and presented in a paper entitled, "The Diurnal and Day-to-Day Variations of Fuel Use for Space Heating," to be submitted for publication. A computer program was written and checked to calculate SO_2 emissions from all sources for any 2-hr period during the winter. This forms one major subroutine for the dispersion model program.

Another subroutine was written and checked to calculate plume centerline trajectories, for each 2-hr emission determine the dispersion parameter values at points along the trajectories, calculate the effective wind speed through the plume, determine the receptor points affected by the plume, and calculate the concentration at these points for the source under consideration. A sample trajectory consisting of a number of line segments is shown as the solid line in figure 4. Trajectories are not calculated for each of the 1200 area sources but for each group of 25. One such group of 25 (5 x 5) area sources is shown in figure 4. A trajectory is calculated for the center source of each group. The trajectory for each of the other 24 area sources is assumed to have the same shape but to have its origin at the center of the source being considered, e.g., the dashed trajectory in figure 4. Individual trajectories are calculated for each of the 62 point sources. Figure 5 shows the same plume centerline trajectory of (fig. 4), but the appropriate plume boundaries are indicated as dashed lines; this example represents a 2-hr emission beginning at time, T. The receptor area is shown as the dashed square. The number in figure 5 indicates the 2-hr period affected by various portions of the plume. T + 0 indicates the 2-hr period of the pollutant emission; T + 4 indicates the period of reception 4 hr after emission. The solid lines across the trajectory separate the time periods.

In order to calculate the plume trajectory and assess atmospheric dilution, wind and stability information over the source areas was specified at 20 points (a 4 x 5 array) with a grid spacing of 50,000 feet. The wind velocity and stability are determined at the end of each segment of the trajectory by double linear interpolation of the information at the specified points. A method has been devised to enable changing from one stability class to another at the end points of trajectory segments, as may be required by the meteorological

data. Two examples of the change with time of the vertical dispersion parameter, σ_z, are shown in figure 6. The dashed lines show the usual variation of σ_z with time when the various stability classes remain constant. The examples of change of stability with time are shown by solid lines.

A program was written and used to read permanent data such as the components of the emission (residential, commercial, and industrial) for area and point sources, coordinates of point sources, coefficients for dispersion parameters, etc.; this information is written on a magnetic tape. The dispersion model program was written to read the above tape, to read meteorological input data on cards for the desired calculation periods, to call the subroutine for calculating source strengths, to call the trajectory and concentration calculations for both area and point sources, and to produce the required printed and punch card output. This program and its components have been checked out on the CDC 6600 computer at the National Meteorological Center at Suitland, Maryland, and production computer runs have begun for the 90-day period for which actual (measured) SO_2 concentrations are available. Measurements of actual 24-hr SO_2 concentrations are available at 40 stations, and 2-hr concentrations are available at 10 stations.

Because of the volume of data — 3600 pairs of observed and calculated 24-hr concentrations and 10,800 pairs of 2-hr concentrations — analysis of the results will be done mostly by computer. Two programs for analysis have been written, and one of these was checked with test data. Production computer runs for the 90-day study period will be completed. Analysis of the dispersion model results, consisting mainly of calculated SO_2 concentrations compared with actual SO_2 concentrations, will be completed. A report describing the model and the results of the study will be written and submitted for review and publication.

4.3 Urban Heat Island Study

Further progress in the development of analytical diffusion models, to describe the transport and diffusion of air pollutants in urban areas and to forecast pollutant concentrations on the urban scale, will require better definition and mathematical simulation of the spatial and temporal variations of turbulence structure in the atmosphere over urban areas. A more complete knowledge of the air structure over urban areas during two periods is needed: (a) the nocturnal hours, when urban and rural environments differ most markedly and (b) the stability transition period following sunrise, when the higher hourly concentrations of non-reactive pollutants are normally observed. An investigation of the structure of urban atmospheres was initiated in the latter part of Fiscal Year 1967. Initial efforts have dealt only with the period near sunrise in the Cincinnati Metropolitan Area.

Surface minimum temperature data were obtained from a network of 16 observing stations in the Cincinnati area. The spatial variation of minimum temperature was analyzed on 17 days encompassing a wide range of meteorological conditions. An urban heat island was apparent on all days. The horizontal temperature difference between urban and rural sites varied from 3° to 14°F; this temperature gradient was greater with increasing stability of the lower atmosphere in the rural area (as indicated by the 0700 EST temperature soundings at Dayton, Ohio). The magnitude of the heat island also appeared to be inversely related to surface wind speed and temperature.

On three occasions the vertical extent of the heat island was assessed by vertical temperature measurements from a helicopter. Vertical soundings were made at selected locations along the path of air flowing over the city, determined from a series of pilot balloon and a surface wind observations in the area. An automobile carrying an aspirated thermistor made several traverses over a surface route which closely approximated that along which the helicopter travelled aloft. The experiments were conducted from about one hour before to about one-half hour after sunrise.

The general topography of the area is shown in figure 7: downtown Cincinnati is located in the Ohio River basin at an elevation of about 550 ft msl; the basin is surrounded by steep hills rising 200 to 400 ft to the general level of a plateau at about 900 ft msl.

The results of the first experiment (May 23, 1967), shown in figure 7, indicated that an isothermal or slight inversion surface layer, capped by a moderate inversion, existed in the

rural area upwind of the city. The vertical temperature profile in the built-up areas of the city was characterized by a superadiabatic surface layer up to about 200 ft above the ground. At that level an adiabatic to isothermal condition began and extended to the base of a moderately stable layer (1400 ft msl), which appeared to be continuous with that of the upwind rural area. Downwind (south) of the city a stable surface layer existed. The wind speed during this experiment increased from 5 mph at the surface (487 ft msl) to a low-level maximum of 23 mph at about 1350 ft msl. During the experiments on June 13 and 15, 1967, the meteorological conditions were similar; the results are described in a composite summary.

The urban mixed layer appeared to extend 200 to 300 ft above the surface and was capped by a very stable layer aloft. This mixed layer existed over the central business district, while a slightly stable layer persisted over the suburban areas downwind of the city and throughout the industrial valley. In the rural sections downwind of the downtown area a very stable layer was re-established at the surface; between this shallow stable layer and the very stable layer aloft there was a shallow layer less stable than that near the ground, suggesting that the urban layer still existed aloft downwind of the city. Over the entire area the temperature profile above 1000 ft msl was essentially unchanged during the course of the experiments.

Preliminary conclusions from the three experiments are that 1) during nocturnal hours the unstable (near-adiabatic) urban mixed layer is relatively shallow (200 to 300 ft); 2) with light winds and a strong inversion in the surface layer of the rural atmosphere, the temperature structure in the surface layer of the area surrounding the central business district is isothermal to slight inversion; this layer is relatively shallow, extending 200 to 300 ft above ground; 3) downwind of the city a stable inversion layer is re-established at the surface while above it occurs a less stable layer, which can be identified as an extension aloft of the unstable surface layer over the downtown area.

During the coming fiscal year studies of the Cincinnati urban heat island will be continued. Observations will be extended to include the total heat-island cycle from formation in the late afternoon to dissipation in late morning. Pilot balloon observations will be obtained at two or three locations along a prescribed route to measure the urban modification of the wind profile. Tracer experiments will be conducted to measure dispersion within the various stability layers over and downwind of the city. From these studies an attempt will be made to model the structure of the urban atmosphere.

5.0 TRAJECTORY STUDIES

5.1 Constant-Volume Balloon (Tetroon) Studies

(This program is a joint effort carried out by personnel of the Air Resources Laboratories in Silver Spring, Maryland, and in field offices. Support is provided jointly by the Atomic Energy Commission and the Public Health Service.)

A major tetroon experiment was carried out at the National Reactor Testing Station (NRTS) in Idaho. Transponder-equipped tetroons were ballasted to float 300 m above the ground and were tracked by two M-33 radars. One radar tracked two flights released simultaneously from sites 500 m apart (in a direction generally perpendicular to the mean flow) and the other radar tracked two flights released simultaneously from the same sites about one-half hour later. During the experiment, four tetroons were tracked simultaneously for periods of several hours. These totalled 13 hr of simultaneous four-tetroon tracks.

The primary purpose of the experiment was to verify the existence of longitudinal roll-vortices (helices) in the planetary boundary layer. Most of the tetroons released in the afternoon exhibited such corkscrew motions. As an example, figure 8 shows trajectories projected into a transverse (vertical-lateral) plane for simultaneously released flights 5A-B and 7A-B. Although these flight pairs were released only 1 hour apart, they vary greatly in the degree of lateral separation. The large lateral separation between flights 5A and 5B provides evidence for the existence of adjacent, counter-rotating helical circulations. The more usual case is represented by flights 7A-B, where lateral separation was slight and consequently both flights underwent a similar sense of rotation in the transverse plane.

Angular velocities in the transverse plane were estimated, at 15-min intervals, by finding the circle that passes through three successive 15-min positions of the tetroon in the transverse plane, and then determining (with the given radius of trajectory curvature) the angular displacement for the 30-min interval. Figure 9 shows histograms of the radius of trajectory curvature and angular velocity for the afternoon flights. There is considerable evidence that the helical flow is one of solid rotation. Consequently, the vorticity in the transverse plane can be estimated by doubling the values of angular velocity presented in figure 9. Thereby it is found that the vorticity about the longitudinal axis averages about 40 times the vorticity of the earth about the local vertical. Furthermore, it can be shown that the vorticity about the longitudinal axis is an order of magnitude larger than the vorticity resulting from the shear of the longitudinal wind with height. It is apparent that at least at the NRTS, the longitudinal roll-vortices represent a major element in meso-scale circulations during the afternoon.

The average tetroon-derived value of the vertical momentum flux during the afternoon was 5 dynes cm^{-2}. Thus, the helices represent an efficient mechanism for the downward transport of momentum. It has been found that this momentum flux is highly correlated with helix size. There is little evidence for kinetic energy flux from mean flow to helix during the afternoon. Consequently, at this time, it is believed that the helices are maintained by buoyancy forces.

5.2 Extended-Range Tracer Studies

The development and testing of sampling and analytical techniques for several halogenated atmospheric tracers is being conducted in the Cincinnati area. These include sulfur hexafluoride (SF_6), octafluorocyclobutane (C_4F_8), and bromotrifluoromethane ($CBrF_3$); analytical sensitivities of 10^{-8} ppm for SF_6 and 30×10^{-5} ppm for the other two gases have been achieved. Of significance to air pollution meteorology is the fact that these three inert gases have been added to the inventory of tracer materials available for diffusion experiments.

During the past year five extended-range experiments were carried out to distances of 115 km. The extended-range experiments were conducted with a fluorescent particle (FP) tracer and a gaseous tracer, SF_6. The objectives of the long-range tracer experiments are (1) to perfect a gaseous tracer system, and (2) to obtain quantitative diffusion data over extended ranges, for which knowledge is almost nonexistent.

Table 3 presents a brief summary of meteorological conditions during the long-range experiments. Normalized "centerline" concentrations observed in the long-range experiments are shown in figure 10. Although data from only three experiments are available, the normalized concentrations observed under near-neutral conditions do not depart significantly from normalized concentrations expected from extrapolation of results of shorter-range experiments; extrapolated concentrations (normalized) in near-neutral conditions are shown in figure 10. Although data from only three experiments are available, the normalized concentrations observed under near-neutral conditions do not depart significantly from normalized concentrations expected from extrapolation of results of shorter-range experiments; extrapolated concentrations (normalized) in near-neutral conditions are shown in figure 10 by the line designated "C," (a Pasquill atmospheric stability class). A summary of these experiments, "Some Results of Multiple-Tracer Diffusion Experiments at Cincinnati", was presented at the 60th Annual Meeting of the APCA in Cleveland, by L. E. Niemeyer and R. A. McCormick.

Future plans call for long-range (100 mi) multiple tracer experiments to be continued in the vicinity of Cincinnati to increase our understanding of intercity-scale transport and dispersion and to perfect techniques for anticipated multitracer experiments in other urban areas.

6.0 CLIMATOLOGY

6.1 Air Pollution Potential

In recent years air pollution meteorologists have employed mixing depth (height above ground of effective vertical mixing) and transport wind speed (within the mixing depth) as the primary meteorological parameters in the National Air Pollution Potential Forecasting

Program. These parameters have also been used as the basic meteorological input to urban diffusion modeling. Because of their general utility and broad applications, an effort is being made to compile the climatology of these parameters. This task is facilitated by the fact that values of mixing depth and transport wind speed are derived from radiosonde data that have been collected routinely by the Weather Bureau at about 70 locations throughout the contiguous United States.

Since mixing depths typically display a large diurnal variation, they have been calculated for two different times of the day: Both calculations are based on data obtained from the 1200 GMT (0700 EST) radiosonde observation. The afternoon mixing depth (height above the ground) is determined by extending the maximum surface temperature, observed between 1200 and 1600 LST, dry adiabatically until it intersects the observed vertical temperature profile. The morning mixing depth over an urban area is defined similarly, except 5°C is added to the minimum surface temperature from 0200 to 0600 LST and used instead of the maximum temperature. The "plus 5°C" factor is to allow for the usual difference between urban and rural minimum temperatures, and for some usual surface heating after sunrise. Thus, morning mixing depths approximate conditions over urban areas near the time of the morning rush hour when pollutant emission rates and concentrations of nonreactive pollutants are usually greatest. The afternoon mixing depth is based on the daily maximum temperature, which is not significantly different in urban and nearby rural areas; this calculation yields a mixing depth value representative of a period when pollutant concentrations usually are comparatively low.

The transport wind speed is the arithmetic average of observed speeds through the mixing depth. The morning speed is based on the 1200 GMT (0700 EST) sounding and the average surface speed from 0700 to 1100 GMT. The afternoon transport speed is based on the 0000 GMT (1900 EST) sounding and the average surface speed from 1900-2300 GMT. If significant precipitation occurs during the morning or afternoon period, the mixing depth and transport speed are classified as "precipitation." Only nonprecipitation cases are discussed in this report.

Tabulations of mixing depth and transport wind speed are being accomplished by the National Weather Records Center in three parts: the first gives the values for each morning and afternoon, and monthly and seasonal averages; the second gives the frequency of occurrence of various combinations of mixing depth and transport speed by month and season; the third gives the frequency of occurrence of episodes of defined air pollution potential of various durations during which specified values of mixing depths and transport speed were not exceeded. To date tabulations for 5 years, 1960-1964, have been received and studied for seven stations, (Columbia, Missouri; Dayton, Ohio; Los Angeles; Nashville; New York City; Pittsburgh; and Salt Lake City.) Tabulations for Washington, D. C., were received recently but have not been evaluated.

Figure 11 shows the average monthly morning and afternoon mixing depths for Columbia, New York, Salt Lake City, and Los Angeles. The values for Columbia are rather similar to those for Dayton, Nashville, and Pittsburgh (not shown). Summertime mixing depths at Salt Lake City display an extremely large diurnal variation (note folded scale for afternoon values) with morning values around 200 m and afternoon values exceeding 3000 m. Los Angeles is characterized by shallow afternoon mixing depths and small diurnal variation during the warm season.

Figure 12 shows average monthly transport speeds for these stations. Except for one case, the afternoon speeds are somewhat higher than the morning speeds. Speeds at New York generally are a little higher than at Columbia and both places show minima during the warm season. At Los Angeles and Salt Lake City the afternoon speeds are similar and the minima occur during the cold season. Morning speeds at Los Angeles are quite low, not exceeding 3 m/s.

An an example of tabulations of the frequency of occurrence of various combinations of mixing depth and transport speed, Table 4 shows the percentage values for autumn afternoons at Los Angeles. Since mixing depth, transport speed, and city size are the parameters used in a diffusion model for metropolitan areas, (Miller and Holzworth, 1967), data in Table 4 may be evaluated quantitatively in terms of the meteorological potential for community air pollution. The Miller-Holzworth model assumes that the pollutants are nonreactive and diffuse from a series of cross-wind line sources until they reach the top of the mixing layer; thereafter, a uniform vertical distribution of pollutants persists. Pollutant emission rates are assumed uniform over each city. The model gives the relative pollutant concentration

(concentration relative to emission rate) averaged over the city. Figure 13 shows the annual cumulative percent frequency of theoretical relative concentrations averaged over Los Angeles, whose size (linear dimension of city) was assumed to be 60 km. The figure shows clearly that high relative concentrations are expected more frequently in the morning than in the afternoon, reflecting the diurnal variation of mixing depths and transport speeds. At the 50 percentile frequency the average relative concentration over Los Angeles for afternoons is 18 s/m, while for morning it is 55 s/m.

For comparison of atmospheric dilution, all cities were assumed to be the same size in computations of relative concentrations; results are summarized briefly in Table 5, which shows the average relative concentrations expected to be exceeded 10, 50, and 90% of the time. The 50 percentile values indicate that poorest dispersion conditions occur at Salt Lake City, followed in order by Los Angeles, St. Louis, and New York.

The material discussed to this point has been prepared for publication("Mixing Depths, Wind Speeds, and Air Pollution Potential for Selected Locations in the United States") and submitted to the Journal of Applied Meteorology.

As mentioned earlier, tabulations have also been obtained of the frequency of episodes (of variable duration) during which specified values of mixing depth and transport speed were not exceeded. Table 6 shows an example of the tabulation. For the seven stations analyzed so far, Los Angeles and Salt Lake City reported the transport speeds of 4.0 m/s or less. Each of these episodes lasted for 10 days (20 consecutive 12-hr periods). Los Angeles and Salt Lake City were the only two stations with episodes longer than 5 days. In general, episodes of longer duration occurred most often in winter and autumn. Except for these two occurrences, episodes at the other stations did not exceed 3 days.

It is planned to extend the tabulations of mixing depth and transport wind speed to additional stations and to analyze the data further. In particular, a means of approximating the potential effects of precipitation will be sought and incorporated into the study. As sufficient tabulations become available, analyses will be prepared to depict the spatial variation of the meteorological dispersion parameters over the United States.

6.2 Atmospheric Turbidity

The primary purpose of this project, initiated in 1960, is to obtain and use the measurements of atmospheric turbidity as quantitative indicators of the aerosol content of urban atmospheres.

A turbidity observation network of about 35 stations in the continental United States, Hawaii, and Panama, is being maintained in cooperation with the Weather Bureau and other public and private agencies. Each station is equipped with a Volz-type sunphotometer to measure the turbidity coefficient, B, at 5000 Å wavelength; B is proportional to the number of particles (0.1 to 1.0 μ size range) between the instrument and the sun. The calibration technique and instrument construction are being modified to improve the data comparability and provide greater stability in the instrument.

The turbidity network data are being summarized for the period of record to provide a turbidity climatology for the United States. Figure 14 shows average monthly turbidity values (measurements on days with 100% possible sunshine and no clouds reported) for several rural and urban sites. Measurements in rural communities like St. Cloud and Huron give a background of the normal atmospheric aerosol content whereas measurements at urban sites such as New York City and Cincinnati indicate the aerosol contribution from large concentrations of residential and industrial sources. It has been found that the mass loading of the total atmosphere in micrograms per cubic meter ($\mu g\ m^{-3}$) may be estimated roughly by multiplying the B value by 10^3. Thus over downtown Cincinnati in July, the average mass loading is about 220 $\mu g\ m^{-3}$ while the background value from measurements at Huron or St. Cloud is about 95 $\mu g\ m^{-3}$. On days with severe pollution, values for Cincinnati and most other cities are two or three times higher than average.

One of the most important factors governing the best balance of the earth-atmosphere systems is the planetary reflectivity or albedo. A suspected secular trend in atmospheric turbidity affecting this heat balance has been the subject of recent investigation.

Angstrom has suggested that a 10% change in turbidity will produce about a 1.5% change in albedo; also that a 1% change in the earth's albedo corresponds to a change in the mean temperature of the earth of close to 1°C providing the average cloud amount does not change.

Preliminary evidence has indicated that the relatively large decrease of solar transmission during clear days can be largely attributed to a deterioration of the pyranometers and changes in the data-reduction procedure. Thirteen stations, mostly in western states, were visited and comparison data obtained from the station pyranometer and several tertiary standards. In every instance in which the preliminary data had indicated a decrease in transmission, the station pyranometer was found to be in poor condition. The color of the black annular ring of the pyranometer had changed to gray or gray-green, resulting in a decrease in sensitivity as high as 12-1/2% in one instance. Study of data-reduction procedures revealed two factors that tended to accentuate the apparent decline in transmission: (1) In July 1957 the basis for calibration of the pyranometers changed from the Smithsonian scale to the International Pyrheliometric scale, resulting in a 2% change; (2) In January 1965 the accepted value of the solar constant was changed from 1.94 to 2.00 Langleys per minute, resulting in a 3% change. Both of these procedural changes caused decreases in tabulated solar transmissions. Figure 15 presents both the uncorrected and the corrected transmission data for several stations. In almost every case, the apparent decline in transmission vanished when the data were adjusted for the known errors.

A paper by McCormick and Ludwig (1967) presents evidence that the atmospheric transmission of total solar radiation decreases with an increase in turbidity. The instrument now being used to obtain data for the solar radiation network does not appear to be sensitive enough to detect small changes in long-term trends of solar transmission that could be due to increasing global air pollution.

A study of current and past turbidity measurements made at Washington, D. C., and Davos, Switzerland, has suggested that the observed increase in turbidity over the past several decades may be responsible for the decrease (since 1940) in worldwide temperatures. The increase in average annual turbidity, β, for Washington and Davos is shown in Table 7. The turbidity is expressed by Angstrom's turbidity factor, β, which is approximately equal to B, the turbidity coefficient, divided by 1.07.

The increase in turbidity indicated for Davos may be representative of a worldwide buildup, whereas part of the increase for Washington is probably due to increased population and urbanization. The β values indicate increases in the average annual number of aerosol particles, in the size range 0.1 to 1.0 μ radius, of 2.8×10^7 cm^{-2} at Washington and 1.05×10^7 cm^{-2} at Davos.

Turbidity and solar transmission data for selected days for Cincinnati and Washington indicated a 100% increase in turbidity from 1962 through 1965; this increase was accompanied by a calculated 5% reduction, on the average, in the transmission of solar radiation to the ground.

A photometer to measure the turbidity at 3500 Å has been developed and is being tested. Several helicopter soundings of the turbidity at both 3500 and 5000 Å in relatively clean and in polluted air have been made in the Cincinnati area, in an attempt to detect selective absorption by aerosols during the formation of photochemical smog. Figure 16 presents results from one of the flights; the vertical profile of turbidity is expressed as a scattering coefficient per 200-ft thick layers. Several aerosol layers are evident; marked differences in turbidity between the two wavelengths are also shown. Analysis of this type of data will continue.

6.3 Natural Radioactivity (Radon)

(This program is supported jointly by the Atomic Energy Commission and the Public Health Service).

Measurements of atmospheric concentrations of radon (Rn^{222}) in the Washington, D. C., area were started in 1961 and were terminated in March 1967. In an attempt to qualify the measurement of natural radioactivity concentration in the lower atmosphere as a technique for assessing mesoscale vertical mixing rates and air pollution potential, these investigations over the past years involved, chronologically, the following phases: (a) development, testing, and calibration of a technique to determine the atmospheric concentration of radon from relatively short (tens of minutes)periods of sampling filtered radon daughter beta activity, corrected for radioactive equilibrium departure; (b) gross relationships of meteorological processes affecting the temporal-spatial distribution of radon in the air; and (c) relationship of the vertical concentration gradient of radon to vertical mixing rate.

The findings of phase (a) have been documented in the literature. The results from phase (b) will be published in the Journal of Geophysical Research. An example of these results is shown in figure 17, which compares the monthly mean radon concentrations for the Naval Research Laboratory, Washington, D. C. (an urban site), and the Weather Bureau experimental site at Sterling, Virginia (a rural site).

The seasonal variation of atmospheric radon concentration compares favorably with results of researchers in Cincinnati and Illinois; the spring minimum is attributed to excess soil moisture and a high frequency of unstable weather. The relatively high concentrations during the summer convective daytime period are interpreted to reflect an increase in radon emanation rates throughout that season. In general, these studies have suggested that the hourly variation in the atmospheric concentration of radon at a given height above ground is mostly a result of atmospheric dilution--specifically, vertical mixing rates. Finally, this study suggested that the urban Washington area did not act effectively as either a source or a sink for radon, relative to the surrounding rural area. This is exemplified in figure 18, which shows the atmospheric radon concentration measured simultaneously, at three observation times at both the urban and rural sites.

Phase (c), the analyses of vertical profile data, will be started later this calendar year.

7.0 ABATEMENT PROGRAM

The Meteorology Section that provides support to the Abatement Program of the National Center for Air Pollution Control (NCAPC), is responsible for gathering, evaluating, and assessing the meteorological information required in abatement actions initiated under the Clean Air Act. Most of the abatement actions initiated under the law require that two circumstances be demonstrated: (1) that interstate transport of air pollutants occurs, and (2) that the air quality is such that the health and welfare of the population is endangered. Other abatement activities concern intrastate control of air pollution at the request of State officials and actions to insure that federal agencies meet established standards of emission. Without exception, where an abatement action arises, the meteorologists are required to make judgments on the extent of the transport of pollutants, usually across state boundaries, and on the probable contribution of various pollutant sources to the degradation of air quality. Most control activities require that the meteorologist determine the relative impact of a particular pollutant source upon an area.

These functions do not require original research; however, they do require that methods for estimating the impact of existing and proposed pollutant sources take into account meteorological effects. The operational demands of abatement activities occasionally require an original application or treatment of meteorological data to meet a specific need. This report describes three such applications made during the past year.

7.1 Metropolis, Illinois

Because of complaints that the TVA Shawnee Steam Plant was seriously affecting the air quality around Metropolis, Illinois, an air pollution study of the area was initiated. A meteorological examination of the area showed that this steam plant was not the only significant source of SO_2 and particulates; therefore, all major sources in the area were considered as potential contributors. An important part of the study, for which the Meteorology

Section was responsible, was to determine how frequently and to what extent each major source affected Metropolis, Illinois.

The Gaussian diffusion equation was used for calculating the downwind ground-level centerline concentrations of SO_2 and particulates that would occur at a point in Metropolis. This was done for each of the sources, for the six Pasquill stability categories, and for five wind speed classes, using frequency distributions of wind and stability data obtained in 3-1/2 yr of wind and temperature measurements on a 170-ft water tower at the Shawnee Steam Plant.

Tables 8a and 8b give the percent of time that the indicated calculated concentrations of SO_2 and particulate, respectively, were exceeded in Metropolis as a result of emissions from each source. On the basis of these data, the following conclusions were drawn: (1) the Shawnee Plant produces about 50% of the SO_2 concentrations $\geq$ 0.1 ppm and about 35% of the particulate concentrations $\geq$ 150 $\mu g\ m^{-3}$; (2) the Shawnee Plant is the main source of concentrations greater than 0.3 ppm of SO_2; (3) the Joppa Steam Plant produces about 20% of the SO_2 concentrations $\geq$ 0.1 ppm and about 15% of the particulate concentrations $\geq$ 150 $\mu g\ m^{-3}$. It rarely, if ever, produces concentrations greater than 0.3 ppm SO_2 or 450 $\mu g\ m^{-3}$; (4) the Metropolis dump and industries produce 40% of the particulate concentrations $\geq$ 150 $\mu g\ m^{-3}$ and may produce concentrations as high as 1400 $\mu g\ m^{-3}$.

From this analysis, it was concluded that the Shawnee Steam Plant by itself made a large enough contribution to the Metropolis air pollution problem to warrant reduction of emissions. The only other sources for which reduction of emissions was suggested were those in Metropolis itself.

7.2 New York - New Jersey Sulfur Dioxide Transport

In abatement actions it is often necessary to demonstrate that interstate transport of contaminants occurs. Photographs of plumes are convincing evidence of the transport of particulate matter. The transport of invisible gaseous pollutants from one state to another could be demonstrated if wind direction and speed and a mean concentration for the pollutant along a boundary were available. With these data, the flux of the pollutant crossing the state boundary could be calculated.

Sign X Labs, Inc., which had miniaturized an electroconductivity SO_2 sensor for aircraft installation, was engaged to obtain data on temperature and SO_2 concentration in the horizontal and vertical in representative areas of the New York - New Jersey Metropolitan region. Particular effort was made to obtain data along the interstate boundaries. Simultaneously, upper wind data (pibal observations) were gathered at Willowbrook Hospital on Staten Island and at the New York University campus in the Bronx. The volume of air crossing a portion of an interstate border below an inversion could then be computed.

On June 15, 1966, the vertical distribution of temperature and sulfur dioxide at Outerbridge Crossing indicated that an inversion was limiting the upward dispersion of the pollutant to the lower 370 m (fig. 19). Several sampling traverses were made along Arthur Kill below the inversion. The lowest traverse was at 30 m, the highest near 200 m. Figure 20 is a replica of the SO_2 concentrations recorded on a traverse made at 155 m. The mean SO_2 concentration for the volume of air below the inversion was calculated by averaging the mean concentrations of the individual traverses. The mean value was converted to mass per volume and multiplied by the volume of air crossing the border per unit time to obtain the flux of SO_2.

Several cross sections were prepared along various sectors of the New York - New Jersey boundary. It was calculated that on a warm summer morning with westerly winds prevailing (June 15, 1966), 26.4 tons of SO_2 per hour were crossing Arthur Kill from New Jersey to New York. This value was compared with the estimated SO_2 emissions[3] upwind (50-70 km to

[3] SO_2 emission inventory, listed by service category for each county, was used. Nine New Jersey counties, the five boroughs of New York City and Nassau, Rockland and Westchester Counties were evaluated to provide a source inventory. A large fraction of the total SO_2 source occurred within the first 15 km of New York City.

the west of New York City) of the boundary. About half the estimated SO_2 emitted upwind was detected crossing the boundary. The estimated upwind emissions pertaining to cross sections along the East and West Sides of Manhattan Island were closer to the calculated flux. A detailed account of the SO_x emission inventory is recorded in PHS Tech. Report, "New York - New Jersey Air Pollution Abatement Activity, Sulfur Compounds and Carbon Monoxide," 1967.

This method of calculating the transport of SO_2 entails large uncertainties. The calculations are particularly sensitive to the magnitude of the normal component of the wind. Nevertheless, the reasonably good agreement (within a factor of 2) between estimated emissions and observed flux provided credence to both the emission inventory data and the accuracy of measurement of meteorological and air quality parameters. The quantitative assessment of the amount of pollutant crossing a boundary provided convincing evidence of the necessity for abatement proceedings. The results were as understandable and impressive to lay observers as to the official participants of the abatement conference.

7.3 Kansas City, (Missouri and Kansas)

The Kansas City Abatement Activity was concerned with the critical reduction of visibility by air pollution at the Kansas City Municipal Airport, Kansas City, Missouri, and Fairfax Airport, Kansas City, Kansas. Both airports experienced flight and traffic control problems due to plumes from individual plants in their areas and at times to a general reduction in visibility. Since this was a visibility problem, the Meteorology Section was assigned to determine the exact nature and extent of the problem. The investigation required both a theoretical study and a series of visibility observations.

Thirteen brightness-detecting telephotometer measurements of a plume from a nearby plant were made from the Fairfax Airport tower at different times of the day and under different lighting conditions. With terrain near the horizon as the viewed object and the sky as the background, brightness measurements made with the telephotometer both outside the plume and through it showed that at the time of these measurements, the ability of an observer to discern the contrast between an object (terrain near horizon) and its background (sky) would have been reduced by 25% to 50%. If the contrast between the two was slight without an obstructing plume, this reduction of contrast could be enough to make an object near the horizon invisible when immersed in the plume.

The Gaussian diffusion equation was used to calculate the average particulate concentration through the plume and the width of each plume affecting the Fairfax and Kansas City Municipal airport towers. Since both towers are approximately 15 m high, it was assumed that the plume centerline was at the height of the tower in all cases except two. Values for particle concentration, size, and density were used to calculate the number of particles in a cubic meter of the plume. Thus, all the parameters necessary to find the transmittance were available.

The transmittance of a plume from the nearest source was calculated for each tower for two atmospheric stabilities. The transmittance is the amount of light incident on a plume that an observer at the tower looking perpendicular to the plume would see if the edge of the plume was passing close to the tower. These data indicated that the greatest equivalent opacities occurred at the Fairfax Tower; this reduction in visibility was attributed to plume originating from a number of plants in the area. The calculated opacities attributed to these plumes, even at relatively long distances downwind from the stacks, all exceed the opacity limits specified in the Los Angeles County smoke regulations for smoke at its source. Equivalent opacity observations made at several of the sources were generally consistent with calculated values; most observed sources, at one time or another, produced emissions of 100% opacity.

At the Municipal Tower the greatest calculated opacities were attributed to plumes from two discrete sources. The opacities produced at this tower by these two sources can be significant, but they are surpassed by the serious visual restrictions imposed at the Fairfax tower.

These calculations demonstrated the relative ability of the various sources to reduce the transmission of light. To substantiate this analysis, plume photography and visibility observations were employed. The plume photography substantiated the ability of plumes to reduce contrast as described and indicated that the calculated opacity values were reasonable. The visibility observations taken at both airports indicated that IFR conditions with smoke as a primary constituent existed about 0.5% of the time. Smoke was most prevalent and conspicuous when the wind was calm or blowing from the industrial areas; smoke plumes, especially at Fairfax Airport, were a severe hinderance to aircraft operations as the theoretical presentation indicated they could be.

8.0 CONTROL AGENCY DEVELOPMENT AND TRAINING PROGRAM

8.1 Technical Support to Training

The major objective of the Air Pollution Training Activity is to provide specialized training to shorten the gap between the development of new technologies and their application by professional people working in the field. Among the trainees are new personnel who will assume full responsibilities as soon as possible. A wide range of air pollution courses is offered to engineers, meteorologists, and various other professional people; 27 of these courses are specifically related to air pollution. Descriptions of each course are published yearly. The courses are designed by a full-time faculty of specialists supplemented by recognized authorities from other governmental agencies, universities, and industry, who appear as guest lecturers and consultants. The courses provide intensive, highly specialized training, usually at the graduate level; they are held primarily at the National Center for Air Pollution Control in Cincinnati or, by special arrangement, at various locations in the field. No tuition or registration fee is charged.

Two courses are concerned specifically with the meteorology of air pollution. The training course, "Meteorological Aspects of Air Pollution," has been presented eight times since 1962 to a total of 233 students. This 1-week course is designed primarily for scientists without meteorological training and for meteorological technicians with sufficient mathematical background. Fourteen meteorologists of the Environmental Science Services Administration (ESSA) have completed the course. The three professions with the highest enrollments are engineers (108), meteorologists (32), and chemists (25). Students have come from 31 states, the District of Columbia, and six foreign countries: Canada (11), Brazil, India, Jamaica, Norway, and Sweden - one each.

The second meteorological training course, "Diffusion of Air Pollution - Theory and Application," has been presented five times since 1963 to a total of 126 students. This 1-week course is designed primarily for meteorologists working in air pollution or nuclear energy, who have had no formal education in atmospheric turbulence and diffusion. A total of 87 meteorologists have completed the course, including 54 from ESSA. In addition, the Department of Defense (primarily U. S. Air Force) has sent 18 students. Six men have attended from Canada.

Many of the 25 other air pollution training courses require lectures on various aspects of air pollution meteorology, tailored to meet the objectives of each course. A list of these courses will indicate the wide audience to whom air pollution meteorology is presented.

Orientation in Air Pollution
Technical Sessions in Air Pollution
Community Air Pollution I-II
Elements of Air Quality Management
Atmospheric Survey
Air Pollution Data Evaluation
Medical and Biological Aspects of Air Pollution
Control of Gaseous Emissions
Measurement of Airborne Radioactivity
Advanced Training for Sanitary Engineer Reserve Officers

At the request of Federal, State, or local agencies concerned with air pollution control, the Training Activity will present many of its resident courses in the field, allowing many persons to attend who could not come to Cincinnati. Lectures on air pollution meteorology were presented as part of specific training courses in the following cities during the past year:

St. Louis, Missouri
Albany, New York
Brooks AFB, San Antonio, Texas
Tampa, Florida
Salt Lake City, Utah
Kirksville, Missouri
Springfield, Illinois
Montgomery, Alabama .

Other lecture presentations included: two sessions of the U. S. Dept. of Agriculture Seminar, "Air Pollution - Electric Power Generation," in Washington, D. C., and one of the lecture series of the American Society of Mechanical Engineers course, "Air Pollution Control," in New York, New York.

The Training Activity is faced with the job of training many more persons than can be accommodated in classes conducted by its staff. To alleviate this problem a 40-hr "package" of instructional materials including illustrated lectures, narrated slide sequences, programmed instruction manuals, and movies is being prepared under the title "Community Air Pollution - Training Package." This package will be available for loan or purchase by air pollution control agencies and other groups for training personnel. Included in this package is a 4-hr block of instruction on meteorology: 1) fundamentals of meteorology - commercial movies, 2) meteorological factors affecting atmospheric pollutants - programmed instruction manual, 3) meteorological instrumentation - narrated slide sequence. A summary presentation is made up of film clips and review material. This training course is about 80% complete; the package will be available near the end of FY 1968.

In April the "Seminar on Human Biometeorology" was published as No. 25 in the Environmental Health Series - Air Pollution. This collection of papers was originally presented at a special seminar in 1964 sponsored jointly by NCAPC and ESSA. Topics included physiological and climatological instrumentation, climates of the U. S., microclimatology, indoor and outdoor weather, ultraviolet light, heat exposure, and air ions.

Future plans call for increased meteorological support to the five sections within the NCAPC Training Activity; these sections are (1) Air Quality Management; (2) Field Studies; (3) Training Assistance; (4) Process Evaluation and Control; (5) Atmospheric Sampling and Analysis. Finally, a curriculum for a short, summer, graduate course in air pollution meteorology at a university is being developed to provide training of air pollution specialists.

8.2 Technical Support to Control Agency Development

The Control Agency Development Program of NCAPC provides technical and consultative assistance to air pollution programs of state and local governments.

8.2.1 St. Louis - Interstate Air Pollution Study

A report describing the climatology, topography, and meteorological instrumentation in the St. Louis area was published in April 1967. This report describes general atmospheric dispersion conditions and evaluates the representativeness of meteorological conditions in the St. Louis area during a limited period of air quality monitoring.

8.2.2 Columbus, Ohio

The complaint of malodors received in recent years by officials of the Division of Air Pollution in Columbus, Ohio, initiated a meeting among State Health and NCAPC officials and representatives of a paper mill in Chillicothe, Ohio, believed to be a primary source of the malodorous pollutant.

In September 1966, following a tour of the paper mill plant, it was concluded that under certain meteorological conditions, emissions from the 475-ft stack at the pulp mill site could reach the Columbus area in sufficient concentrations to cause complaints of malodors. This was established on March 24, 1967, when the plume from the stack was tracked 45 mi, visually and by olfactory sensing, by means of aircraft reconnaissance.

After review of climatological factors, it was concluded that meteorological conditions conducive to the persistent transport of malodorous compounds from the plant to the Columbus area might be expected to occur 9 to 12 times a year, most likely during October, November, and December.

8.2.3 Kanawha Valley, West Virginia

During 1964 at the request of citizens of the state of West Virginia, a 2-yr study of air pollution conditions in the Charleston-Kanawha River Valley area was initiated. A resident meteorologist was assigned to Charleston and a network of meteorological stations established to acquire climatological information. During periods of intensive meteorological observations, vertical temperature measurements, pilot balloon observations, and tetroon runs were conducted to obtain a detailed picture of meteorological conditions existing in the valley. The meteorological portion of this report is nearing completion and will be ready for publication soon.

8.2.4 International Joint Commission Study (Detroit-Ontario)

Authorities of both Michigan and Ontario, Canada, asked for a study of air pollution conditions in the Detroit and Port Huron areas. Near Detroit the industry is mostly on the American side, whereas, at Port Huron the industry is mostly on the Canadian side. A preliminary design for a meteorological study in support of this program was prepared in Fiscal Year 1966. This program, activated in Fiscal Year 1967, is known as the International Joint Commission Study; it will be in full operation during Fiscal Year 1968.

8.2.5 New York, N. Y.

Background material, including calculated ground-level concentrations of sulfur dioxide, was prepared for Mr. Vernon MacKenzie's appearance before the Federal Power Commission. His testimony supported the proposed allocation of natural gas to power production in New York City.

Assistance to New York City was provided in selection of sites for 36 air quality sampling units, including 10 sites from which data are to be telemetered to a central computer-equipped location. Representation on the Meteorological Advisory Committee was also furnished.

9.0 PUBLICATIONS

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Table 1. Correlation coefficients obtained between observed and calculated SO_2 concentrations for summer and winter* weekday periods using summer base level and space heating SO_x emission rates, as indicated. (St. Louis)

	0600-0800 CST		1400-1600 CST	
Month	Includes Space Heating Emissions	Excludes Space Heating Emissions	Includes Space Heating Emission	Excludes Space Heating Emissions
May 66	0.76 (20)	0.81 (20)	0.64 (20)	0.64 (20)
Jun 66		0.89 (20)		0.21 (20)
Jul 66		0.80 (18)		0.01 (14)
Aug 66		0.53 (19)		0.83 (17)
Sep 66	0.33 (20)	0.38 (20)	0.17 (20)	0.24 (20)
Oct 66	0.66 (19)	0.59 (19)	0.75 (16)	0.75 (16)
Nov 66	0.47 (20)	0.47 (20)	0.65 (16)	0.62 (16)
Dec 66	0.57 (20)	0.35 (20)	0.58 (20)	0.35 (20)
Jan 67	0.29 (20)	0.56 (20)	0.60 (17)	0.68 (17)
Feb 67	0.33 (20)	0.63 (20)	0.37 (15)	0.69 (15)
Mar 67	0.64 (20)	0.57 (20)	0.23 (18)	0.03 (18)
Apr 67	0.07 (20)	0.11 (20)	0.46 (15)	0.57 (15)

* For purposes of this report, a winter day is regarded as one during which heating degree days occur.

Table 2. Statistical comparisons between standard deviation of horizontal wind direction fluctuation (σ_θ) and wind direction range, St. Louis, Missouri.

Station	Range	Linear Correlation Coefficient	Ratio = Range/σ_θ
Periphery	Extreme	0.94	7.5
	3rd	0.95	5.9
	5th	0.94	4.9
Television Tower	Extreme	0.79	8.0
Lower Sensor	3rd	0.83	5.7
(127 ft)	5th	0.79	5.0
Television Tower	Extreme	0.83	7.2
Upper Sensor	3rd	0.86	5.8
(459 ft)	5th	0.85	4.7

Table 3. Summary of long-range experiments, Cincinnati, Ohio

Exp. No.	Date	Time (EST)	Tracer	Release		V_s	Mixing Depth	V_L	$\Delta\theta$	ΔV
				gm/sec	h(m)	(m/sec)	(m)	(m/sec)	(deg)	(m/sec)
C-6	10/13/66	0900-1015	FP	3.60	1.0	6.2	1300	12.3	22	7.1
			SF_6	6.96	1.0					
C-7	11/17/66	1000-1130	FP	3.69	1.0	6.0	1120	12.0	19	7.1
			SF_6	7.37	1.0					
C-9	1/20/67	1225-1340	FP	3.65	1.0	4.8	670	9.6	25	9.3
			SF_6	9.07	1.0					

V_s = Av. surface wind speed

V_L = Av. wind speed in mixing layer

$\Delta\theta$ = Wind direction shear, surface to top of mixing depth

ΔV = Wind speed shear, surface to top of mixing depth.

Table 4. Percent frequency of occurrence - Los Angeles - autumn afternoon

Mixing Depth (meters)	Transport wind speed (meters per second)								
	≤ 1.0	1.1-2.0	2.1-3.0	3.1-4.0	4.1-5.0	5.1-6.0	6.1-8.0	8.1-10.0	10.1-12.0
≤			1	1	3	3	*		
251-500	*	1	3	5	11	7	4	1	
501-750		*	3	4	8	3	2		
751-1000		*	3	3	5	2	1	*	
1001-1500			1	5	5	2	2	1	*
1501-2000			1	*	2	1	*	*	*
2001-2500				*	*	1	*	1	
2501-3000				*	*	*	*	*	
3001-3500						*			
3501-4000								*	
>4000					*	*			

*Less than 0.5%

Table 5. Theoretical relative concentrations (sec/meter, averaged over each city area) expected to be equaled or exceeded 10%, 50%, and 90% of the time annually, based on a common city size of 60 km.

	Morning			Afternoon		
	10%	50%	90%	10%	50%	90%
Salt Lake City - 60 km	147	71	22	37	16	13
St. Louis - 60 km	127	37	17	22	15	12
New York - 60 km	94	21	16	22	14	12
Los Angeles - 60 km	206	55	25	35	18	14

Table 6. Frequency of the number of consecutive 12-hr periods of specified duration or longer* with mixing depth ≤ 1500 m and transport wind speed ≤ 4.0 m/s, 1960-1964

		Number of consecutive 12-hr periods								
		2	4	6	8	10	12	16	20	30
Columbia	Winter	10	2							
	Spring	2								
	Summer	7	1							
	Autumn	11	4							
Dayton	Winter	7	2	1	1	1				
	Spring	7								
	Summer	16	2							
	Autumn	19	4							
Los Angeles	Winter	58	32	19	10	6	3	1	1	
	Spring	29	4	1	1					
	Summer	53	18	7	2	1				
	Autumn	56	17	8	5	2	1			
Nashville	Winter	26	5	2						
	Spring	7								
	Summer	14	3							
	Autumn	33	9	3						
New York	Winter	6	1							
	Spring	1								
	Summer	4								
	Autumn	12	3	1						
Pittsburgh	Winter	9	6	2	1					
	Spring	6								
	Summer	13	3							
	Autumn	32	7	2						
Salt Lake City	Winter	45	31	23	14	6	4	2	1	
	Spring	3	2							
	Summer	0								
	Autumn	32	16	11	5	1				

*Frequencies for episodes of exact duration can be obtained by subtracting consecutively across each row from right to left. Thus, at Dayton in winter one episode lasted exactly 10 consecutive 12-hr periods, none lasted exactly six or eight periods, one lasted exactly four peiods, and five lasted exactly two consecutive 12-hr periods.

Table 7

Mean Annual Turbidity (β)

Washington, D. C.	1903-07 .098	1962-66 .154	$\Delta\beta$ .056	% increase 57
Davos, Switzerland	1914-26 .024	1957-59 .043	0.21	88

Table 8. Cumulative percent of time indicated (a) SO_2 and (b) particulate concentration values were exceeded in Metropolis as the result of emission from a particular source (time interval 3-15 min)

(a) SO_2

Average concentrations of SO_2 ppm Equal to or greater than	Paducah	AEC	Joppa	Shawnee	Total
.1	.04	.70	.71	1.52	2.97
.2		.19	.32	.95	1.46
.3			.10	.70	.80
.4				.57	.57
.5				.46	.46
.6				.39	.39
.7				.27	.27
.8				.18	.18
.9				.13	.13
1.0				.08	.08
1.1				.05	.05

(b) Particulates

Average concentrations of SO_2 ppm Equal to or greater than (ug/m^3)	Paducah	AEC	Met. Dump & Industry	Joppa	Shawnee	Total
150	.01	.39	1.86	.61	1.52	4.39
300		.11	.85	.27	.95	2.18
450			.44	.09	.70	1.23
600			.23		.57	.80
750			.12		.46	.68
900			.10		.39	.49
1075			.08		.27	.35
1250			.05		.18	.23
1400			.01		.13	.14
1550					.08	.08
1700					.05	.05

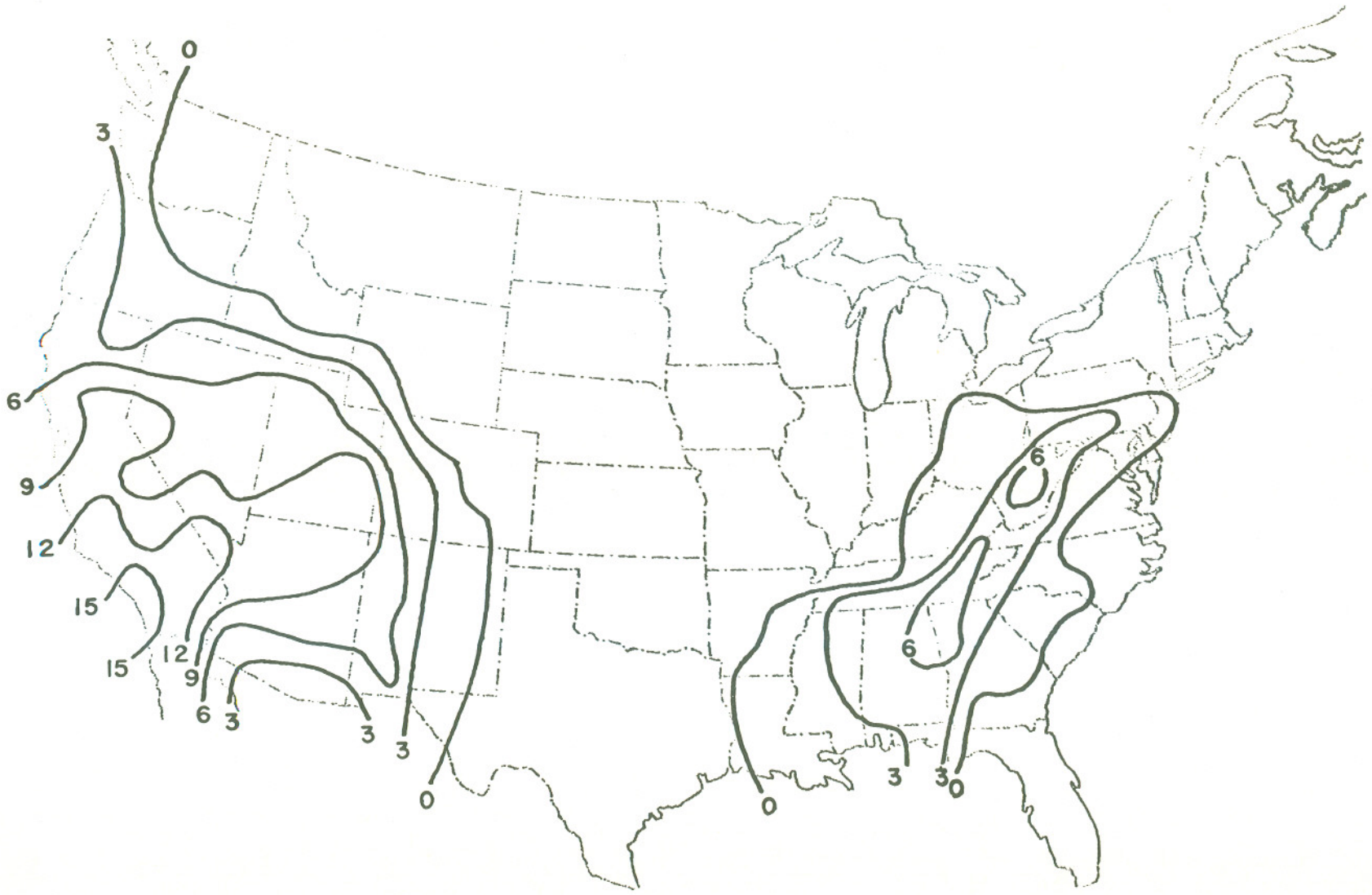

Figure 1. Number of high air pollution potential forecasts issued for U. S. (July 1966-June 1967).

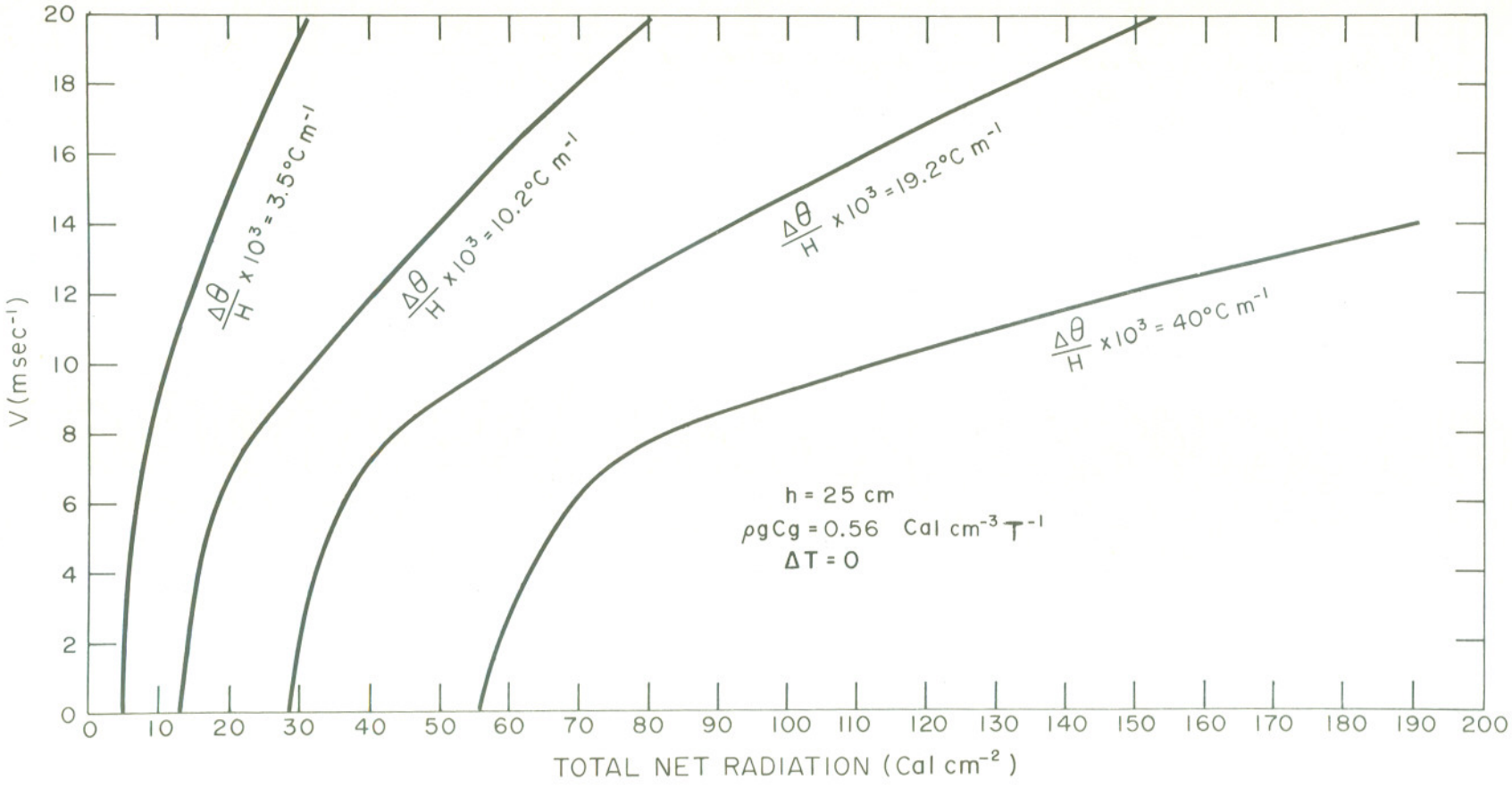

Figure 2. Graphical solution to energy balance equation for the surface of the earth. (When the values at h, $\rho_g C_g$, and ΔT are as specified, the lapse rate, $\frac{\Delta\theta}{H}$, in the planetary layer can be determined from a knowledge of the wind speed, V, at the top of the boundary layer and from the total net radiation).

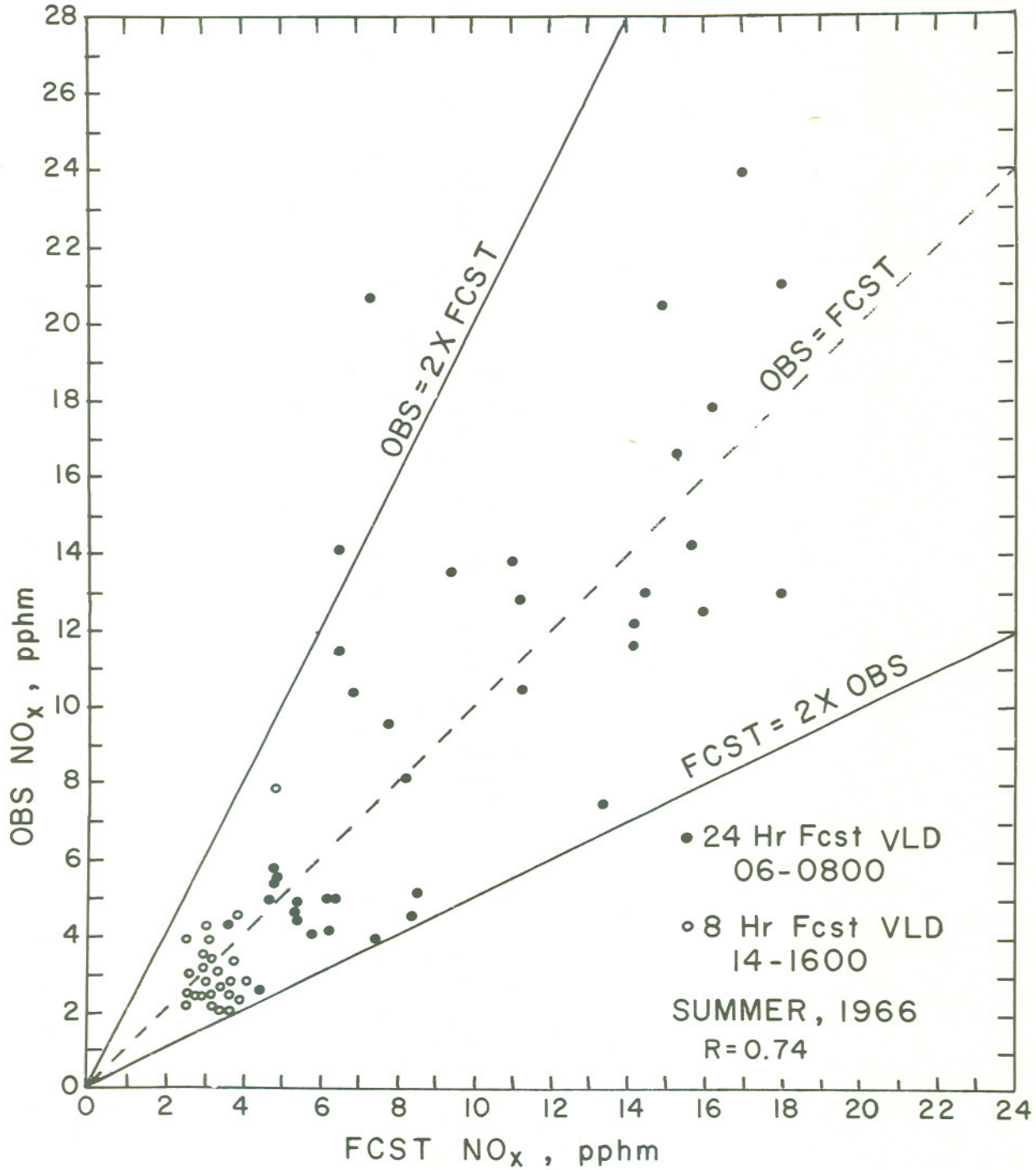

Figure 3. Forecast versus observed concentration of NO_x at Cincinnati CAMP station (Summer 1966). "R" is the correlation coefficient,

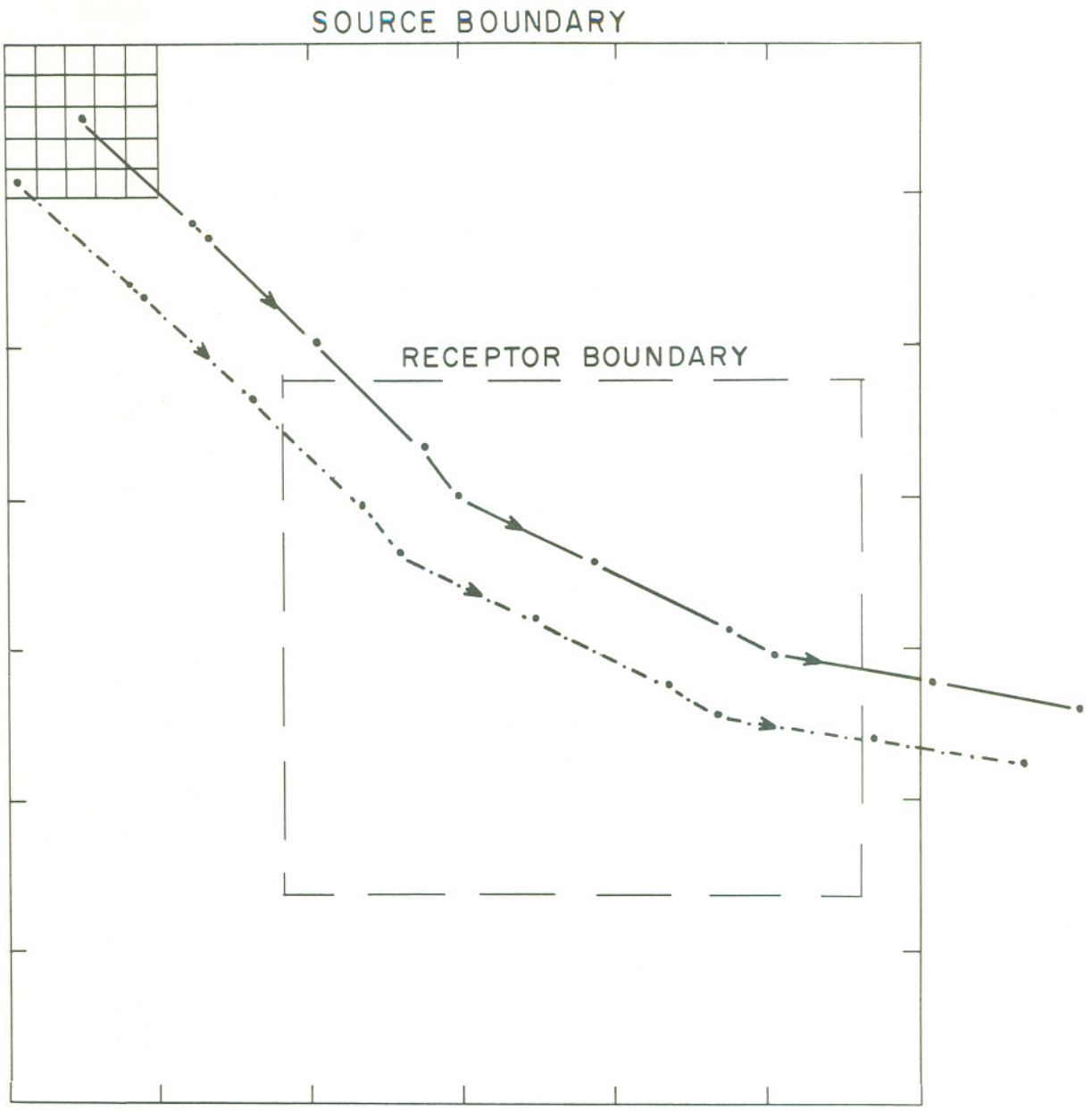

Figure 4. Example of computer calculated trajectories. Trajectories are not calculated for each of the 1200 area sources, but for the center source for each group of 25 (5 x 5) as shown. The trajectory for each of the other 24 area sources is assumed to have the same shape but to have its origin at the center of the source being considered.

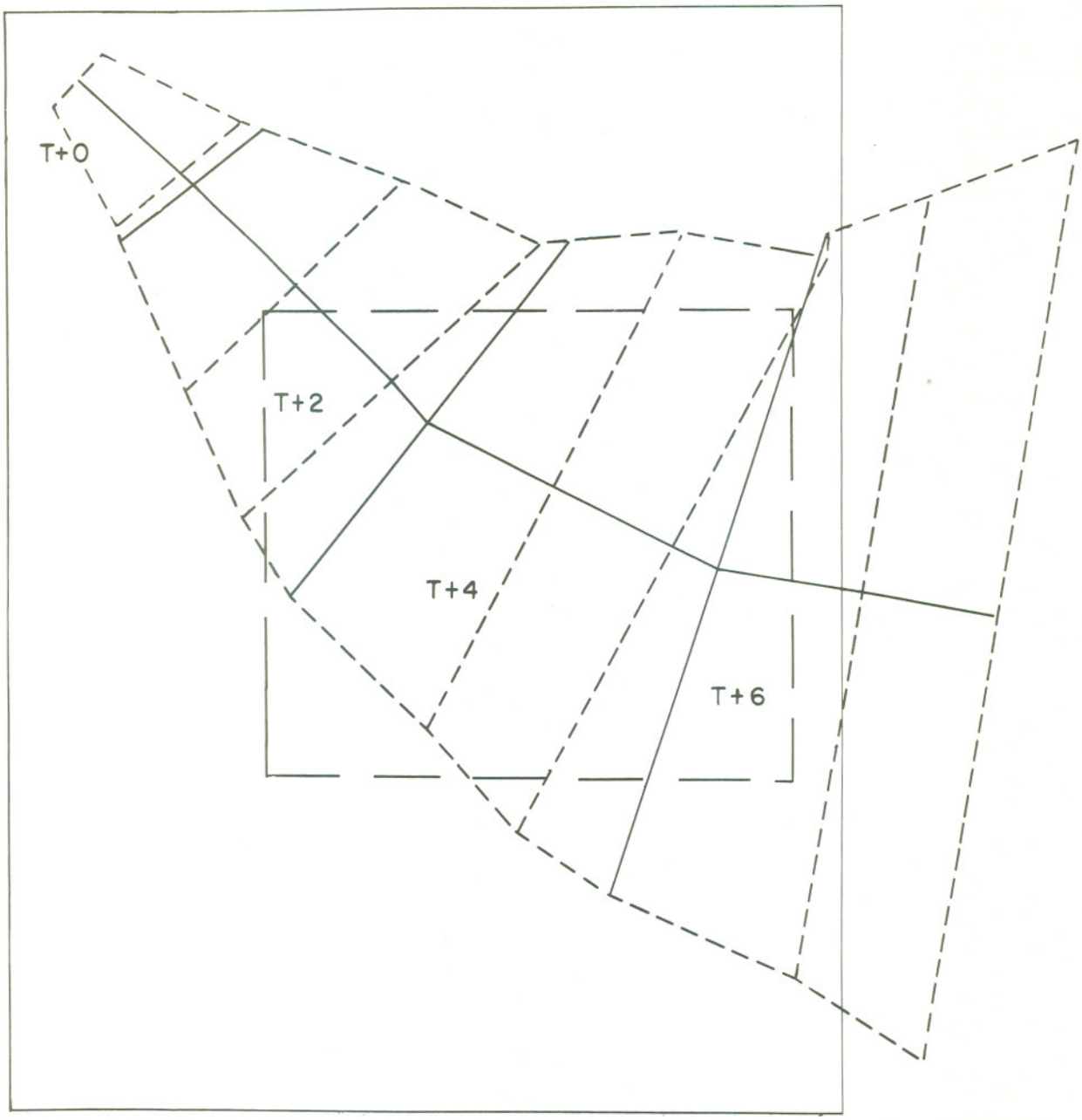

Figure 5. Plume centerline trajectory of Figure 4 with approximate plume boundaries added as dashed lines. The receptor area is shown as the dashed rectangle. The numbers indicate the 2-hr period affected by various portions of the plume; T + 0 indicates the 2-hr period of the pollutant emission; T + 4 indicates the period of reception 4 hr after emission. The solid lines across the trajectory separate the time periods.

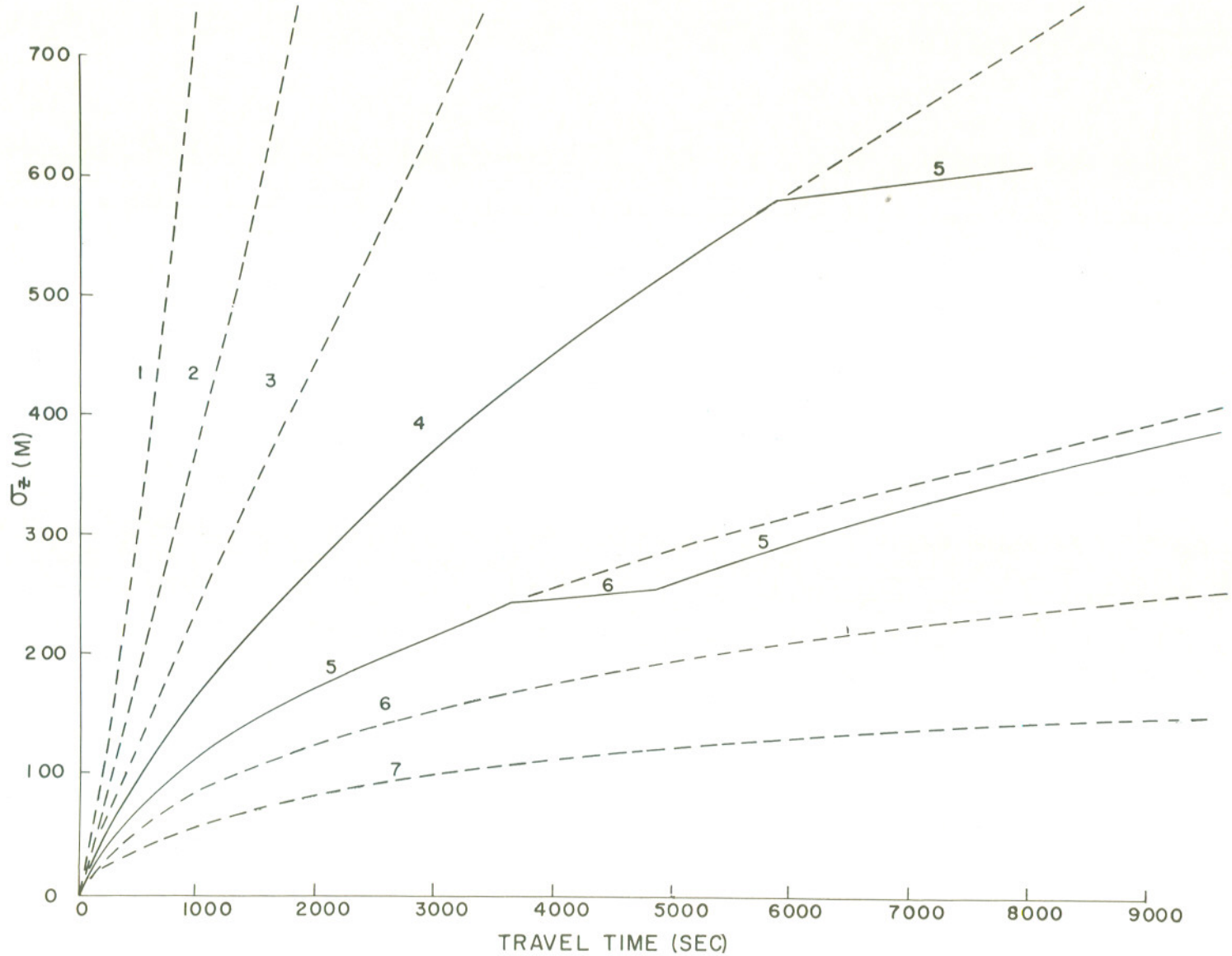

Figure 6. Examples of the σ_z variation with travel time for changes of stability class along the trajectory. Dashed lines indicate the usual variation of σ_z with time when various stability classes remain constant. Solid lines indicate a change of stability with time.

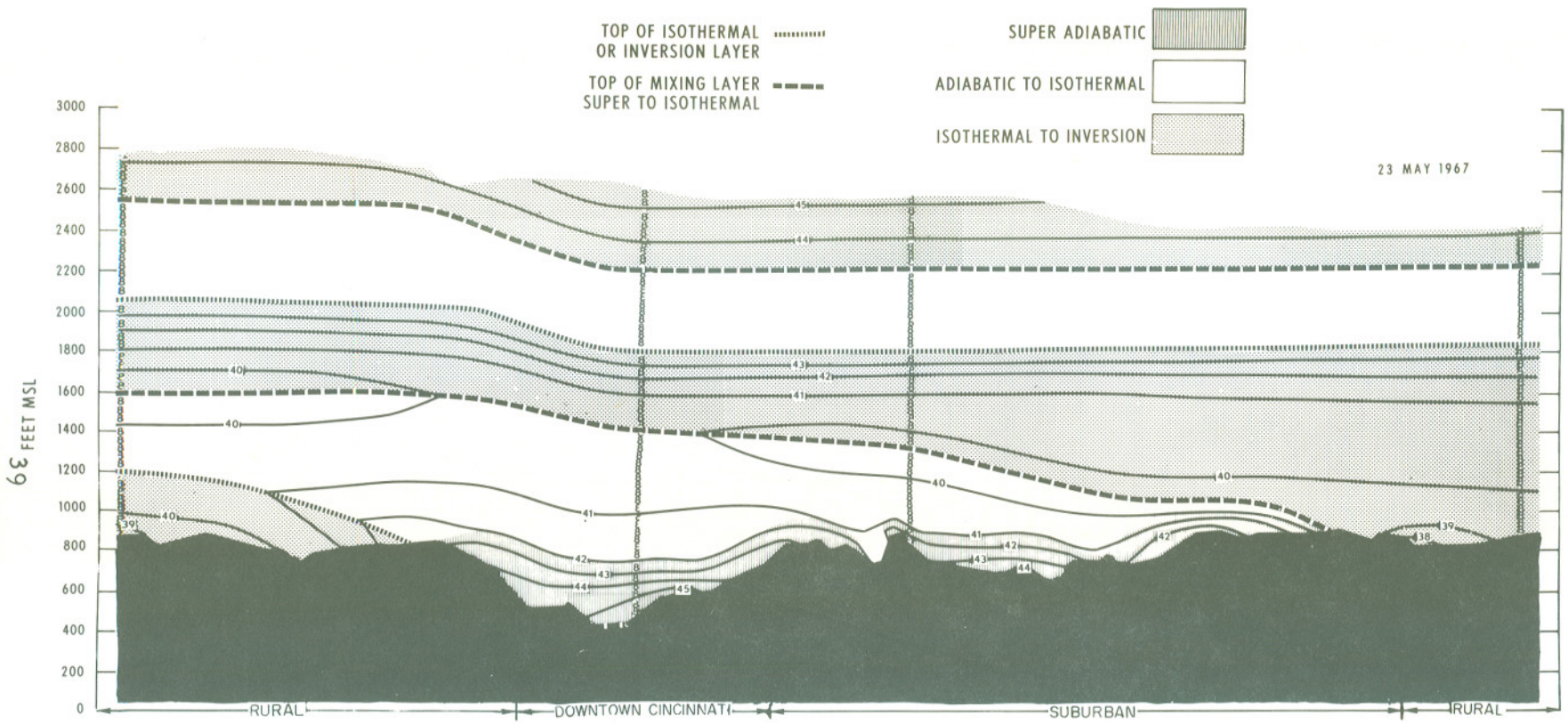

Figure 7. Vertical cross-section of the Cincinnati metropolitan area (looking west). The general flow of air (~~south~~NORtherly) was from ~~left~~RIGHT to ~~right~~LEFT; the vertical lines indicate the location where temperature soundings were made by helicopter.

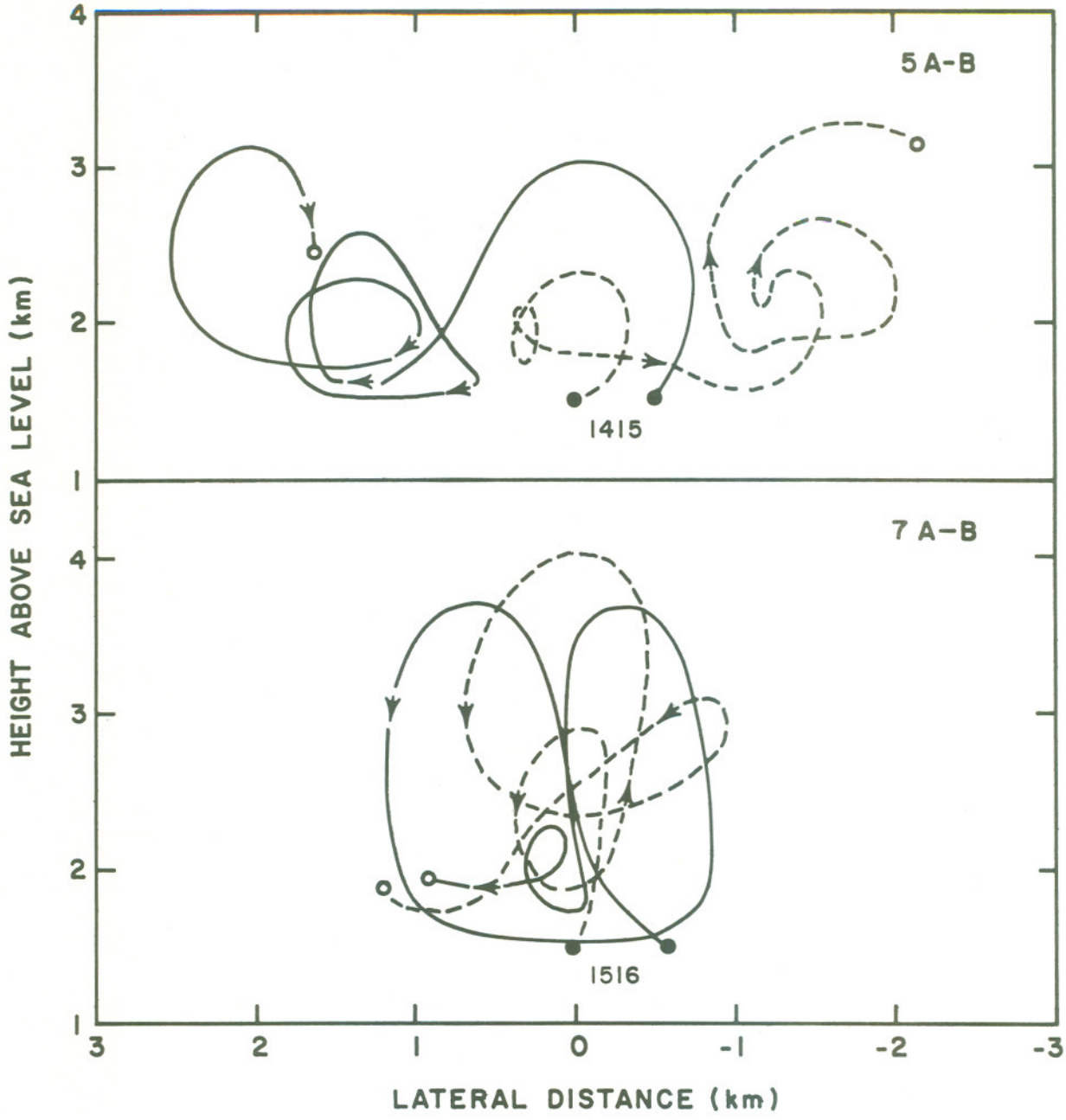

Figure 8. Tetroon trajectories projected into the transverse (vertical-lateral) plane for simultaneously released flights.

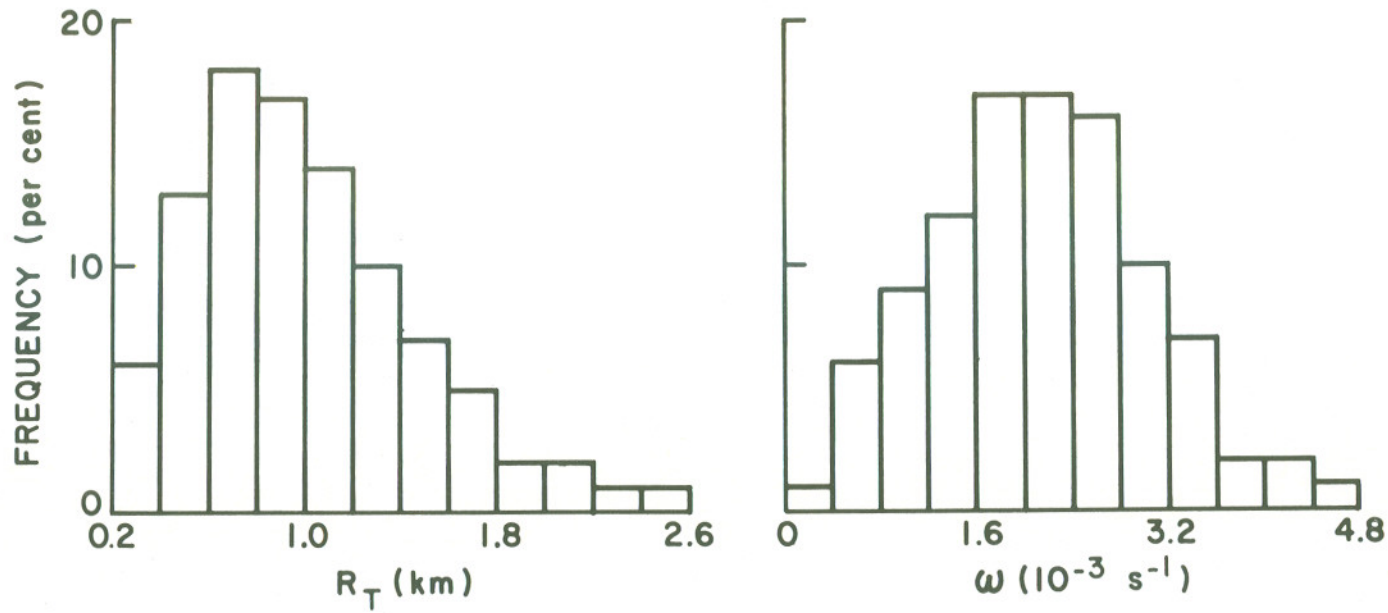

Figure 9. Histograms of the radius of trajectory curvature and angular velocity for the afternoon tetroon flights. Vorticity in the transverse plane can be estimated by doubling the values of angular velocity.

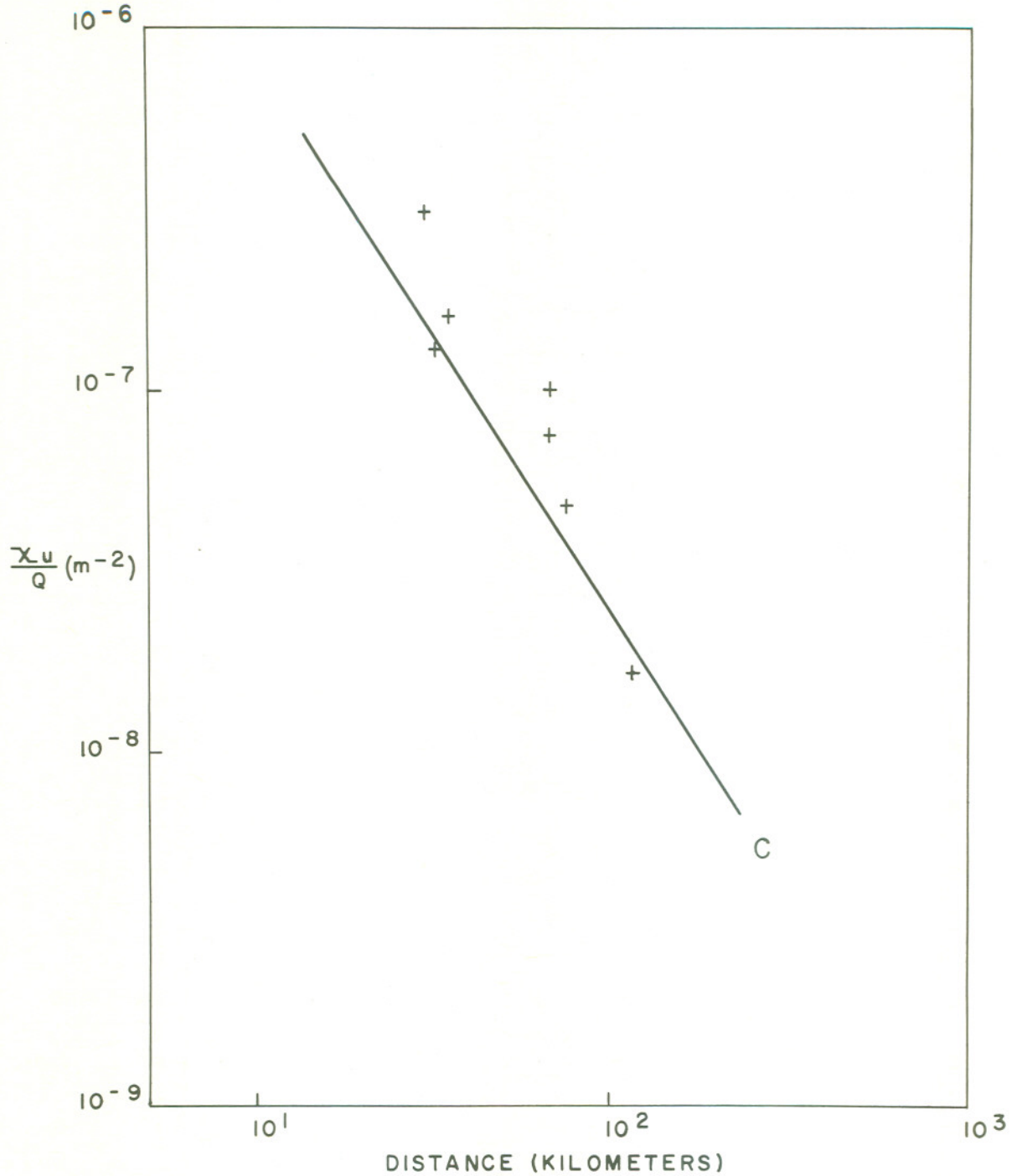

Figure 10. Normalized "centerline" concentrations observed in long range tracer experiments in Cincinnati, Ohio. The line labeled "C" is the "Pasquill" stability class.

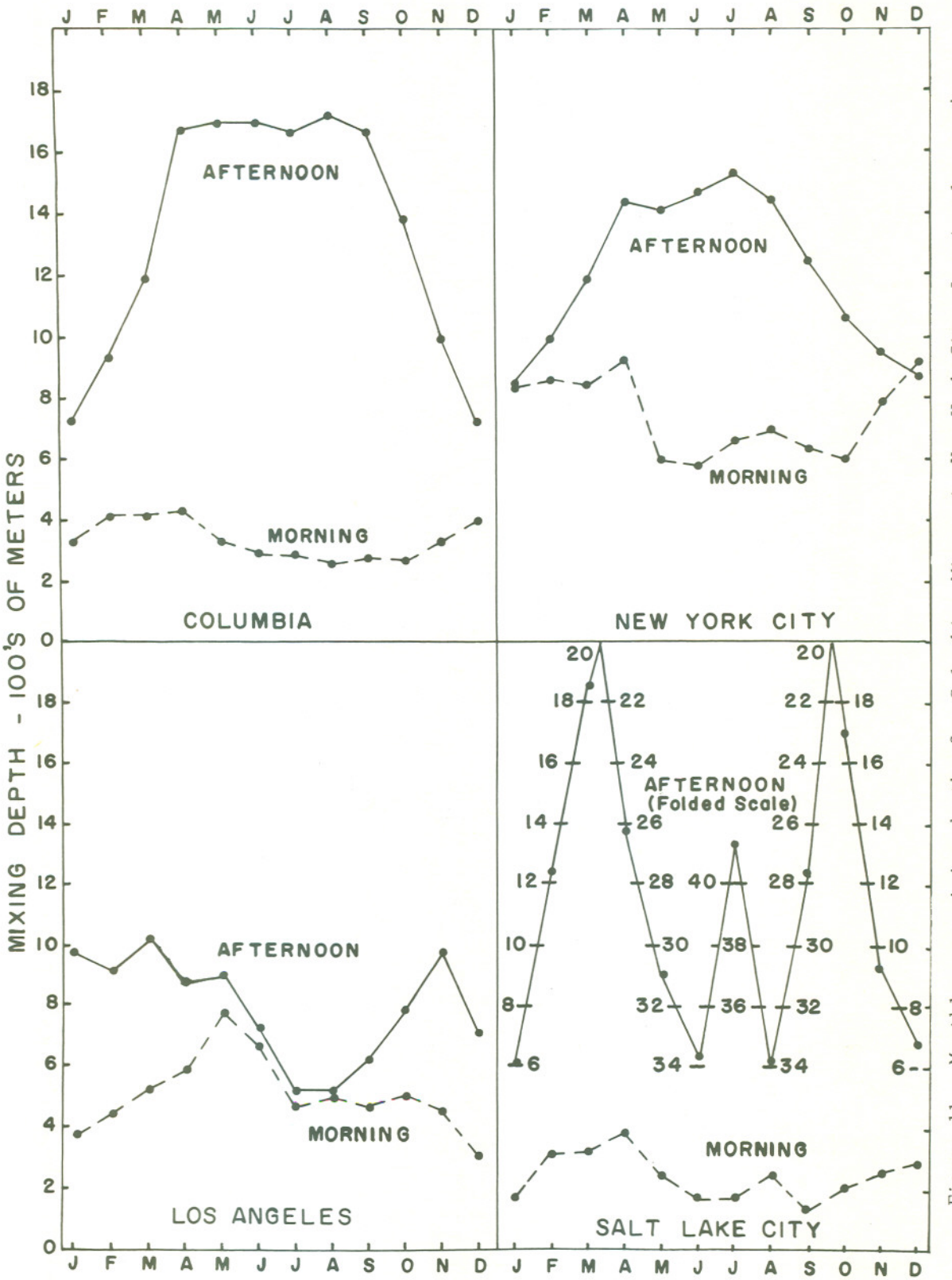

Figure 11. Monthly mean mixing depths for Columbia, Missouri, New York City, Los Angeles, and Salt Lake City.

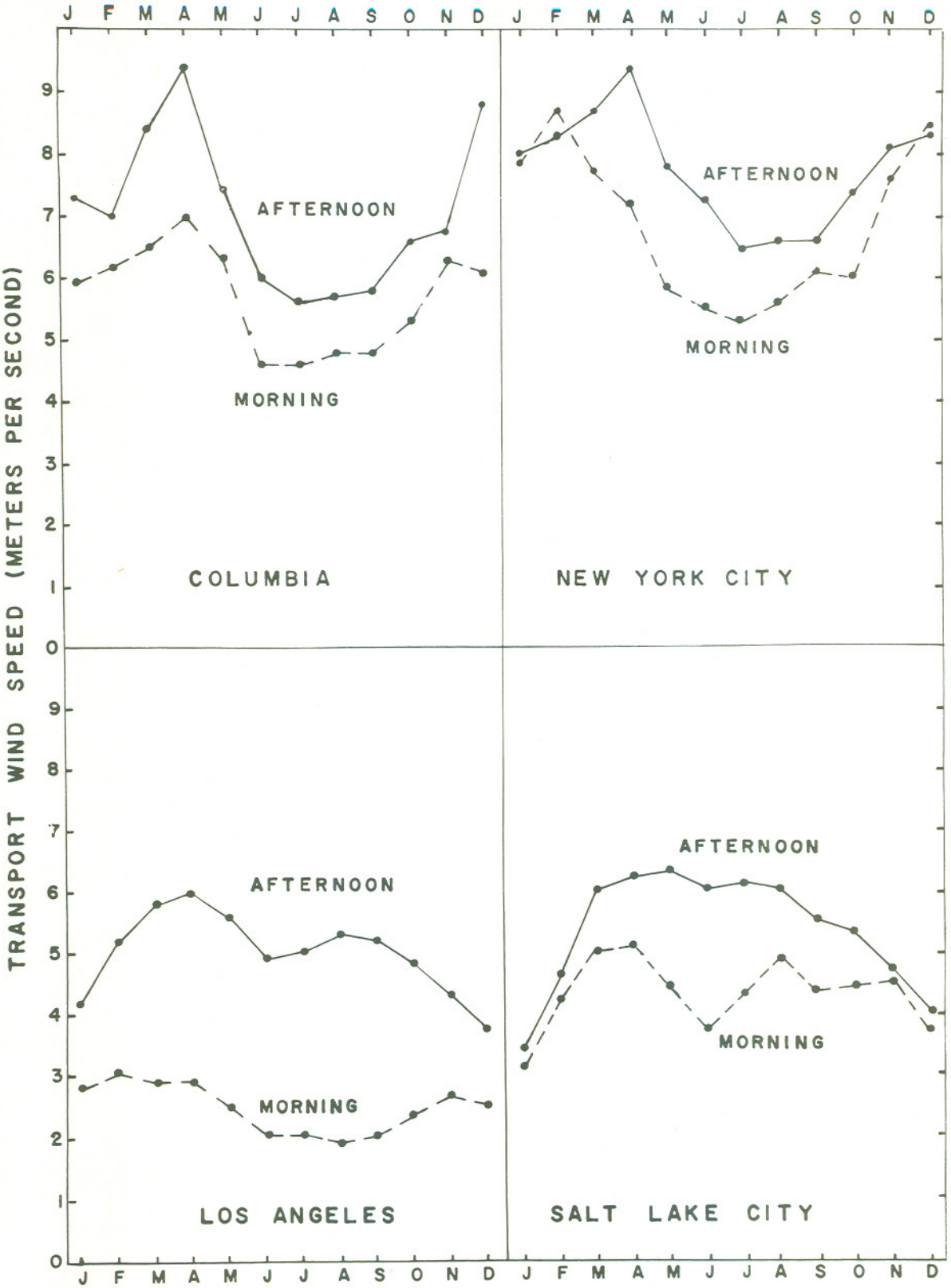

Figure 12. Monthly average transport speeds for Columbia, Missouri, New York City, Los Angeles, and Salt Lake City.

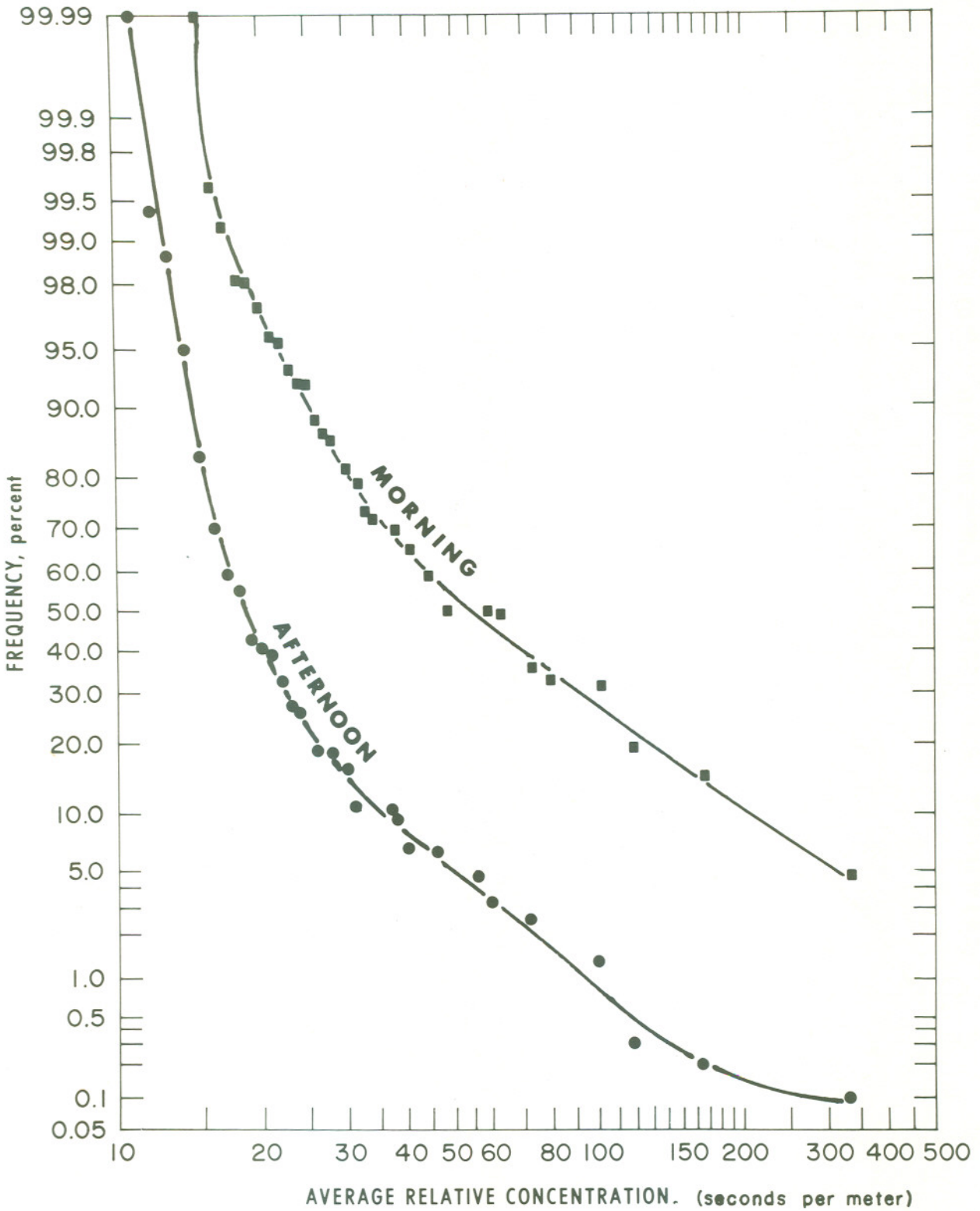

Figure 13. Annual frequency of theoretical relative pollutant concentration averaged over Los Angeles area) equal to or greater than abcissa values.

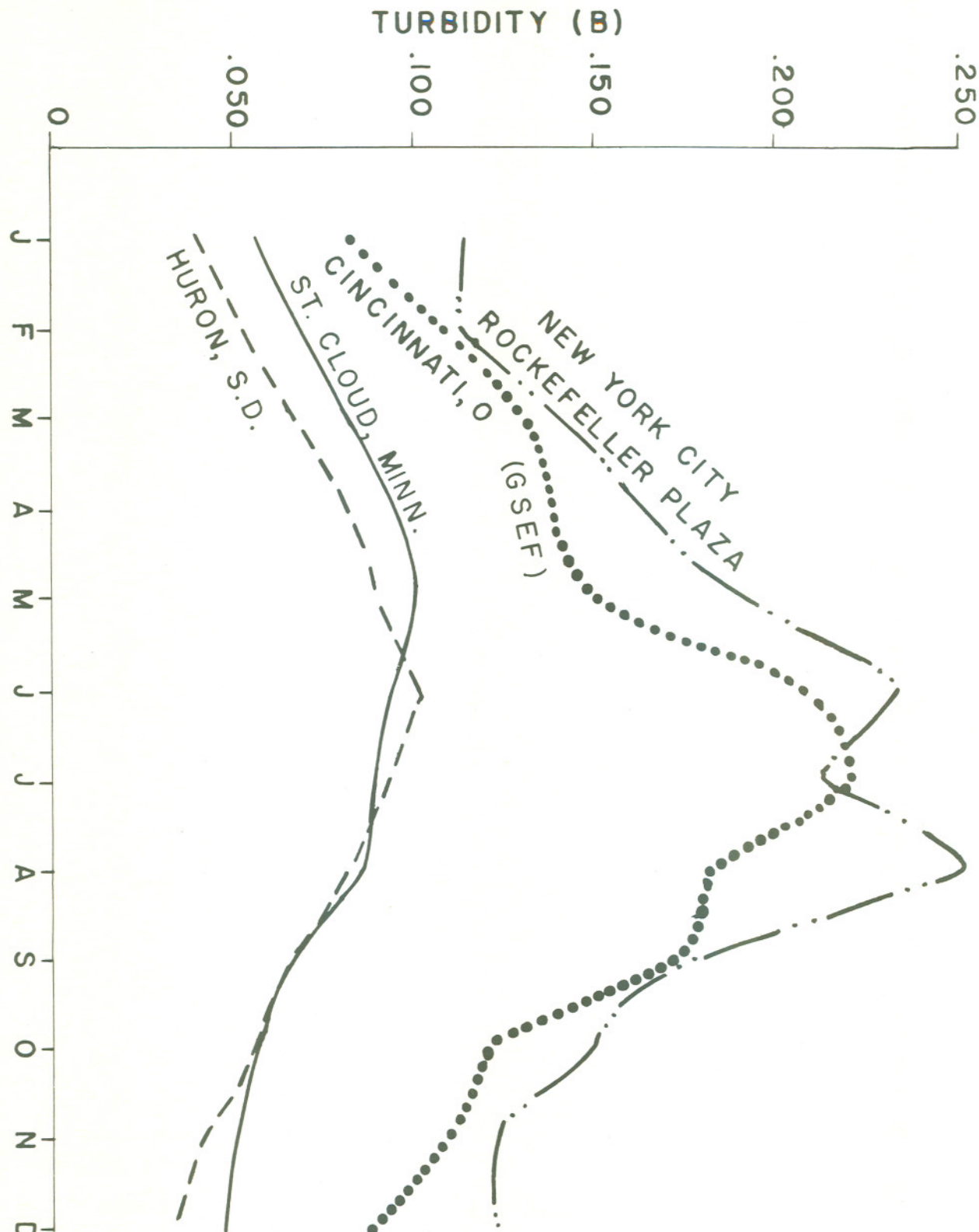

Figure 14. Average monthly turbidity values for New York City, Cincinnati, St. Cloud, Minnesota, and Huron, South Dakota.

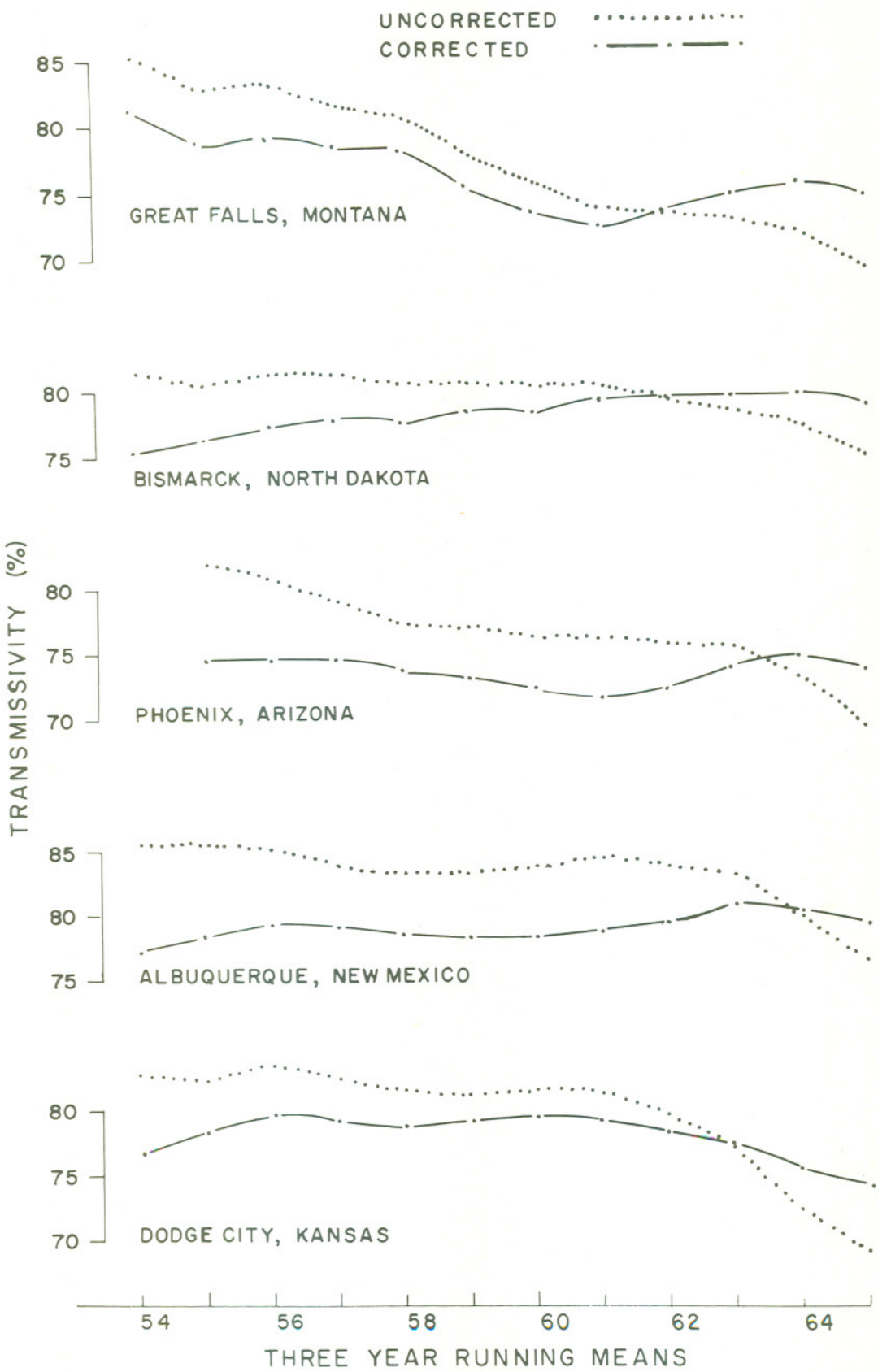

Figure 15. Solar transmissivity (%) for Great Falls, Bismarck, Phoenix, Albuquerque, and Dodge City. (3-yr running means).

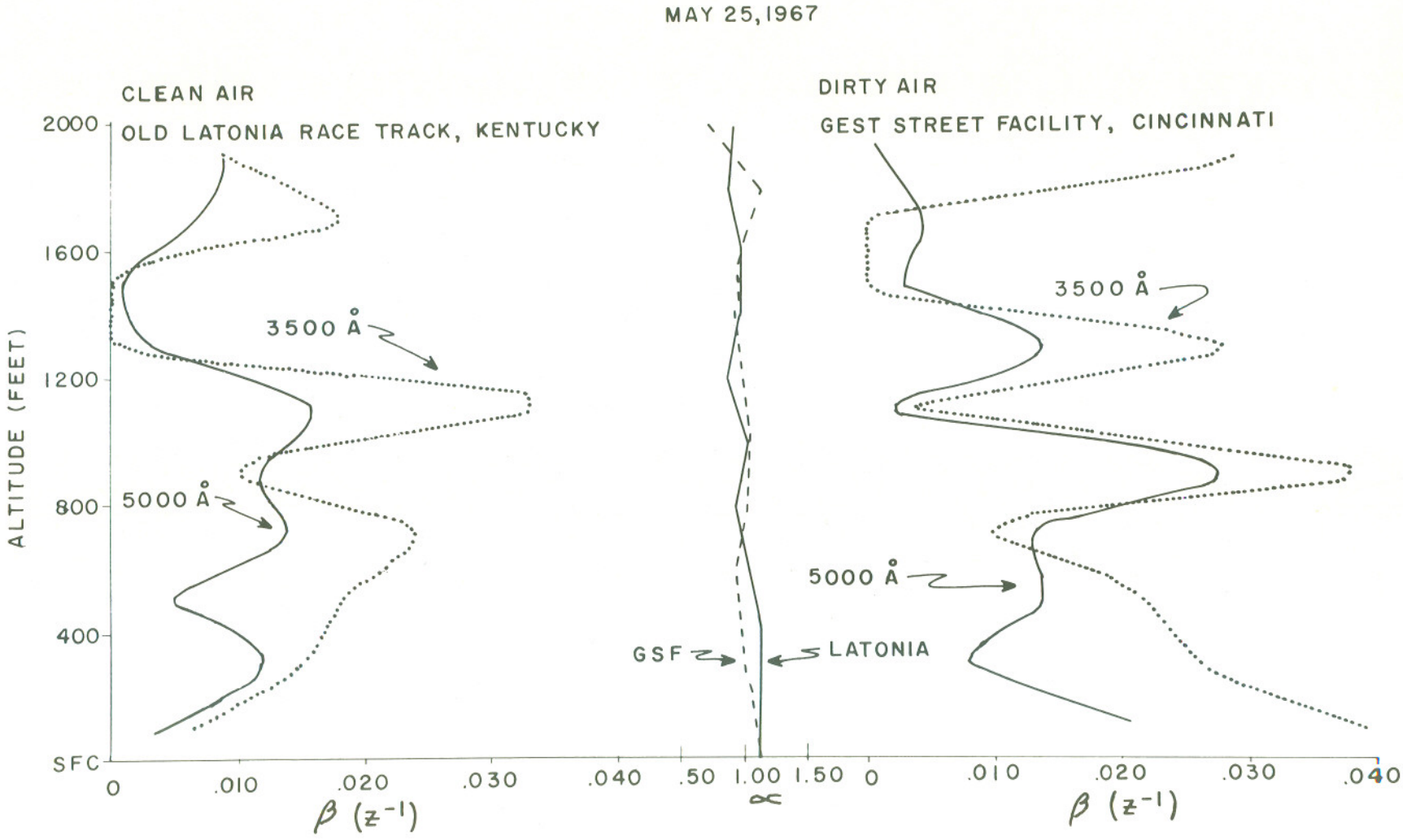

Figure 16. Vertical profile of turbidity at two sites in Cincinnati area, May 25, 1967. α is the wavelength factor which is supposedly related to particle size.

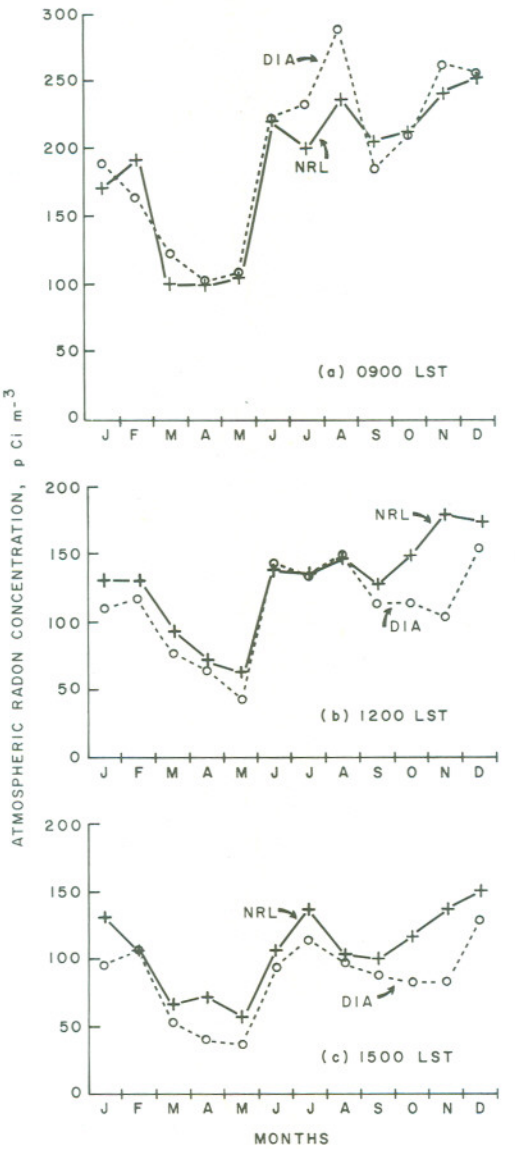

Figure 17. Monthly mean atmospheric radon concentrations (pCi m^{-3}) at the U. S. Naval Research Laboratory, Washington, D. C. (NRL) and at Sterling, Virginia (DIA) for (a) 0900 LST, (b) 1200 LST and (c) 1500 LST, December 1965-February 1967.

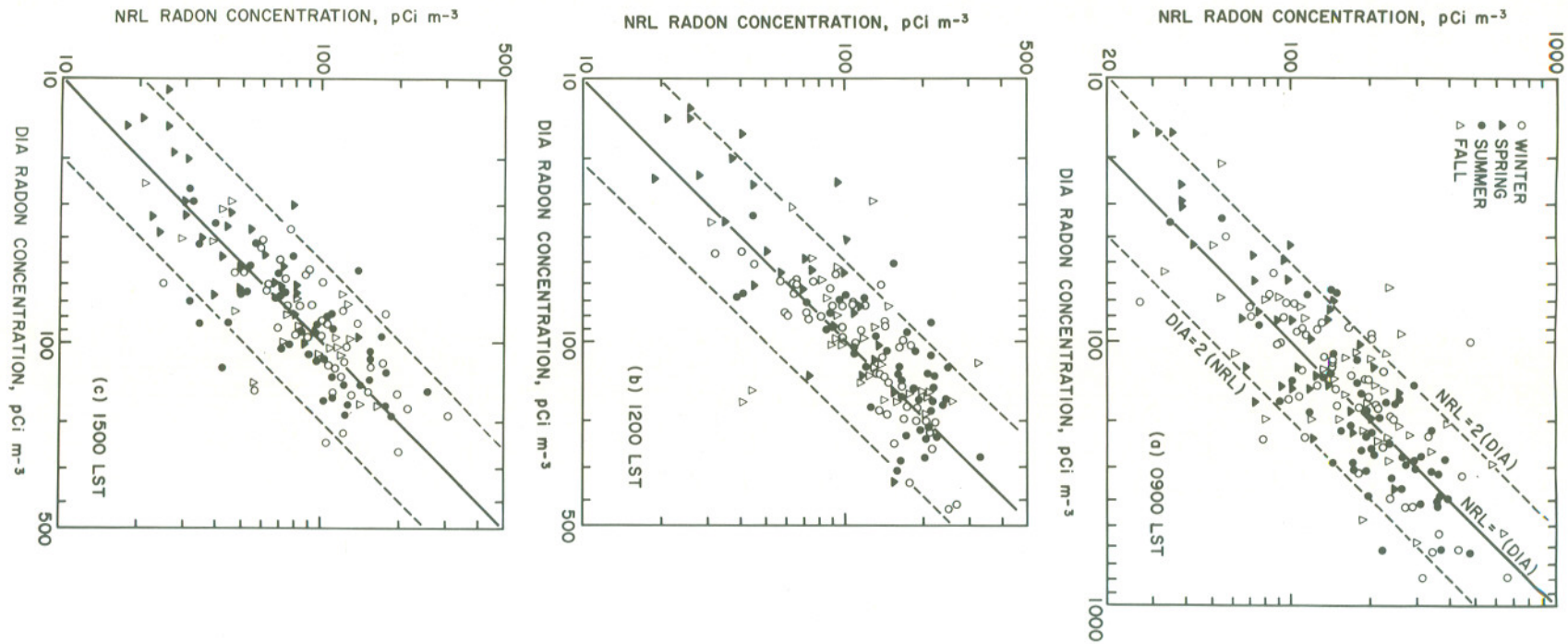

Figure 18. Atmospheric radon concentrations (pCi m^{-3}) taken simultaneously at U. S. Naval Research Laboratory, Washington, D. C. (NRL) and at Sterling, Virginia (DIA) at (a) 0900 LST, (b) 1200 LST and (c) 1500 LST.

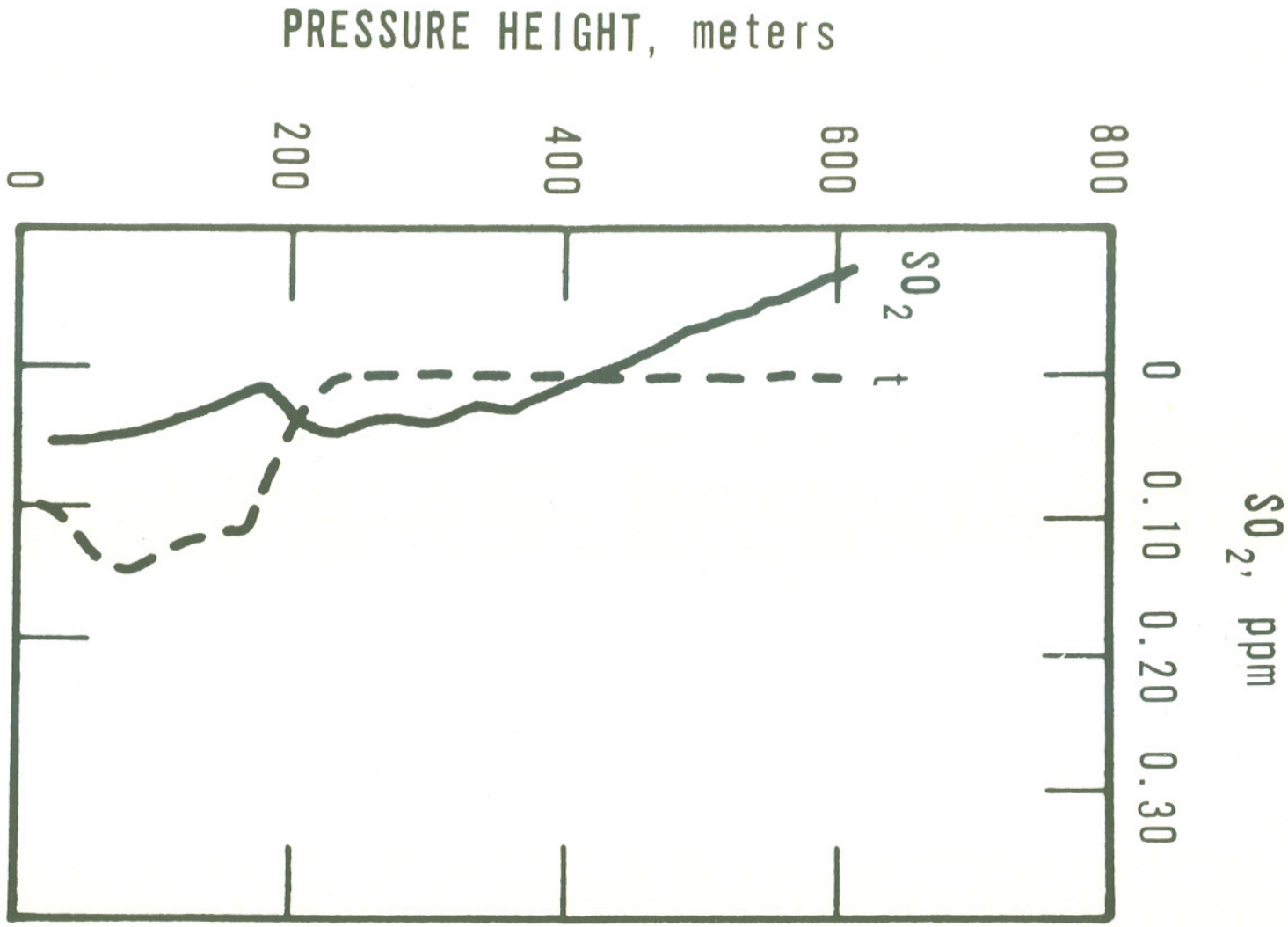

Figure 19. Temperature and SO_2 versus pressure height at Outerbridge Crossing, N. Y. at 0728 EST, June 15, 1966 (from Sign X Labs., Inc.).

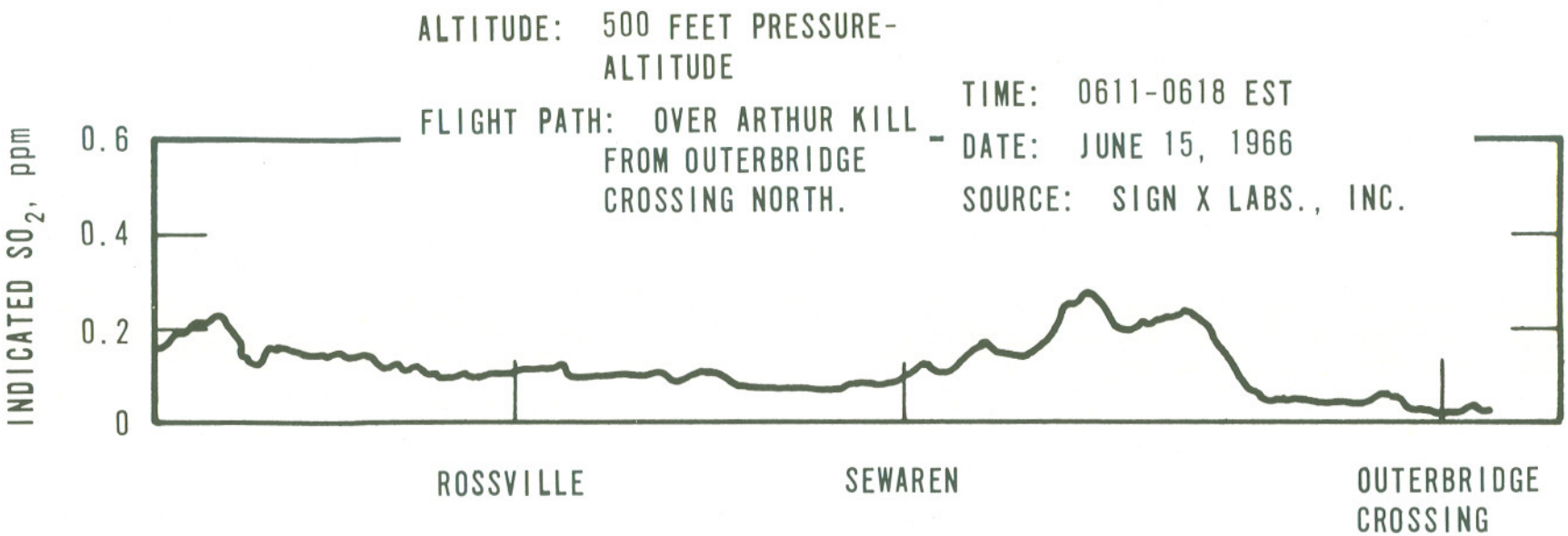

Figure 20. Replica of portion of recorder trace from airborne SO_2 sampler, 0611-0618 EST, June 15, 1966.

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