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U.S. DEPARTMENT OF COMMERCE
ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION
Research Laboratories

Fiscal Year 1969 Summary Report of Division of Meteorology Support to the National Air Pollution Control Administration U.S. Department of Health, Education, and Welfare

Air Resources Laboratory
RALEIGH, N. CAROLINA
February 1970

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ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION

BOULDER, COLORADO

U.S. DEPARTMENT OF COMMERCE
Environmental Science Services Administration
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FISCAL YEAR 1969 SUMMARY REPORT OF DIVISION OF METEOROLOGY SUPPORT TO THE NATIONAL AIR POLLUTION CONTROL ADMINISTRATION U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE

Air Resources Laboratory
Division of Meteorology (NAPCA)
Raleigh, North Carolina
February 1970

PREFACE

Effective 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 be left 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 was funded by the National Air Pollution Control Administration (NAPCA) and was done under agreement between the NAPCA and the Environmental Science Services Administration (ESSA), dated November 8, 1968.

Any inquiry on the research being performed should be directed to Mr. R. A. McCormick, Director, Division of Meteorology (NAPCA), 3820 Merton Drive, Raleigh, North Carolina 27609.

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FISCAL YEAR 1969 SUMMARY REPORT OF DIVISION OF METEOROLOGY SUPPORT TO THE NATIONAL AIR POLLUTION CONTROL ADMINISTRATION DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE

The following brief summaries of meteorological research and other activities attempt to convey the present status of a variety of projects being conducted by the Division of Meteorology (DM) for the National Air Pollution Control Administration (NAPCA).

Uniterms: Air Pollution Potential forecasting, air quality control region, climatology, dispersion modeling, diffusion modeling, lidar study of stack plumes, large power plant effluents, turbidity, radiation, urban boundary layer, urban heat island.

1. HIGHLIGHTS

The Large Power Plant Effluent Study, now in its second year, was undertaken to determine the amount of air pollution produced by a large complex of coal-burning power plants and the effects of that pollution on the local environment. Studies are being carried out at a power generation complex in western Pennsylvania, which will daily emit into the atmosphere about 2500 tons of sulfur dioxide (SO_2). By use of instrumented aircraft and a mobile lidar, operated under contract, measurements were obtained of plume rise and geometry, plume dispersion and associated ground-level SO_2 concentrations, fly ash particle-size distributions, and turbulence. Peak ground-level SO_2 concentrations as high as 1.6 parts per million (ppm) were measured at a distance of 1 kilometer (km) from the stack source, and 30-minute average concentrations of 0.3 ppm were detected at distances of 9-10 km from the source. The SO_2 concentrations were measured during two month-long periods of tests.

During the past year, nine episodes of high air pollution potential were forecast by the ESSA National Meteorological Center. Selected meteorological parameters, which are used to indicate the presence of regions of slow diffusion and transport, have been programmed to yield an index number that indicates areas of atmospheric stagnation.

Primary efforts in urban diffusion modeling were conducted through contracts. Arrangements were made for an international symposium on the subject of Multiple Source Urban Diffusion Models to be held at the University of North Carolina. The proceedings of this symposium will be published in 1970. A Symposium "Advances in Instrumentation for Air Pollution Control" was held in Cincinnati. Reports on the state of the art were given by industry and government scientists.

A theoretical and experimental program to describe the structure of the urban planetary boundary layer was started. Initial experiments in Cincinnati showed an apparent outflow of urban air aloft during nocturnal stability conditions. This phenomenon was termed the "urban heat plume".

Measurements of atmospheric turbidity in the Cincinnati area indicated that the city receives about 6 per cent less ultraviolet (UV) radiation than the adjacent rural area. It is hoped that future measurements of the vertical divergence of the net UV and the total radiation through the pollution layer will provide a more direct indication of selective absorption by pollutants.

A theoretical study and analysis of remote sounding methods for measuring vertical profiles of wind and turbulence was carried out for the Division of Meteorology by ESSA's Wave Propagation Laboratory.

Results suggest that acoustic radar or crossed-beam correlation techniques may be feasible for determining wind profiles and turbulence within the planetary boundary layer; additional studies along these lines are planned.

The contractor, Sperry Rand Corporation, has provided a Mark I millimeter radiometer, named the Radiometric Thermasonde, for remotely determining the vertical temperature profile. Performance and durability tests of the Mark I were started in early 1969.

Climatological data (mixing heights, vertically averaged wind speeds, etc.) from 62 Weather Bureau sounding stations, have been compiled to provide information on the diffusion climate of the contiguous U. S.

2. TRANSPORT AND DIFFUSION OF AIR POLLUTANTS

2.1 Large Power Plant Effluent Study (LAPPES)

A comprehensive investigation of the transport and dispersion of plumes from tall stacks (800-1000 ft) constituting the Large Power Plant Effluent Study (LAPPES) continues at a coal-burning power station complex in western Pennsylvania. By use of instrumented helicopters, a fixed-wing aircraft, and a mobile lidar, measurements have been obtained of plume rise and downwind geometry, plume dispersion and associated ground-level SO_2 concentrations, fly ash particle-size distribution, and turbulence. Peak ground-level SO_2 readings as high as 1.6 ppm have been measured 1 km from the stack source; 30-minute average concentrations of 0.3 ppm have been detected at a distance of 9-10 km.

The LAPPES project, now in its second year, was undertaken to determine the extent and effects of air pollution produced by the largest complex of coal-burning power plants in the United States. Three mine-mouth stations each designed to generate approximately 2000 megawatts of electrical power, are located equidistant along a northwest-southeast line, 25 miles long, about 50 miles east of Pittsburgh, Pennsylvania. When operational, these stations will daily emit more than 2500 tons of SO_2 into the atmosphere through four 800-ft and two 1000-ft stacks.

In an attempt to resolve some of the more pressing questions regarding dispersion from tall stacks and associated ground-level concentrations, the DM is conducting and sponsoring comprehensive field studies in the vicinity of these large power-generating facilities. Three objectives are being pursued:

1. Develop and verify transport and dispersion models that may be used to calculate expected ground-level concentrations of effluents from large power plants.

2. Measure the magnitude, frequency, and spatial distribution of ground-level SO_2 concentrations from large power plants and tall stacks, singly and in combination, and compare the observed data with calculated predictions.

3. Evaluate the deleterious effects of sulfur compounds and other effluents from a large power-plant complex on vegetation in the region of the installations.

Field studies conducted during the past year to meet these objectives consisted of two month-long series, the fifth and sixth since LAPPES was initiated. In the autumn series and half of the spring series, measurements were conducted on one 800-ft stack at the Keystone Plant; in the remaining half of the spring series both Keystone stacks were monitored. The plume was sampled by an instrumented helicopter on 34 days during the two scheduled periods. On 22 days the plume could not be probed because of adverse weather conditions, power plant outage, or helicopter malfunction. The helicopter was operated a total of 139 hours during the two series.

Observations by DM personnel involved extensive measurements of the plume aloft and at the earth's surface. A specially instrumented helicopter, in addition to having temperature, pressure, and moisture sensors, had a fast-response SO_2 detector system. Portable bubblers were used to obtain 30-min average SO_2 measurements at random ground-level locations under the plume. Meteorological support consisted of regularly scheduled radiosonde, rabal, and double-theodolite pibal observations.

In addition to observations by DM personnel during the October 1968 series, three LAPPES contractors provided data of interest. A team of scientists from Stanford Research Institute (SRI) used a Mark V lidar to measure plume rise and to define the geometry of the Keystone plume at various distances from the stack. This was accomplished by a vertical scanning technique with increments of $1/3^\circ$ to 10°, depending upon the plume's vertical extent. Such scans were obtained by locating the lidar at the side of the plume and scanning perpendicular to its mean centerline, and at 45° on each side of the perpendicular, thus obtaining three cross sections from a single location. The lidar was also used to check plume continuity by obtaining cross sections at a fixed distance downwind and at 15-min intervals during an entire morning.

The feasibility of lidar for stack plume studies was fairly well established from the results of the SRI experiments. The factors involved in interpreting the lidar data in terms of plume rise and diffusion are discussed in a final contract report to DM (Johnson and Uthe, 1969). Although calculated values of plume-rise agree reasonably well with the observations, inspection of the cross sections indicates clearly that the important effects of bifurcation and vertical wind direction shear (plume tilting and fanning), and vertical changes in stability (e.g., plume trapping) must be considered in predicting plume rise and diffusion.

A second contractor also probed the plumes. A meteorologist from Sign X Laboratory used an instrumented helicopter to obtain cross sections and to perform vertical ascents and descents through the plume within a distance of 8 km from the stack. The Sign X helicopter was instrumented like the LAPPES helicopter with one addition: a space-charge derivative unit was used to detect charged particles in the plume. By this means SO_2 and particulates were measured simultaneously in each plume traverse.

A third contractor, Meteorology Research, Incorporated, flew an instrumented Aztec aircraft to determine particle-size distribution in the Keystone plume and measure turbulence parameters in the vicinity of the plume. By use of a continuous-cloud-particle sampler and a moving-slide impactor, fly ash particle size was measured in both the dirty and clean plumes, 'dirty' referring to plumes with 50 per cent passage of fly ash out of the stack, and 'clean' denoting the plume produced with all precipitators in operation. Turbulence measurements were made with a universal turbulence indicator system under various meteorological conditions in the Keystone plume and in the vicinity of the Homer City and Conemaugh generating stations. The flight pattern for measuring both particles and turbulence parameters consisted of longitudinal flights in the plume and successive traverses downwind.

Data obtained by helicopter, as well as supporting meteorological measurements obtained thus far, are presented in Figures 2-1A and 2-1B. These are composite graphs of average-peak and maximum-peak ground-level SO_2 concentrations under the plume's longitudinal axis; 'peak' here denotes the highest instantaneous reading in a 1-km interval, e.g., out of 20 runs at the 5-km interval, the highest single reading would be the maximum peak, and the average of the 20 individual peaks would be the average peak. The dots in Figure 2-1B are individual observations made when both Keystone stacks were operating. These data, obtained in 67 days of helicopter measurements near ground level, clearly show the looping-plume effect close to the stack. A secondary maximum at 18 km may have resulted from plume downwash during inversion breakups. Figure 2-2 presents the maximum 30-min SO_2 concentrations detected by the portable bubblers during the past six series and shows the total number of measurements. The intermittent nature of the looping plume apparently contributed relatively little to the bubbler readings near the stacks; the higher values occur downwind, where higher ground-level concentrations are more persistent and are associated with coning or limited dispersion in the mixing layer. In none of the figures have the ground-level data been classified according to variable plant load.

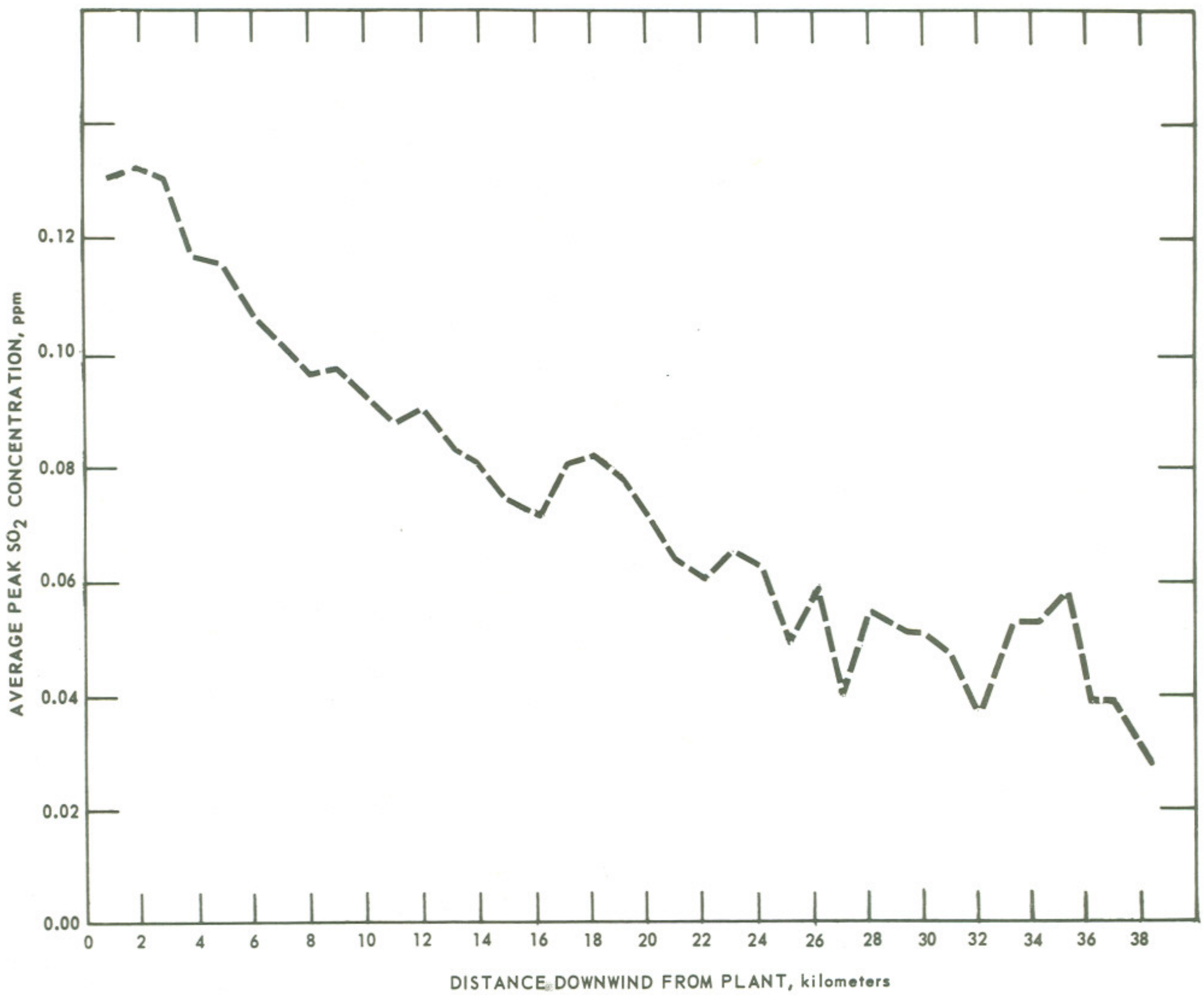

Figure 2-1A. Average peak ground level SO_2 concentrations measured by helicopter under the Keystone plume's longitudinal axis. From the large power plant effluent study in Western Pennsylvania.

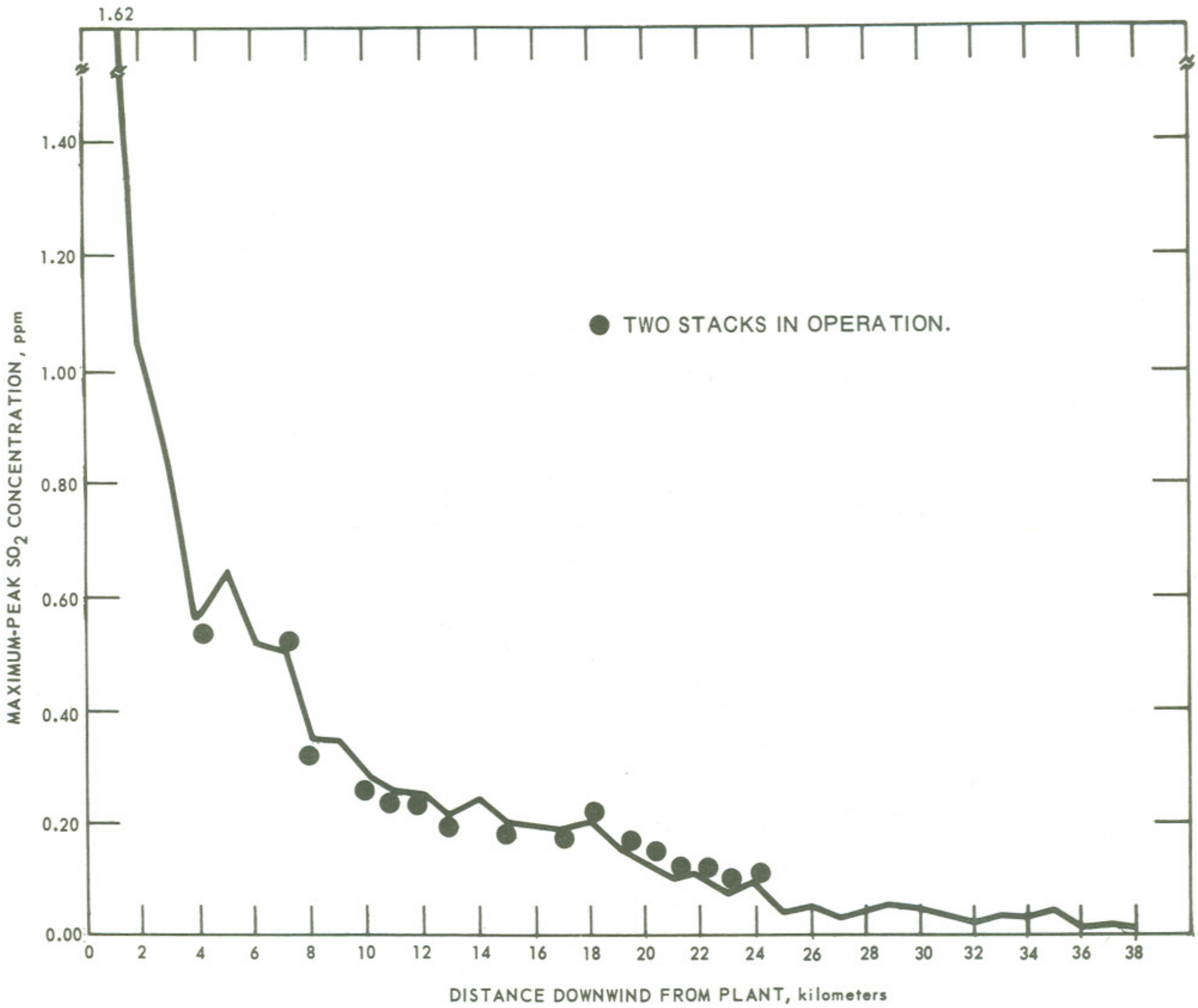

Figure 2-1B. Maximum peak ground level SO_2 concentrations measured by helicopter under the Keystone plume's longitudinal axis. From the large power plant effluent study in Western Pennsylvania.

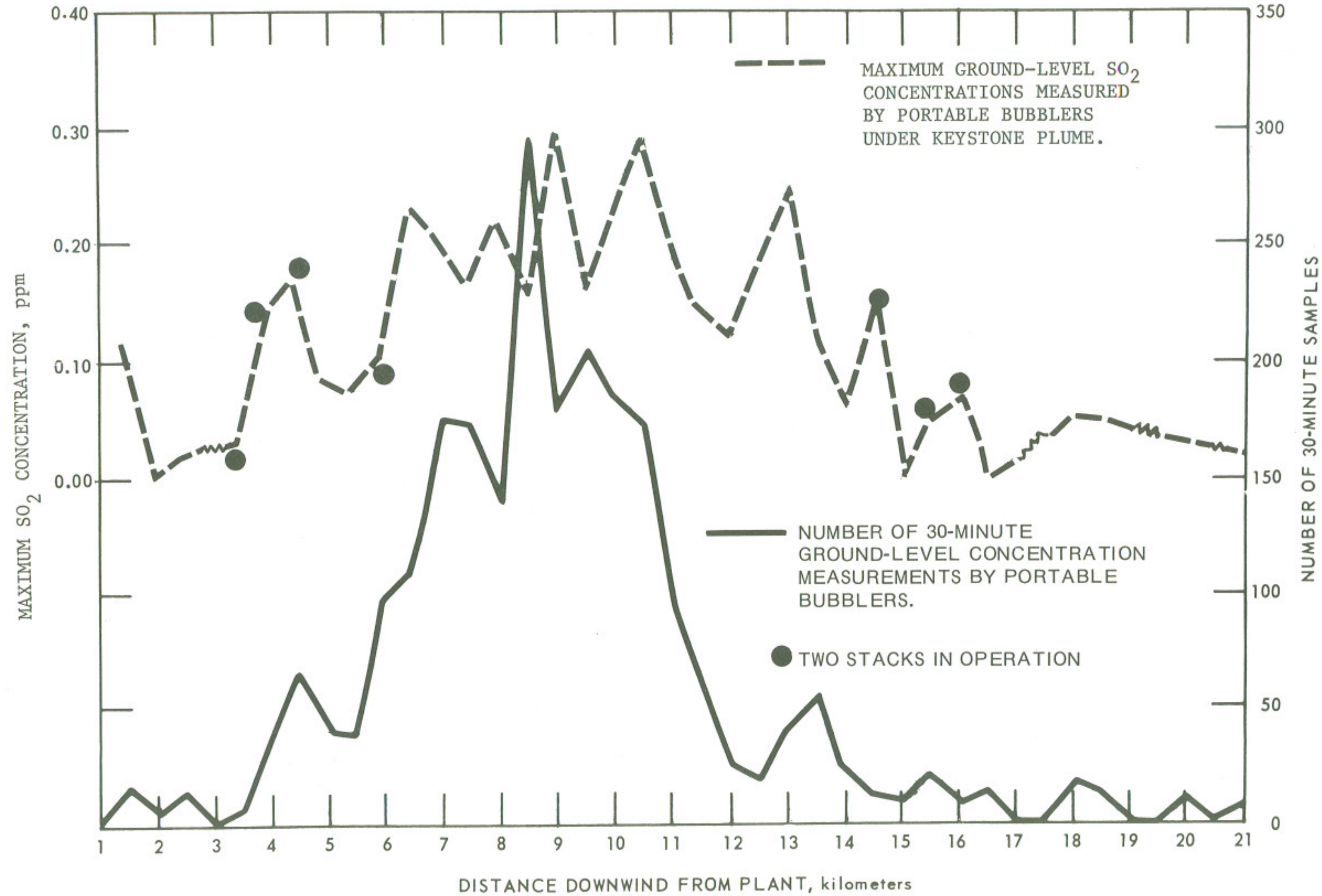

Figure 2-2. Maximum 30-minute SO_2 concentrations detected by the portable bubblers.

Rainfall samples were collected under the plume three times during the past year and analyzed for sulfates, nitrates, and alkalinity (pH) levels. Preliminary results show that pH values provided the best indication of cross-plume distribution; values for sulfates and nitrates correlated only fairly well.

The agricultural portion of the LAPPES study, conducted by the Agriculture Section of NAPCA, is designed to determine effects of power plant emissions on the agricultural economy of the adjacent region. Two types of sites, designated primary and secondary, have been selected for agricultural experiments.

Instrumentation at the primary agricultural sites will include a Mast meter with recorder for oxidant measurements, two sequential samplers for SO_2 and NO_2 measurements, and at some sites a conductometric SO_2 analyzer. Eight primary sites have been selected to ensure similarity of soil types and drainage patterns and proximity to farm ponds used for irrigation; the sites are at least 2 miles from any source of SO_2.

Each primary site is divided into two locations, which are in turn divided into two plots. One plot in each location is irrigated to isolate the effects of soil moisture on plant damage. Thus, each test site includes two irrigated and two nonirrigated plots. Each plot contains 25 replications of four tree species.

The secondary agricultural sites are instrumented with lead peroxide candles for measurement of sulfate levels. The secondary sites are located in plantations of scotch and white pine trees, in a part of western Pennsylvania known for its Christmas tree industry. Similarity of slopes and drainage patterns was considered in selecting the secondary plots. Ten trees were randomly selected within a 100-tree grove, and arrangements were made with the plantation owner not to shear and shape the trees.

Three times during the growing season the selected trees, as well as native and other commerical vegetation, are sampled for sulfate levels. In the fall, growth of the trees selected for study is measured.

Yield and growth data from the eight primary agricultural sites will be evaluated with reference to the air quality measurements taken at the site and in terms of distance from the power plants. Sulfate levels obtained at the secondary sites with lead candles and by analysis of leaf samples will also be evaluated to determine any effects on trees at the secondary plots.

Plans call for two field experimental series during fiscal year 1970 to be conducted on one- and two-stack configurations at the Homer City Plant. Collection and analysis of rainfall under the Keystone plume by Battelle Memorial Institute, Northwest, will continue. They will relate their data to the existing natural precipitation, meteorology, and plume parameters.

Meteorology Research, Inc., is continuing its efforts to determine the mean effective plume height and the meteorological parameters that govern effective plume height under selected atmospheric conditions. The IIT Research Institute is determining the weather modification effected by the enormous output of water vapor and heat from the LAPPES cooling towers.

2.2 Air Pollution Potential Forecasting

During the past year, nine episodes of high air pollution potential were forecast by ESSA's National Meteorological Center (NMC) meteorologists. This lower-than-average number (average is about 12) attested to the good ventilation of this period.

With the acquisition of a full-time computer programmer at NMC, it has been possible to reach several of the programming goals set at the beginning of the year. Since April, selected meteorological parameters, which are used to indicate the presence of regions of slow dispersion (see 1968 Annual Report, ESSA, 1969) have been programmed to yield an index number. These experimental numbers (see Table 2.1) can be plotted to determine areas of large-scale stagnation. The areas so determined, called "caution areas," are based on meteorological data obtained at 12-hour intervals. At present data are received for "this morning", "this afternoon", and "tomorrow morning and afternoon." When a significantly large area is in a "caution" status for at least three successive 12-hour periods, high pollution potential is evaluated further in terms of the box-model normalized concentration. The downwind concentration of a city is given by

$$\chi/Q = \frac{C}{\text{vent}},$$

where vent = [Transport wind speed (m s^{-1})] [mixing height (m)],

χ = Concentration (g m^{-3})

Q = area emission rate (g m^{-2} s^{-1}), and

C = city size (m) (distance across the city along the wind direction.)

For convenience, a C of 100,000 m is used.

Table 2.1 Stagnation Index Numbers

Index Number	Criteria
00	caution area indicated; no stagnation criteria violated
01	12-hour temperature change exceeds/5°C/at 5000 ft. above sea level.
02	wind exceeds 10 mps at 5000 ft. ASL
03	observed precipitation in previous 6 hours exceeds 0.01 inch.
04	combination of 01 and 02
05	combination of 01 and 03
06	combination of 02 and 03
07	combination of 01, 02, and 03
10	12-hour/vorticity change/exceeds 30×10^{-6} sec^{-1}
11 to 17	same as 10 plus 01 to 07 above
20	observed vorticity exceeds 100×10^{-6} s^{-1}
21 to 27	same as 20 plus 01 to 07 above
30	both vorticity and vorticity change exceed limits
31 to 37	same as 30 plus 01 to 07 above

A sample of this type of model analysis, now performed routinely, is given in Figures 2-3 and 2-4 for the morning and afternoon of May 10, 1969, selected because it was the first day an NMC advisory was issued when caution area index numbers and normalized concentration data were available. On these charts a caution area occupies the western states. High values of χ/Q both for "today" and for the forecasts of the "following day" are found along the coast and valley of California. In this instance, the forecast advisory was issued by the NMC meteorologist.

Observed pollutant variations at Cincinnati during April and May and the days the caution charts indicated weak circulation (bars), are shown in Figure 2-5. During these months, anticyclonic pressure fields tended to predominate over the eastern United States, hence there were frequent days of weak circulation. Figure 2-5 shows that the peak concentrations occurred during the two periods of persistent weak circulation, May 3-7 and May 27-31. The secondary peaks are also generally observed during the shorter stagnation periods.

Forecasts of the mixing height for "tomorrow morning", a value needed to compute the morning forecast χ/Q value, were accomplished by the technique presently used to predict "tomorrow afternoon" mixing height [Miller, 1967]. Regression curves were determined from two years of climatological data, and the regression coefficients were used in a computer program to generate morning mixing height.

During the year, three newly assigned Weather Bureau urban meteorologists visited the DM for a week of familiarization with the air pollution potential forecasting program. As a part of their indoctrination, a study was begun to analyze the extreme pollution days in 1965 for each season at each of the cities they serve.

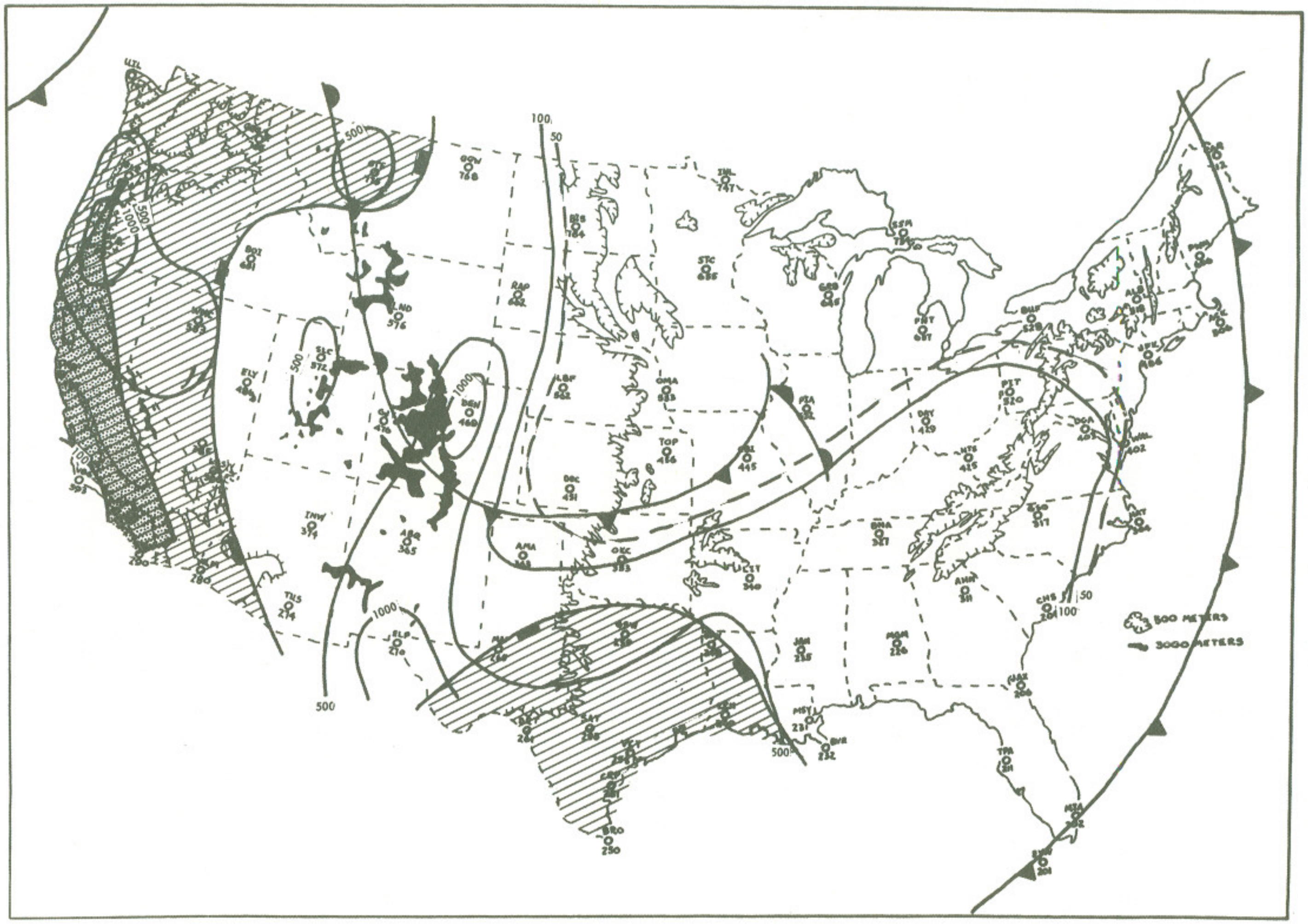

Figure 2-3. Caution chart for the morning of May 10, 1969. Areas of weak circulation are indicated by heavy piped lines and cross hatching. Isolines are for values X/Q (box model). Frontal positions are indicated by their usual symbols. The advisory area is shown by heavy straight lines over the west coast of the United States and is stippled.

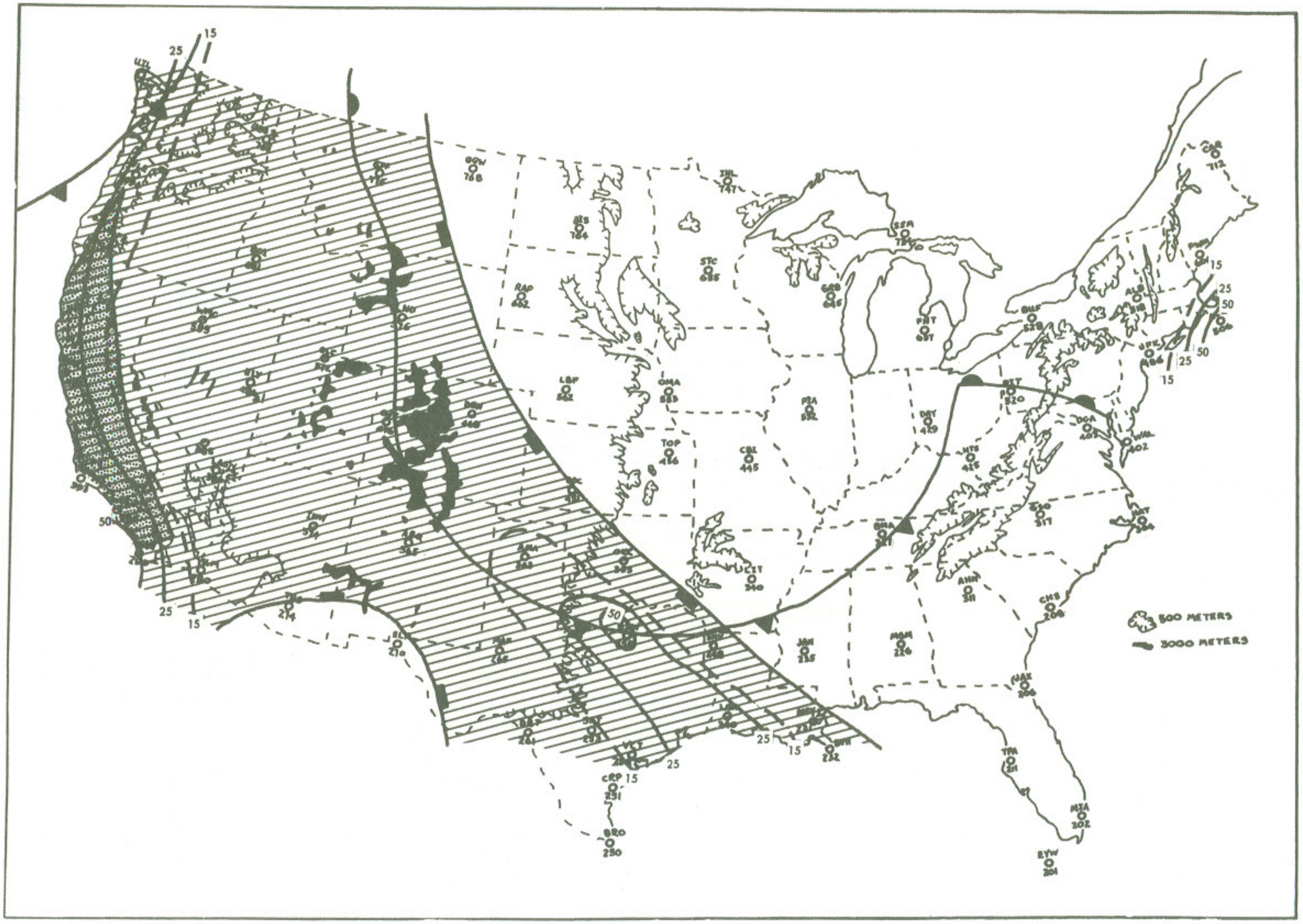

Figure 2-4. Caution chart for the afternoon of May 10, 1969. Areas of weak circulation are indicated by heavy piped lines and cross hatching. Isolines are for values of X/Q (box model). Frontal positions are indicated by their usual symbols. The advisory area is shown by heavy straight lines over the west coast of the United States and is stippled.

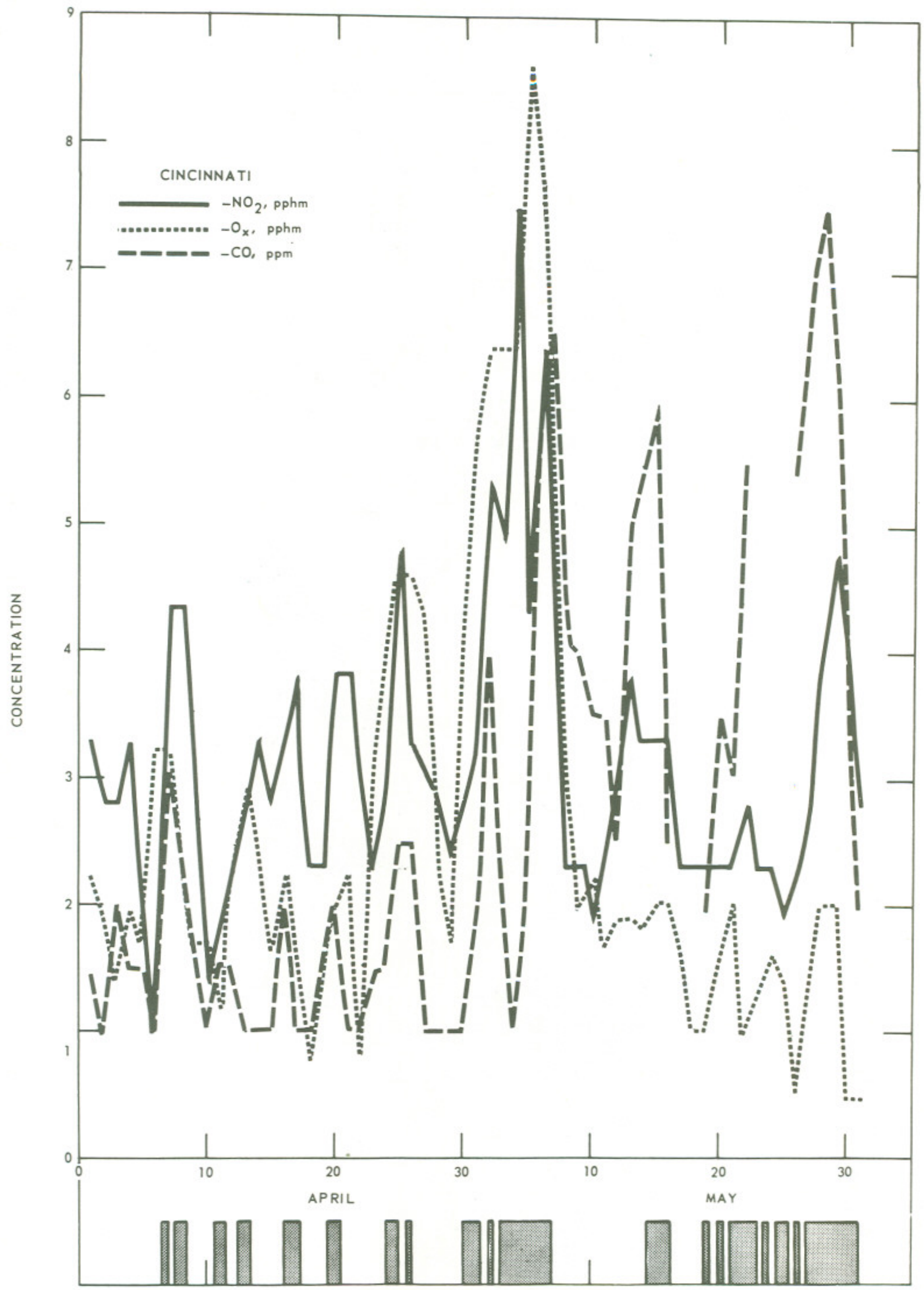

Figure 2-5. These pollutants (NO_2, O_x, CO) observed at Cincinnati for April and May 1969. The solid bars on the bottom of the diagram indicate those 12-hour intervals when the caution index was zero, that is when all the criteria indicating stagnation were satisfied.

2.3 Urban Diffusion Modeling

Primary efforts in urban diffusion modeling were carried out by contractors. Contractual work included a continuation of previous modeling efforts with the Argonne National Laboratory (funded jointly by the Atomic Energy Commission, NAPCA, and the Chicago Department of Air Pollution Control) to develop a sophisticated Gaussian-puff type, multiple fixed-source diffusion model. Also a new contract, jointly supported by NAPCA and the Coordinating Research Council, was placed with Stanford Research Institute to develop a theoretical urban diffusion model specifically related to automotive-produced air pollution.

Arrangements were made for NAPCA support of a major symposium on multiple-source urban diffusion models to be held at the University of North Carolina, Chapel Hill, in October 1969. This will include invited speakers from overseas as well as many from the United States. Arrangements have been made for publication of the proceedings in 1970. The symposium will provide for extensive technical interchange between many of the active workers in the field, and the proceedings will constitute a readily available permanent record of current modeling technology.

A paper on the current status of modeling efforts and their potential applications was presented in March 1969 at the Mid-Atlantic States Section of the Air Pollution Control Association. This paper, "Urban Atmospheric Dispersion Models - Past, Present, and Future," was presented by D. Bruce Turner.

3. PROPERTIES OF THE URBAN BOUNDARY LAYER

3.1 Dynamics of the Urban Boundary Layer

A theoretical and experimental program is underway to study the structure and related dynamics of the urban planetary boundary layer. An immediate goal consists of developing skill at forecasting urban meteorological parameters based upon rural counterparts, and of providing improved meteorological input into mathematical models of urban dispersion. A more fundamental long-term aim is development of physical and mathematical models of atmospheric processes and attendant diffusive properties within the urban boundary layer.

The initial experimental effort consisted of a series of nocturnal field investigations in metropolitan Cincinnati, Ohio. A detailed account of the experimental program and its principal results was presented in the previous Annual Report [ESSA, 1969]. Basically, measurements were made of the vertical temperature and wind fields across the metropolitan area in line with the mean wind. Analysis of the measurements showed a developing thermal boundary layer increasing in depth as air with a rural history traversed the urban settings. The shape and depth of this thermal mixing layer appeared to be significantly related to the upwind rural thermal structure. Downwind of the urban area, air near the surface restabilized. Above this stable layer of air, advection of warmer urban air appeared to occur. This apparent urban outflow aloft has been termed "the urban heat plume."

In order to verify and further quantify the findings of the Cincinnati study for other locales and to generalize the primary results, a series of comprehensive field investigations was conducted in metropolitan Columbus, Ohio, selected for its relatively flat terrain. A total of 12 nocturnal experiments were spaced over three series (June 1968, September 1968, and March 1969). On each occasion, measurements normally began at sunset and continued until sunrise, except for a 2-3 hour period around midnight. Stability conditions associated with the experiments ranged from neutral to very stable. The observational program consisted of: (1) temperature and wet-bulb temperature soundings via helicopter; (2) winds aloft measured by single and double theodolite at several locations across the metropolitan area; (3) air temperature measured near the surface by automobile traverses; (4) "radiation surface" temperature remotely measured with an infrared radiometer flown in a fixed-wing aircraft; and, (5) turbulent wind fluctuations measured with bi-directional vanes (sometimes anemometer bivanes) at two elevations in the downtown area on building platforms. During the last experimental series, temperature, moisture, and net (longwave) radiation (Suomi-Kuhn radiometer) at several elevations were obtained in tethered balloon ascents at an urban location. "Constant-level" balloons (tetroons) also were flown across the city during this series. On three occasions, grab samples of CO at several elevations and locations across the metropolitan area were obtained during helicopter ascents. On one occasion a meteorological tracer (SF_6) was disseminated, and air was sampled at several locations near the surface and in the vertical (via helicopter ascents) with Saran bag collectors.

At the culmination of this field phase of the program (with the March series), a comprehensive analysis of the experimental data was begun. Computer programs were written to process the data on turbulence, temperature, and moisture, and to plot wind profiles, temperature profiles, and cross sections. The programs are being tested. An existing program was adapted to compute wind profiles from single- and double-theodolite pibal observations. The pertinent data were prepared for machine processing, and initial machine output from the pibal observations has been edited. Preliminary manual analysis of the near-surface temperature and radiation-surface temperature patterns is nearly complete.

Preliminary results of the Columbus experiments generally agree with those reported earlier for Cincinnati. During the experimental periods in Columbus, the apparent depths of the thermal boundary layer were roughly between 200 and 500 ft. The meteorological tracer material disseminated in the upwind suburban section (on a single occasion) went aloft downwind of the city, thus furnishing experimental evidence for the concept of the urban heat plume and for the downwind restabilization of air near the surface. In general, the radiation-surface temperature variations correlated closely with the existing land-use. In addition, quite similar indications of the magnitude and spatial distribution of the surface projection of the urban heat island were noted in the radiation-surface and near-surface temperature patterns. Further results will be reported on completion of the analysis.

A literature survey on the urban planetary boundary layer was completed and summarized in an internal document.

A two-volume report describing the meteorological tracer experiments over metropolitan St. Louis, Missouri, was published [McElroy and Pooler, 1968a, 1968b]. A condensed version of this report was published in the Journal of Applied Meteorology [McElroy, 1969].

3.2 Radiation and Turbidity

An atmospheric turbidity project was begun in 1960 to provide a turbidity climatology for the United States; it is hoped that the measurements can serve as quantitative indicators of the aerosol content of urban atmospheres. About 40 observational stations are maintained in the United States, and additional observations are received from Mauna Loa, Hawaii; Poona, India; and Bet Dagan, Israel. A summary of the network turbidity measurements titled "Atmospheric turbidity over the United States--1961-1966," was submitted for journal publication. Figure 3-1, taken from this report, shows annual turbidity curves for the network stations. The shapes of the curves, which are similar for all stations, roughly indicate a doubling of turbidity from winter to summer. Urban-suburban turbidity differences are illustrated by the curves for Cincinnati and New York City; in Cincinnati, the GSEF station is located downtown and T-2 is on the eastern edge of the city; in New York City, Rockefeller Plaza represents the center of the city and Brookhaven National Laboratory represents the suburbs on Long Island. These locations contrast markedly with the relatively clean rural atmosphere illustrated by Huron or St. Cloud. Current efforts in the turbidity program are directed toward expanding the worldwide network and developing improved instrumentation.

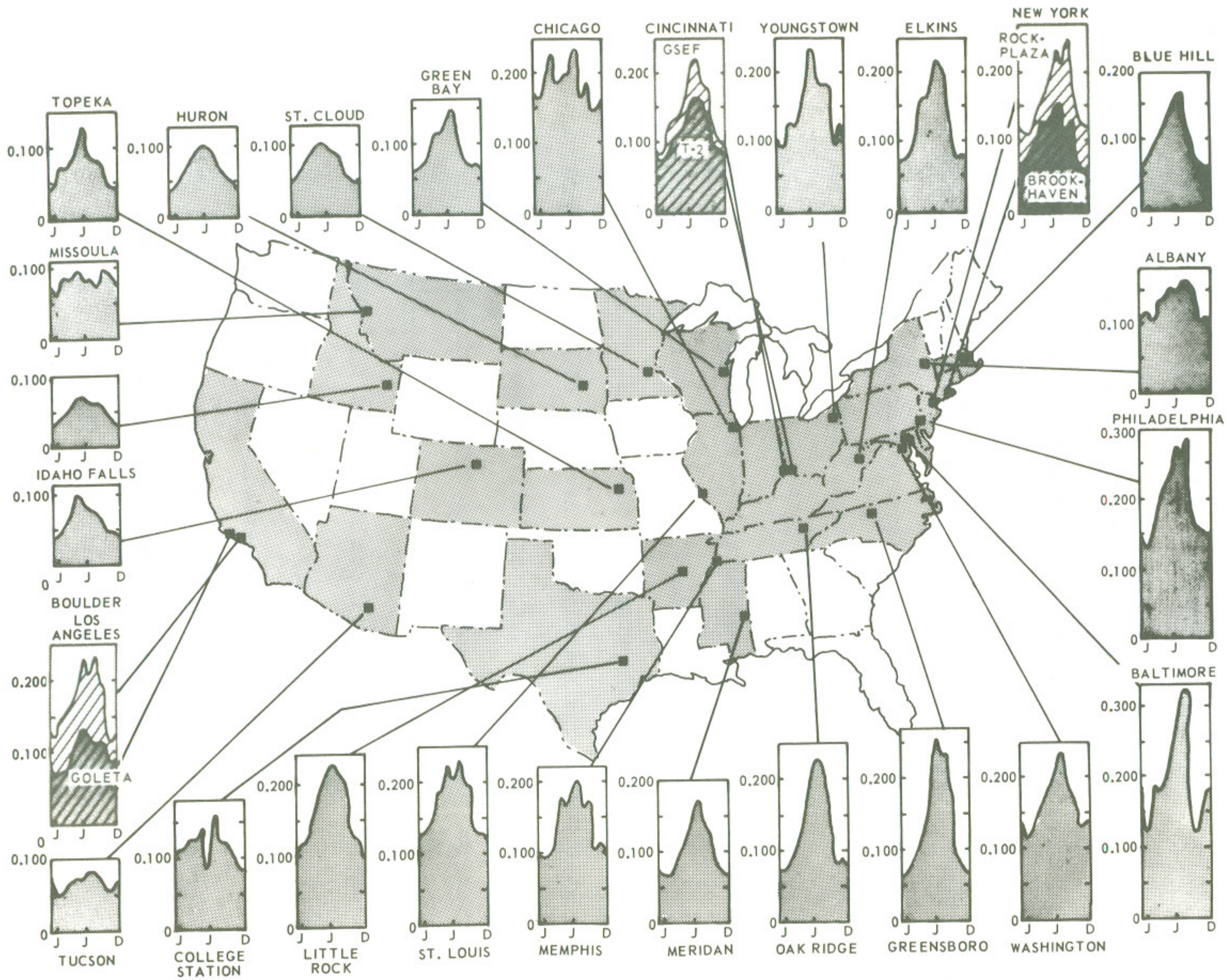

Figure 3-1. Monthly average turbidity (B) at network stations.

The ultraviolet irradiation of a horizontal surface in the wavelength interval from 0.29- 0.38 μm has been measured both in downtown Cincinnati (GSEF) and at the Indian Creek Wildlife Area (ICWA) located about 35 miles east of Cincinnati. The measurements are made continuously, and comparison of all data for the period from July 1968 through February 1969 indicates that the city receives about 6 per cent less UV radiation than the rural site. Considering only cloudless days, the urban/rural ratio of UV irradiation varies from 0.92 to 1.0 and appears to be related to the atmospheric turbidity measured in the city. That is, with relatively low turbidity the urban-rural difference is small and the difference increases as the turbidity increases. Table 3.1 presents the monthly urban/rural UV ratios for all days and for cloudless days. Each month except December had one cloudless day; October and February each had two cloudless days.

Table 3.1 Monthly Urban/Rural UV Ratios

	1968				1969			
	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB
All days	0.949	0.973	0.939	0.956	0.948	0.925	0.911	0.897
Cloudless days	0.934	0.945	0.925	0.999/ 0.922	0.989	-----	0.963	0.955/ 0.964

The differences in urban and rural UV irradiation may indicate anomalous absorption of UV by the city's atmosphere. Other evidence in support of this idea may be found in the variation of the ratio of ultraviolet irradiation (0.29--0.38 μm) to total solar irradiation (0.30--3.0 μm) at the GSEF station in Cincinnati. Figure 3-2 presents such comparisons for 15 cloudless days during the period from April 1968 through

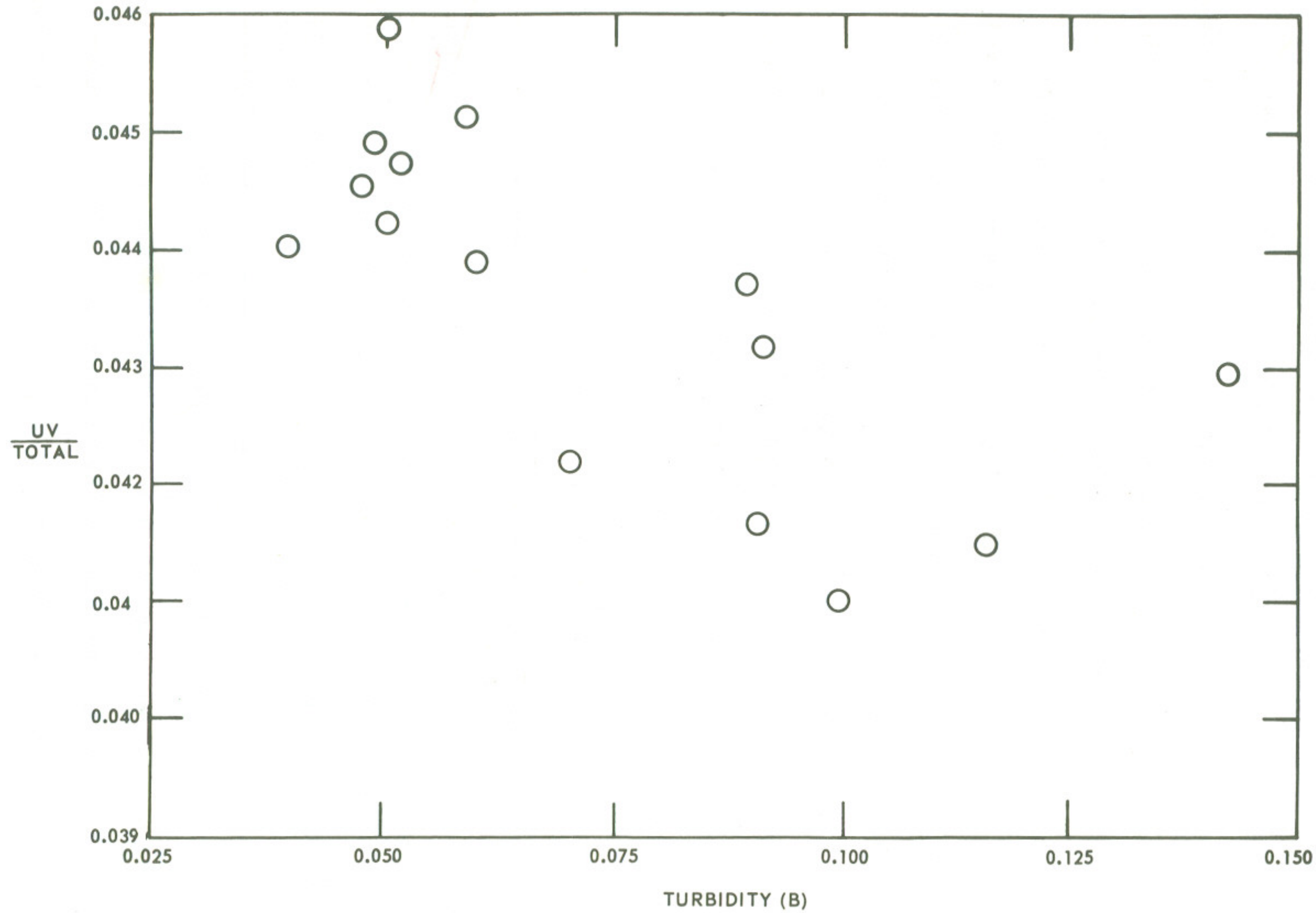

Figure 3-2. Variation of the ratio of ultraviolet/total solar irradiation with turbidity (B) for cloudless days at GSEF, Cincinnati, Ohio.

February 1969. The ratio of UV to total solar irradiation decreases as the turbidity increases. The turbidity measurement, made at a wavelength of 0.50 μm, essentially indicates attenuation of the direct solar beam by aerosols. The UV and total measurements indicate the sun-plus-sky irradiation of a horizontal surface. Since large particles predominantly scatter the radiation in the forward direction, an increase in the scattering of the direct beam radiation as indicated by an increase in the turbidity factor does not necessarily produce a comparable decrease in the sun-plus-sky radiation reaching a horizontal surface. If there has been a change in particle-size distribution toward a larger proportion of small particles with the increased turbidity, then the observed decrease in UV irradiation evidenced in the smaller ratio of UV to total radiation may be the result of increased back-scattering of the incoming solar beam. It does not appear, however, that aerosol size-distribution is uniquely related to the absolute value of the aerosol extinction. Determinations of Angstrom's wavelength coefficient, which is related to the particle-size distribution, by pyrheliometer filter measurements in Cincinnati, failed to establish a systematic relationship between variations in the wavelength coefficient and turbidity factor. Thus if the particle-size distribution is essentially the same for a clean and a polluted urban atmosphere, then the ratios of the scattering coefficients in the UV and total regions of the solar spectrum should also be the same for clean and polluted atmospheres. It then follows that a decrease in the ratio of UV to total radiation for a polluted atmosphere indicates anomalous selective absorption in the UV spectral region. Measurements of the divergence of the net UV and total irradiation through the pollution layer should provide a more direct indication of selective absorption, presumably by pollution gases. Such a study is part of a program concerned with the radiation budget of a city and its environs, which is expected to begin in early 1970.

3.3 Radiometric Temperature Profiles

Since late 1965, DM has supported efforts of the Sperry Rand Corporation to develop a technique of remotely measuring the vertical temperature profile in the lower 1.5 km of the atmosphere, with a groundbased millimeter-wave radiometer. Studies have led to development of the MARK I Radiometric Thermasonde, a prototype radiometer, operating at the 54.5 GHz region of the microwave spectrum, where there exists an absorption band due to molecular oxygen.

DM accepted delivery of the MARK I Radiometric Thermasonde from Sperry Microwave Electronics Division in February 1969. At that time the MARK I was operated in conjunction with Sperry Rand's MARK 0 radiometer. This is believed to be the first time that two 54.5-GHz radiometers were operated in the same place and at the same time. The two radiometers yielded nearly identical data, which were confirmed by vertical temperature profiles taken simultaneously by helicopter. Since February 1969 the MARK I has been operated on a semi-routine basis at the DM's Gest Street Facility in Cincinnati. Radiometric vertical temperature profiles were taken during morning and afternoon lapse conditions; in some cases of predicted inversion conditions measurements were made continuously to record inversion formation and breakup. In all cases profiles were taken simultaneously by radiosonde and/or helicopter probe for comparison with the radiometric data.

Figure 3-3 exemplifies the results obtained. The dashed line represents radiometer data and the solid line represents the radiosonde data taken for comparison. Note that the radiometer tends to smooth the inversion. This is a consistent feature of the radiometric techniques, occurring whenever the actual temperature profile does not exhibit a constant slope.

To date 41 radiometric temperature profiles, with confirming radiosonde or helicopter data, have been made under a wide variety of environmental conditions. The data indicate that the MARK I is consistent and reliable. After more than 3 months exposure to rather wide temperature extremes, heavy rains with high winds, and other adverse conditions, the MARK I required no repair or adjustment. Evaluation of the MARK I will continue, and a detailed performance report is expected in 1970 (see Figure 3-4).

DM support to Sperry Rand during the coming fiscal year will focus on improving analytical capability to detect elevated inversions radiometrically.

The ESSA Wave Propagation Laboratory completed a feasibility study of remote sensing techniques for measuring winds and turbulence in the planetary boundary layer. Further efforts will be devoted to perfecting and testing such a technique in 1970.

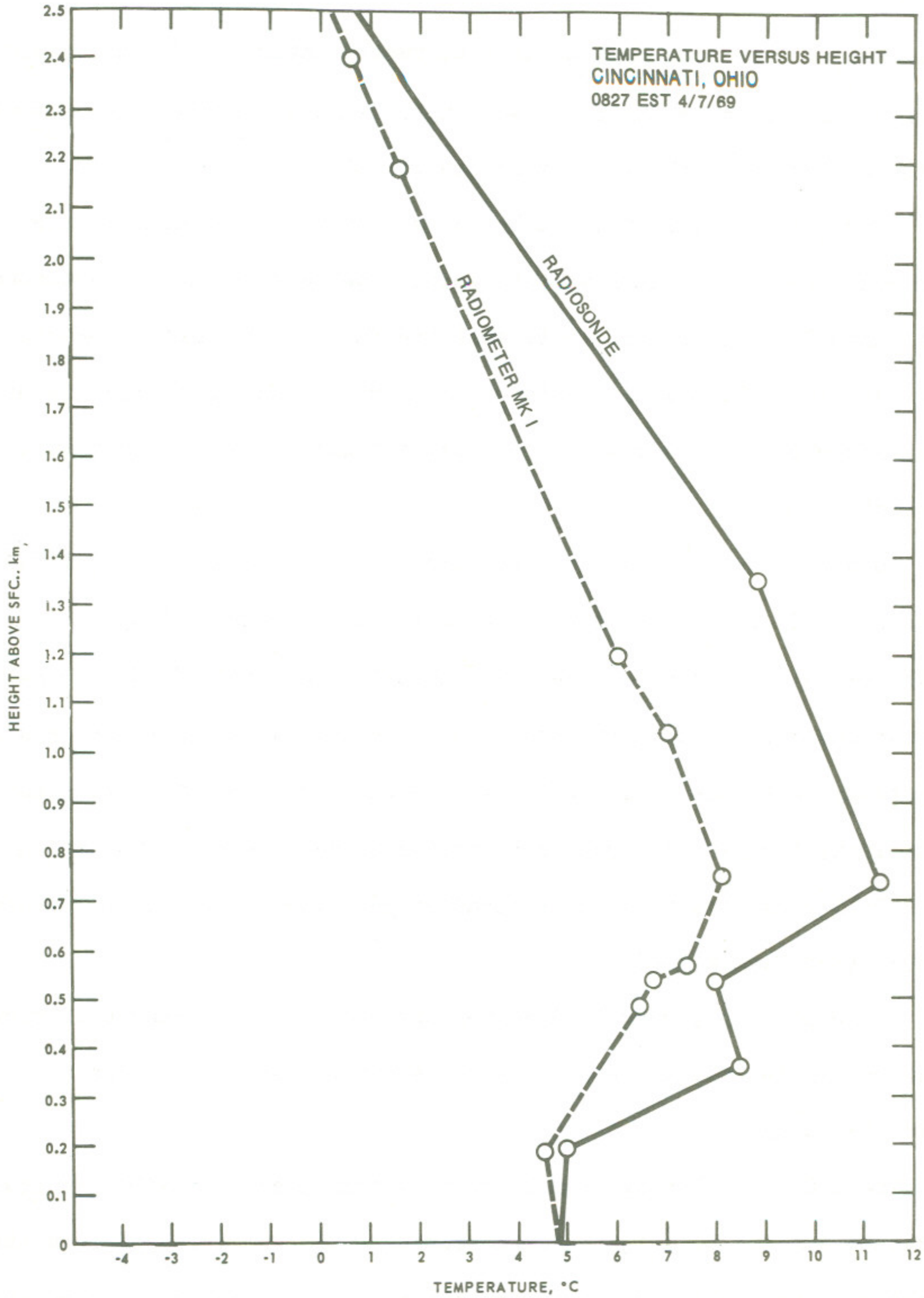

Figure 3-3. Vertical temperature profiles taken by thermasonde and radiosonde.

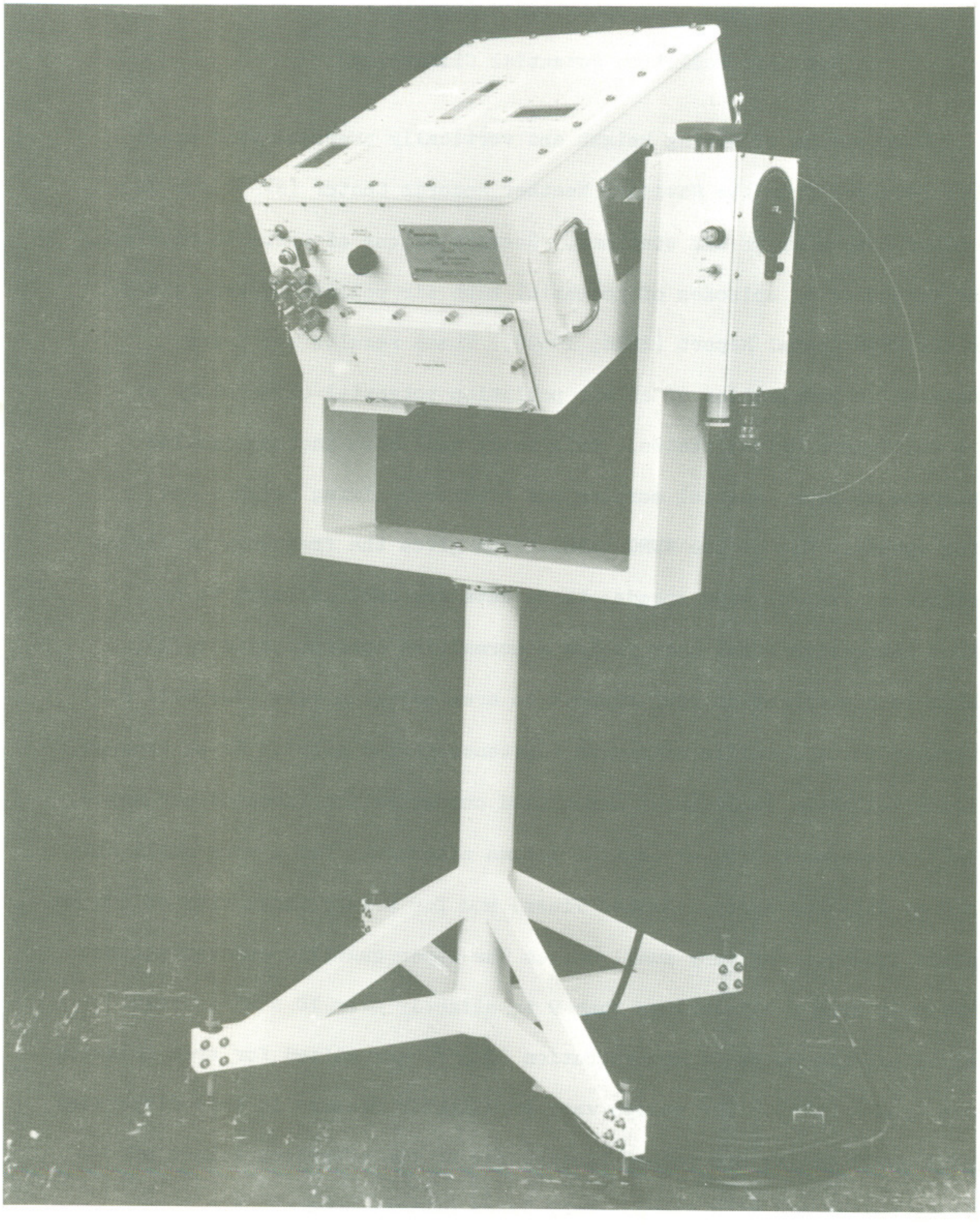

Figure 3-4. The portable MARK I Thermasonde.

4. AIR POLLUTION CLIMATOLOGY

4.1 Air Pollution Potential Climatology

Tabulations of mixing height and vertically averaged wind speed were received from the National Weather Records Center (NWRC) for 62 Weather Bureau upper air stations. Results of one of these tabulations, the frequency of episodes of potential high air pollution, were given in the 1968 Annual Report [ESSA, 1969]. These results are being analyzed in preparation of an air pollution potential climatology of the contiguous United States. This study will also include isoline analyses of mean seasonal morning and afternoon mixing heights and wind speeds. One of the NWRC tabulations gives the frequency of mixing heights at various wind speeds; these data are used as input to an urban dispersion model that yields a normalized concentration (χ/Q), which is concentration with respect to area emission rate (see Sec. 2.2) averaged for a specific city size (distance across city). As an example, Figure 4-1 shows isolines of normalized concentration (seconds per meter, s m^{-1}) exceeded on 25 per cent of autumn afternoons for a very small city of 5 km distance across (dashed lines) and for a very large city of 100 km (solid lines). For very small cities the upper quartile concentrations vary only from a little less than 9 to slightly over 10 s m^{-1}; these values are the units of concentration (g m^{-3}) normalized for area emission rate (g m^{-2} s^{-1}). The values vary so slightly because in this dispersion model small cities are rather insensitive to the afternoon values of mixing height and wind speed. Very large cities, however, are more sensitive to afternoon values of these parameters, and the upper quartile value of normalized concentration (in Figure 4-1) for a 100-km city ranges from less than 20 to more than 40 s m^{-1}. Isoline analyses of additional city sizes and percentile values of concentration are being prepared. Thus, geographic comparisons of the meteorological potential for community air pollution will be readily available. Furthermore, by projecting the increase in size of any city in the United States the normalized concentration may also be projected.

4.2 Urban Climatology

A comprehensive review was made of recent literature on urban climates. Urban-rural differences of the following parameters were considered: temperature, precipitation, humidity, visibility-aerosols, solar radiation, and wind speed and direction. A report "The Climate of Cities: A review of Current Literature" will be published by NAPCA as an internal document.

A statistical analysis of the distribution of SO_2 over metropolitan St. Louis was based on measurements from The Interstate Air Pollution Study of 1964-1965. A paper, "Distribution of Sulfur Dioxide over Metropolitan St. Louis, as Described by Empirical Eigenvectors, and its Relation to Meteorological Parameters," presents a technique for describing the areal distribution of normalized pollutant values and shows the dependence of the derived patterns on meteorology. Attempts are continuing to apply this descriptive technique to prediction of pollutant patterns based on meteorological parameters.

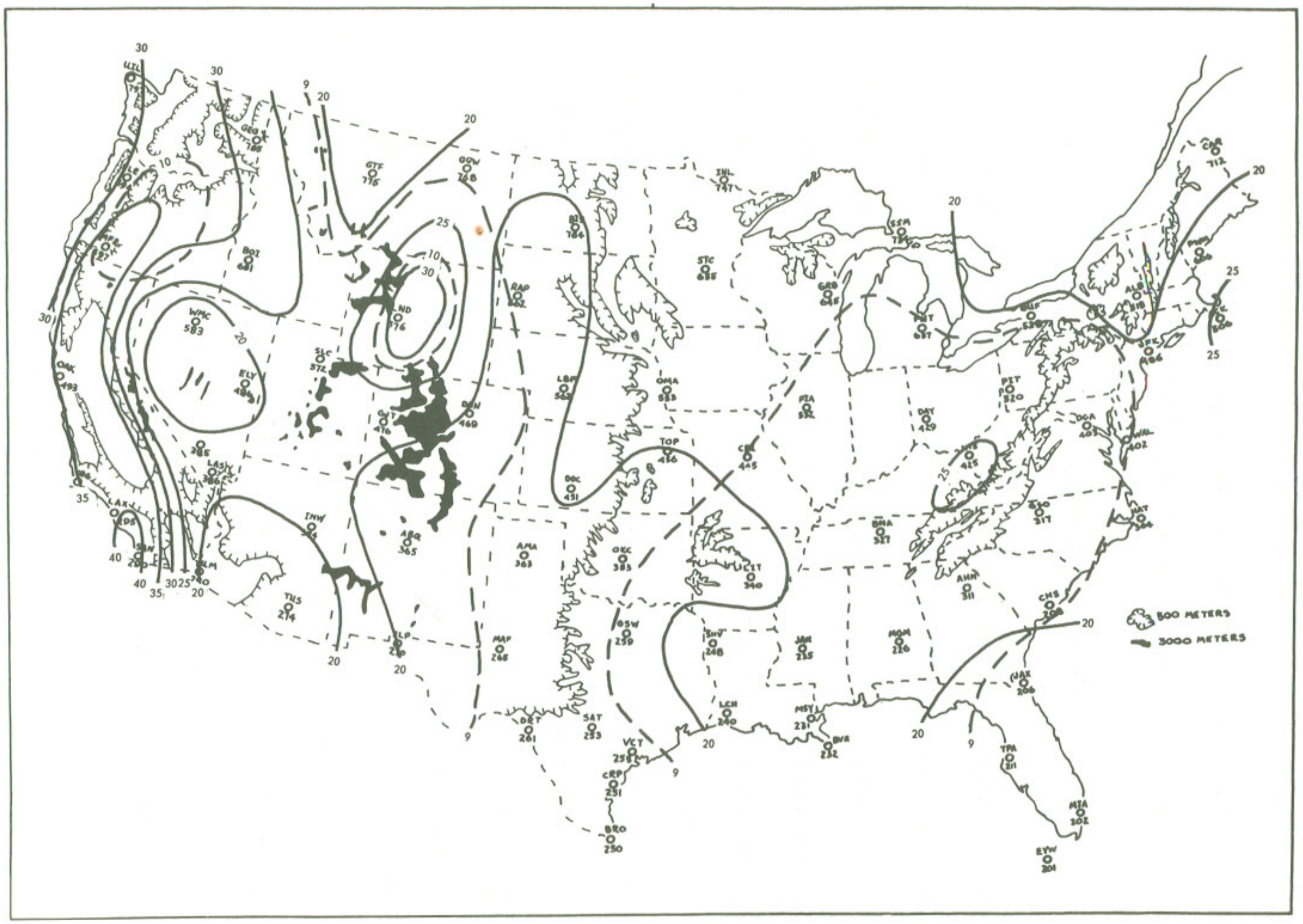

Figure 4-1. Isolines of normalized concentration (s/m), averaged over a city, that are exceeded on 25 percent of autumn afternoons for a 5-km size city (dashed lines) and for a 100-km city (solid lines).

5. SUPPORT TO NAPCA PROGRAMS

5.1 Division of Air Quality and Emissions Data

To determine the percentage of ambient carbon monoxide (CO) that is attributable to motor vehicles, roadside sampling of CO was carried out during the summer months of 1968 in Cincinnati, Ohio. Samples were taken on streets adjacent to the Cincinnati station of the Continuous Air Monitoring Program (CAMP) and were analyzed by the same type of infrared instruments used at CAMP stations. Initial results showed CO concentrations higher than those calculated on the basis of estimated emissions and diffusion.

In order to determine visually the behavior of automobile exhaust in the wake of a car, a smoke generator was attached near the exhaust pipe and motion pictures were taken as the car passed at different speeds. These pictures, although not conclusive, showed that the exhaust does not immediately mix extensively in the vertical; the smoke tended to remain within the first 5 feet above the road for as much as 10 car lengths behind the car. Such aerodynamic induced diffusion may help explain the higher-than-expected concentrations observed at the 4-foot level near the highway.

In order to account for a decrease in annual average values of suspended particulate in 1965 and 1966 (CAMP stations), computer-drawn composite graphs showing 10-year trends of particulate concentrations were constructed for different regions of the United States. This study suggests that wind direction has the greatest effect in changing the suspended particulate values.

5.2 Division of Health Effects Research

Meteorological support was provided to the New York State Ragweed Pollen Study, conducted near Saratoga Springs, New York, to assess ragweed pollen concentrations during August and September 1968. This effort was a feasibility study to determine the number of samplers and the meteorological data required for anticipated large-scale sampling of six cities in New York State in 1969. The purpose of the sampling was to provide background data with which to assess the effects of ragweed eradication scheduled in 1970. Wind and temperatures were measured at two sites; the data were analyzed with respect to selection of an appropriate area for ragweed eradication.

In Tennessee a network of three wind systems was installed in support of the Chattanooga School Children Pulmonary Function Study, conducted during November 1968 and March 1969. Wind data were reduced and compiled with temperature, humidity, and precipitation data to complement the air quality and health statistics.

In April 1969 a health effects surveillance network of three cities (Greensboro, Atlanta, and Birmingham) was established to determine dose-response relationships of pollutants for which criteria are still to be developed, reevaluated, and updated. A special computer summary of hourly values of temperature, humidity, wind, and precipitation was developed to aid in one part of the surveillance study--the effect of climate on the response to air pollution exposure. Summaries are produced and distributed each month for the duration of the study. It is expected that another three-city network will be established soon.

Special meteorological summaries were produced for a program of carbon monoxide measurements in Phoenix, Arizona, and Las Vegas, Nevada, during January and February 1969.

A network of wind systems and hygrothermograph sites was maintained in Cincinnati as part of a general air quality sampling and dustfall program.

5.3 Division of Abatement

The Division of Abatement is responsible for gathering and evaluating air quality and meteorological information needed for abatement actions by the States and the Federal government.

5.3.1 Air Quality Control Region (AQCR) and Abatement Activities

a. Parkersburg, West Virginia - Vienna, West Virginia - Marietta, Ohio

For this abatement activity meteorological observations and special aerial and ground-level sampling of sulfur dioxide and particulates were carried out during the fall and winter 1968-69.

b. New Cumberland, West Virginia - Knox Township, Ohio

Analysis of meteorological and air quality data gathered over a 10-day period for this abatement activity indicated that the control activities instituted at a power plant were not adequate to protect the health and welfare of the citizens of New Cumberland, West Virginia. As a consequence, the Federal government and the States of Ohio and West Virginia proposed that the Secretary of Health, Education, and Welfare recommend control measures in addition to those the power company was taking.

c. New York - New Jersey

Plans were developed for Phase III of the New York - New Jersey Abatement Action. Phase III is concerned with measuring photochemical smog and its basic constituents, and surveillance for sulfur oxides and particulates. Meteorologists participated in rearrangement of the sampling network. Two UV radiometers were acquired.

d. Steubenville, Ohio - Wheeling and Wierton, West Virginia

A technical report of the nature and extent of air pollution along the Ohio River in the vicinity of Steubenville, Wierton, and Wheeling was prepared for a proposed abatement action. This report included an account of the climatology, interstate transport of contaminants, impact of the great variety of sources, and distribution of the pollution in the area. The relative contributions of major sources to the area's pollution, and the efficiency of several abatement strategies to reduce contamination of sulfur dioxide and suspended particulates were calculated.

e. Chattanooga, Tennessee

A program to develop an air-use plan for Chattanooga included an analysis of the mean (climatological) atmospheric transport and dispersion of pollutants in this mountainous area.

To test an indirect aerial sensing system and to provide added data for the study, Barringer Research, Ltd. made a series of flights with a correlation spectrometer designed to sense the total mass of NO_2 or SO_2 below the aircraft.

Figure 5-1 shows horizontal profiles of SO_2 in parts per million-meters, downwind of a power plant. This is a continuous sampling of the total concentration of SO_2 in the air space below the aircraft.

5.3.2 Activities in Support of Air Quality Control Region (AQCR) Program

Meteorologists perform two tasks in the initial development of AQCR's: (1) prepare the meteorological portions of the status report, and (2) assist in evaluating the resources of the AQCR and in identifying "gap" areas, those areas in which the AQCR's lack resources to properly develop implementation plans to meet regional air quality standards.

The status report consists of an inventory of the resources of the AQCR. The meteorological section of the report lists the installed meteorological sensing equipment and discusses available meteorological data, application of atmospheric dispersion models, and forecasting systems for issuing air pollution advisories. Action is taken to publish the status report soon after an Air Quality Control Region is designated. Reports on Washington, D. C., Denver, Philadelphia, and Chicago have been prepared.

The status report is made available to the State and local agencies that comprise the AQCR. The Division of Abatement then evaluates the resources and capabilities of the AQCR to maintain or improve the quality of the air. A team of pollution control specialists, including a meteorologist, meets with the State and local agencies and, using the status report as a data base, the group identifies the strengths

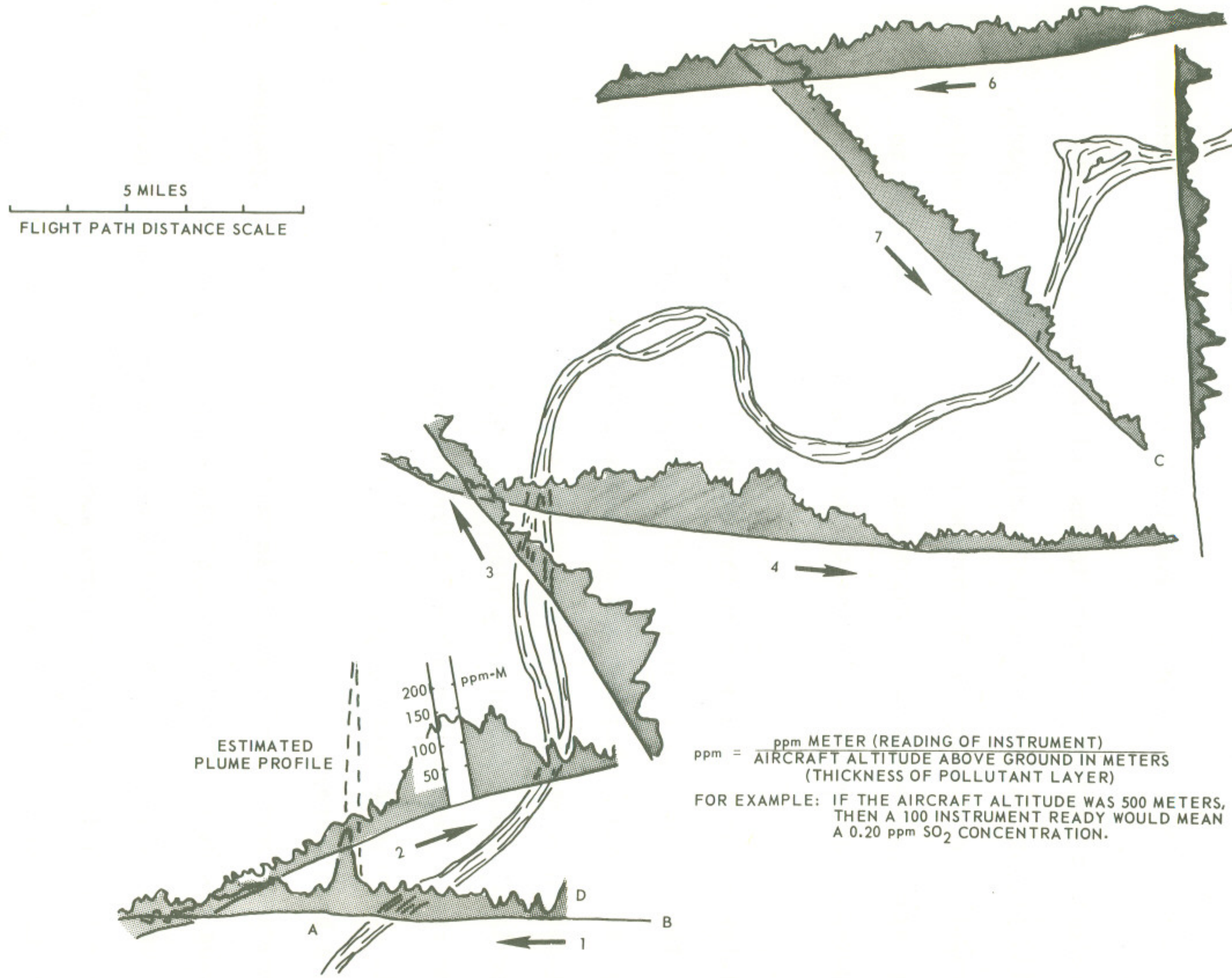

Figure 5-1. The results. The widows Creek power plant is situated at A; the flight starts at B and finishes at C. The sulfur dioxide gas burden between the aircraft and the ground is given, in ppm-M, by the perpendicular distance from the flight track to curve D, according to the scale shown.

and inadequacies ("gap" areas) of existing control capabilities. In these proceedings the meteorologist is usually the most knowledgeable person on matters dealing with atmospheric dispersion models and forecasting systems for issuing air pollution advisories. The first evaluation meeting was held in Denver.

5.3.3 Simulation Models for Standards and Implementation Plans

The Clean Air Act of 1967 requires States that are designated as part of an AQCR to select air quality standards and to develop plans for achieving these standards. To fulfill this obligation, States must possess detailed knowledge of existing air quality levels and must be able to show that the air pollution control plans that they have developed will allow the standards to be achieved and will not degrade the present quality of the air.

Because of a limited amount of air quality data and the time constraints imposed by the law, many States may be forced to use simulation techniques to meet these obligations. To assist them, a NAPCA contractor is systematizing an atmospheric dispersion model so that the spatial distribution of existing levels of pollutant concentrations and the effects of various control plans can be simulated. The model is based on a long-term average concentration model developed by Martin and Tikvart (1968).

5.3.4 Technical Support to Federal Facilities Branch

Technical assistance was supplied in two areas to the Federal Facilities Branch, Division of Abatement: stack height requirements for a new stack at the Boston Navy Yard were evaluated; and a United States Army report concerning sheep deaths in Skull Valley, Utah, was reviewed with attention to meteorological aspects.

5.3.5 International Joint Commission Study

A field study of air pollution, including a meteorological survey, in the vicinities of Detroit and Port Huron, Michigan, and neighboring Canadian communities in Ontario Province was completed in November 1968. The study was directed by the International Joint Commission (IJC), which will report to the two governments on the extent of trans-boundary air pollution.

5.3.6 National Emissions Standards Study

The Clean Air Act of 1967 requires a report to the Congress on the need for and effect of national emission standards for stationary air pollutant sources. Identifiable health and welfare effects of emissions from single sources are specifically requested. Because few well-documented case histories are available, atmospheric modeling techniques were developed to estimate these effects for a wide range of environmental systems.

The following steps were taken: (1) a realistic geographical area (Figure 5-2) with a number of typical major sources of air pollutants (particulates and sulfur dioxide) was developed; (2) an atmospheric dispersion model was applied to estimate air pollutant concentrations for a number of environmental conditions, including annual average and 24-hour average concentrations in both valley and open terrains for a single source in a rural area, a single source in an urban area, and multiple sources in an urban area; (3) estimates were presented so that they could be related to documented health and economic effects; (4) estimates were made of the change in air quality that would result from imposition of hypothetical national emission standards. Figures 5-3 and 5-4 illustrate the reduction in average sulfur dioxide concentrations that might result in an urban complex positioned (see Figure 5-2) in a valley locale if national emission standards were imposed. In addition, the impact of the world-wide air pollution on man's environment was briefly documented, accentuating this nation's obligation to participate in lessening the quantity of contaminants emitted to the earth's atmosphere.

5.3.7 Air Monitoring Equipment

Five nephelometers were ordered to provide a capability to sense short-term levels of particulate contamination. Need for these instruments was demonstrated dramatically when daily values of suspended particulate pollution at New Cumberland, West Virginia, exceeded 200 $\mu g\ m^{-3}$ on a day when the Hi-Vol samples could not have been subjected to the major source of particulate more than 3 hours of the 24-hour period. On days when the wind conditions were such that the source could not have affected the sampler, daily concentrations were less than 60 $\mu g\ m^{-3}$.

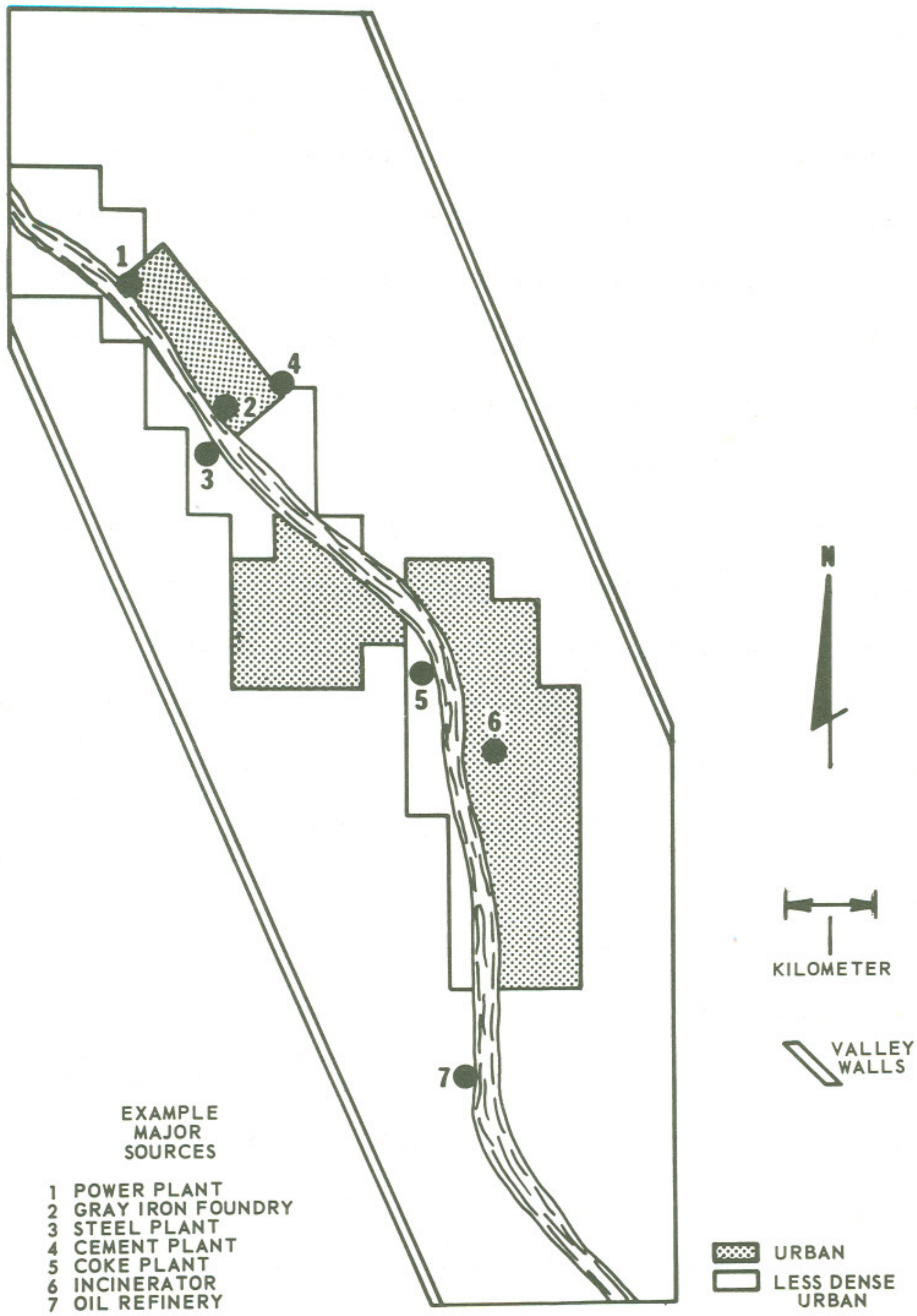

Figure 5-2. Basic regional profile: urban area.

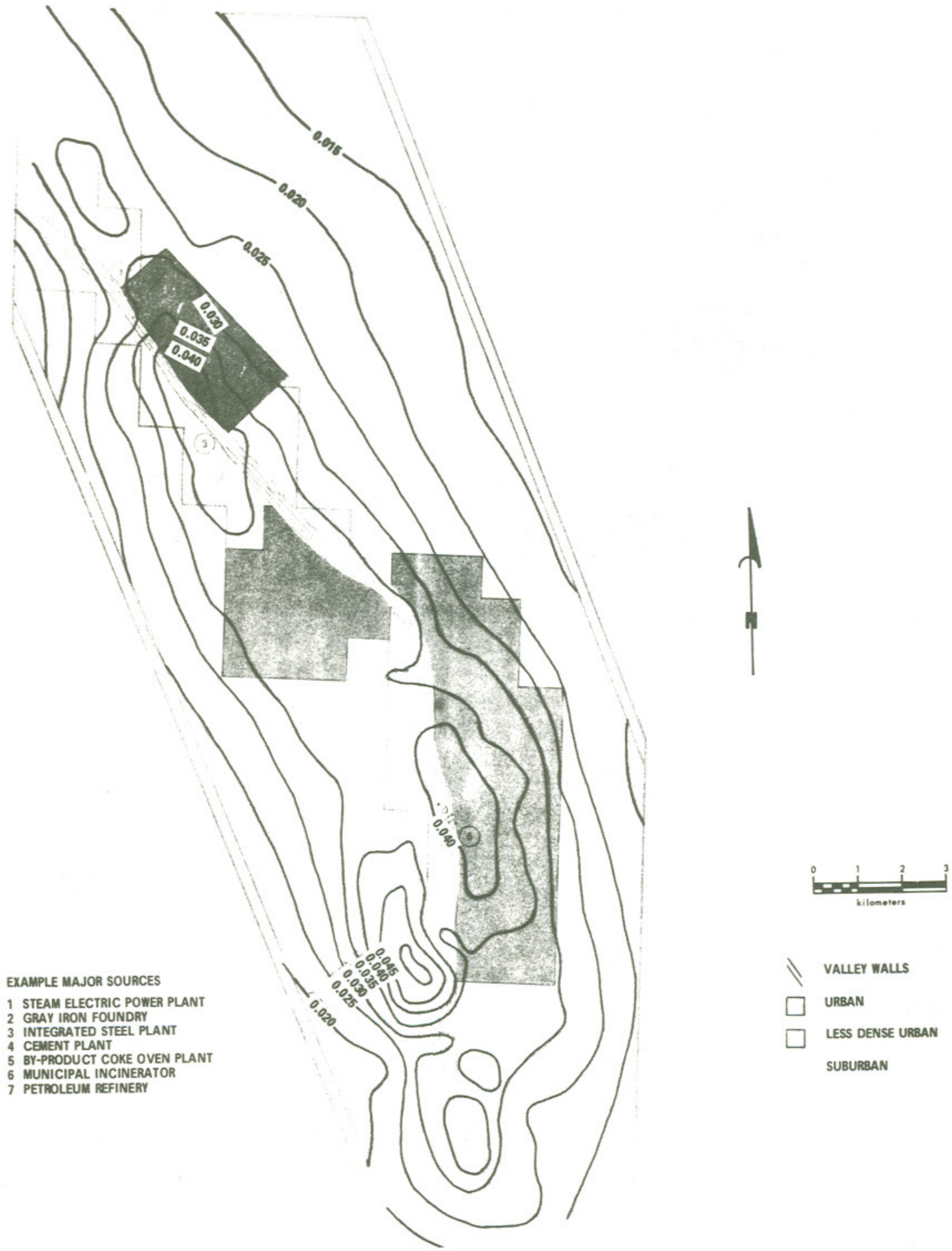

Figure 5-3. Distribution of annual average sulfur dioxide concentrations (ppm): valley terrain, urban complex.

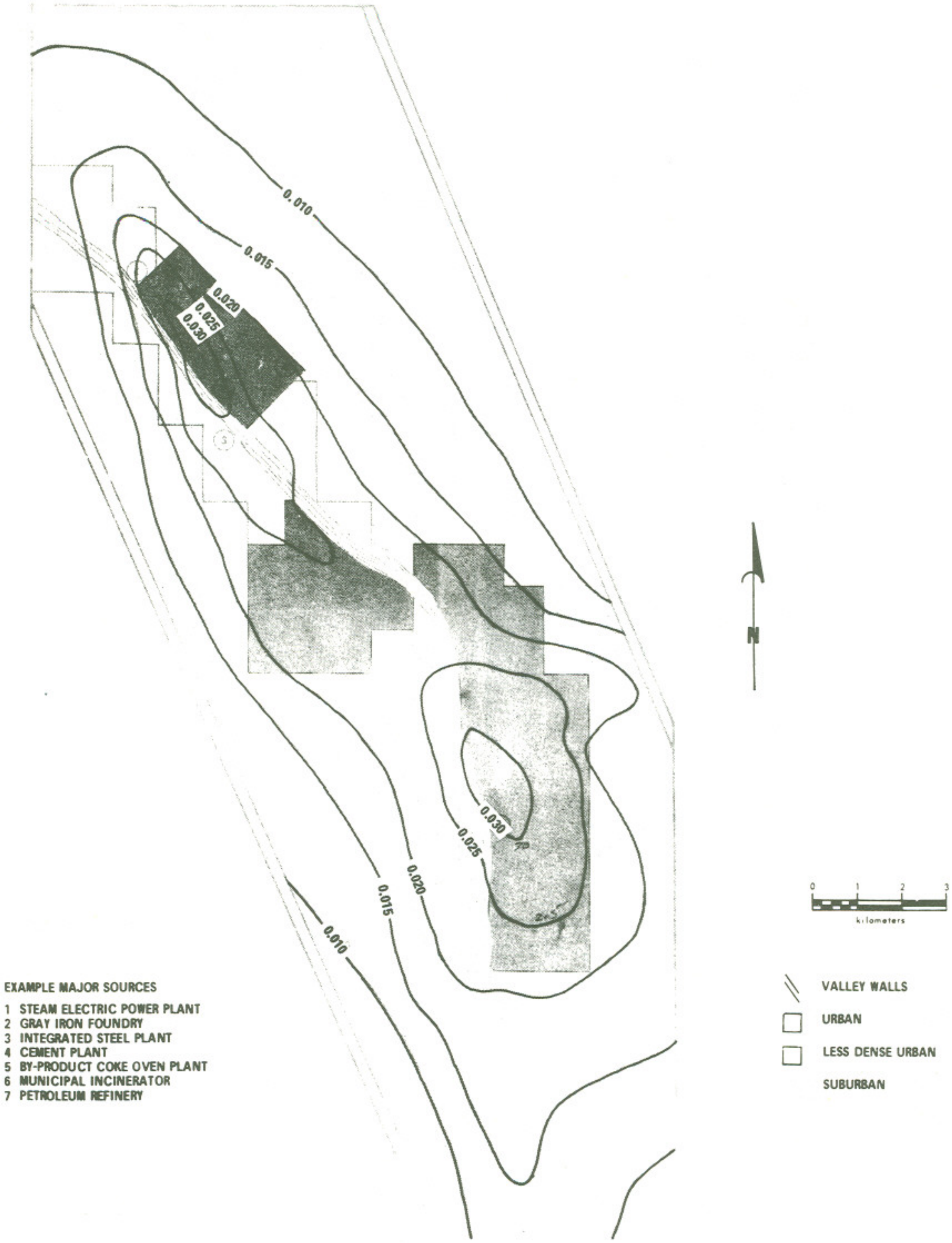

Figure 5-4. Distribution of annual sulfur dioxide concentration levels (ppm): controlled emissions, valley terrain, urban complex.

Since the nephelometers are particularly sensitive to particulates with an effective radius of 0.5 μm, they also provide data that correlate with visibility.

5.4 Division of Control Agency Development

Meteorologists assigned to the Division of Control Agency Development provided technical information and consultation on all aspects of air pollution control. Programs, surveys, and demonstration grants were reviewed. Assistance was given in the development of local emission standards and control practices and in delineating of Air Quality Control Regions.

Some typical assignments are mentioned below:

(1) Consultation was provided to the State of New Mexico pertaining to regulations that applied to large power plants. A meteorologist visited the Four-Corners Power Plant near Framington, New Mexico, and will report on the impact of present and future power generating units on the atmosphere of the State. Effects close in and at distances of 100 miles are partially evaluated.

(2) A chapter titled "Dispersion from Stacks" was prepared for the document, "Control Techniques for Sulfur Oxide Air Pollutants," which was required by the Air Quality Act of 1967.

(3) An appendix titled, "Meteorology and Plant Sites", was provided for the publication, "Considerations Affecting Steam Power Plant Site Selection", sponsored by the Energy Policy Staff, Office of Science and Technology, Executive Office of the President.

A demonstration grant to the State of Connecticut was monitored. The grant supports the development of a mathematical diffusion model, being tested in the Hartford, Connecticut, area. The model employs a "backward" trajectory, starting with a downwind end point; vertical diffusion is considered to be a function of downwind distance, and horizontal diffusion is considered to be a function of time.

Assistance was given in evaluation of a demonstration grant made to the Argonne National Laboratory (ANL). ANL is developing an objective technique for forecasting air pollution concentrations. From this grant, an Incident Control manual will be prepared which can be used as a guide to other cities to develop control plans for application in an air pollution incident.

Various grant applications from state and local air pollution control agencies were reviewed. These applications deal with meteorological equipment, services, and technical assistance.

The following example shows the type of technical assistance that was provided on request:

> The impact of a proposed aluminum plant near Frederick, Maryland, on the rich dairy lands nearby was evaluated. The plant will emit fluorine from 124 roof-top vents. Estimates were made of both short-term and annual average ground-level concentrations of fluorine.

Because topography prevents application of the mathematical model regularly used in defining Air Quality Control Regions, drafts were prepared giving qualitative evaluations for AQCR's at Los Angeles, San Francisco, and Seattle.

Technical aspects of reports prepared under contract for the delineation of AQCR's were reviewed for the following metropolitan areas:

Washington, D. C.	Cleveland	Minneapolis - St. Paul
New York	Pittsburgh	Indianapolis
Chicago	Buffalo	Hartford
Philadelphia	Kansas City	Baltimore
Denver	Detroit	St. Louis
Boston	Cincinnati	

5.5 Office of Manpower Development--Training Institute

The Division of Meteorology supports the Institute (which is a Branch within the Office of Manpower Development) by providing two meteorologists on a full-time basis; one functions as Chief, Air Quality Management Section, the other as a member of the Field Studies Section. The Institute offers the following three one-week courses in the meteorology of air pollution:

(1) "Meteorological Aspects of Air Pollution"--designed for scientists having no meteorological training and for meteorological technicians.

(2) "Diffusion of Air Pollution - Theory and Application"--for meteorologists working in air pollution control and for graduates of the Meteorological Aspects course.

(3) "Meteorological Instrumentation in Air Pollution"--for engineers and technical personnel responsible for designing, procuring, and maintaining networks of air pollution measuring instruments having meteorological sensors.

Since the pilot presentation of the first course in 1962, nearly 650 attendees have received certificates for completing these courses.

A narrated 35-mm slide sequence entitled "Meteorological Instrumentation in Air Pollution" was recently completed and distributed to NAPCA's Regional Program Directors for comments and evaluation in the field. After incorporation of changes, the sequence will be submitted for clearance.

5.6 Office of Regional Activities

The Office of Regional Activities discussed the mathematical model with, and provided meteorological data (wind and mixing depth) to, the TRW research staff. TRW is doing computer work defining Air Quality Control Regions (AQCR) on the basis of the model and of meteorological and source inventory data. Wind and mixing-depth data for approximately 40 metropolitan areas have been transmitted to TRW.

The Office critically reviewed technical aspects of reports dealing with the first 18 AQCR's.

Since the mathematical models were not applied to the Los Angeles, San Francisco, and Seattle areas because of local topography, qualitative reports summarizing air flow, mixing depth, and diffusion potential were prepared for these areas as substitutes for the model.

6. INTERNATIONAL ACTIVITIES

Mr. R. A. McCormick returned to the U. S. in July 1968 from a 3-month invited assignment as visiting professor at the Institute for Theoretical Meteorology, The Free University of Berlin.

Dr. Rikita Inouye, professor of meteorology at the University of Hokkaido in Sapporo, Japan, completed a 12-month invited assignment with the Division of Meteorology.

The U. S. - Japan Air Pollution Panel activities continued with a periodic exchange of research results. Plans were formulated for a tour of U. S. meteorological installations prior to the next Panel meeting scheduled for November 1969.

In March 1969, Mr. McCormick attended a meeting of the WMO Working Group on Air Pollution and Atmospheric Chemistry in Geneva.

In June 1969, Mr. R. A. McCormick attended a meeting of the Organization for Economic Cooperation and Development (OECD) in Paris, France. Mr. McCormick chaired an OECD Expert Study Group on Mathematical Models for the Prediction of Air Pollution. Mr. McCormick also traveled to Geneva to present a paper, "Air Pollution in Industrial Regions", at the World Meteorological Organization (WMO) meeting; the paper will be published as a WMO Technical Note.

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