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Research and Development

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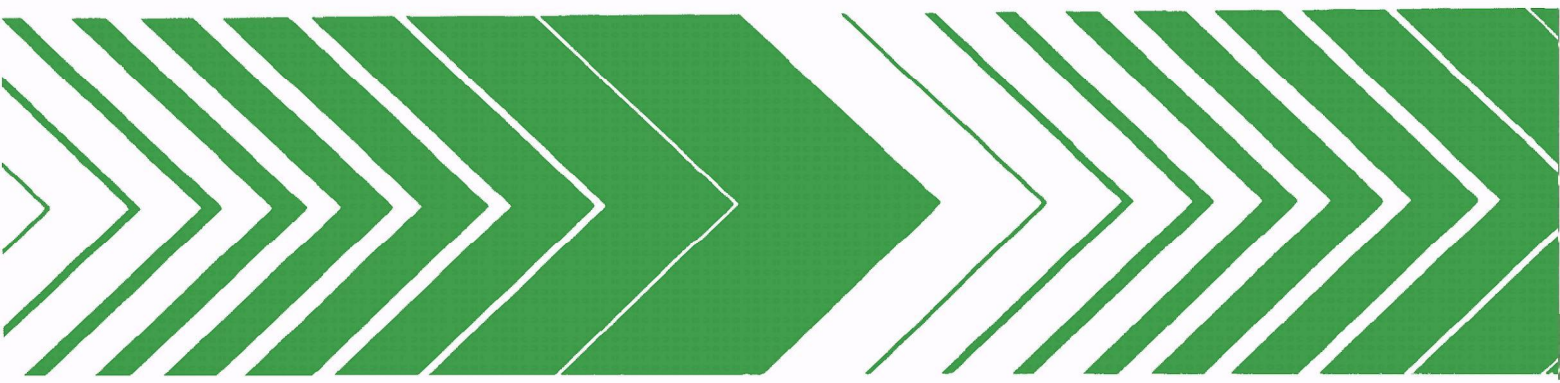
Microscale Variations in Ambient Concentrations of Pollutants in St. Louis Air



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EPA-600/2-79-183
September 1979

MICROSCALE VARIATIONS IN AMBIENT CONCENTRATIONS OF POLLUTIONS IN ST. LOUIS AIR

by

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ABSTRACT

As part of the Regional Air Pollution Study (RAPS), a series of studies were carried out in St. Louis during the summers of 1974, 1975, and 1976 primarily to determine the sub-grid concentrations of ambient air pollution. One primary pollutant gas, CO, and one secondary pollutant gas, ozone, were chosen to be representative. Methodology for determining sub-grid concentration variations of these gases is discussed.

Portable monitors and the collection and analysis of bag samples were used to determine pollutant concentrations. In some cases the monitors were moved along selected paths while the measurements were made; in other cases the monitors were placed at selected sub-grid locations. The data were collected at six sites during the first year, and at two sites during the final two years. Both urban and rural sites were selected. All the data were collected during daylight hours generally between 10:00 a.m. and 4:00 p.m.

This report was submitted in fulfillment of Grant R-803300 by the University of Michigan under the sponsorship of the U.S. Environmental Protection Agency. It covers a period from November 1, 1974 to March 31, 1979 and the work was completed as of December 31, 1978.

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ABBREVIATIONS AND SYMBOLS

AID	--	Analytical Instrument Development Company
CO_2	--	Carbon Dioxide
CO	--	Carbon Monoxide
EPA	--	Environmental Protection Agency
GE	--	General Electric Company
GFC	--	Gas Filter Correlation
Hz	--	Cycles per second
JAPCA	--	Journal of Air Pollution Control Association
KI	--	Potassium Iodide
MIT	--	Massachusetts Institute of Technology
NBS	--	National Bureau of Standards
NERC	--	National Environmental Research Center
NO	--	Nitric Oxide
NO_2	--	Nitrogen Dioxide
NO_x	--	Nitrogen Oxides
O_3	--	Ozone
ppb-v	--	parts per billion by volume
ppm-v	--	parts per million by volume
RAMS	--	Regional Air Monitoring System
RAPS	--	Regional Air Pollution Study
RTP	--	Research Triangle Park, N.C.
SLU	--	St. Louis University
SO_2	--	Sulfur Dioxide
SRM	--	Standard Reference Material

ACKNOWLEDGEMENTS

The cooperation of Rockwell International Air Monitoring Center is gratefully acknowledged and, in particular, Mr. Al Jones who supplied all the preliminary test site information as well as the other Rockwell personnel who responded to the numerous requests for RAMS data.

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The author is especially grateful to St. Louis University and to Dr. John Forsberg who made laboratory space available for daily calibrations.

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The author thanks Dr. W.A. McClenny for his many suggestions and review of this report prior to final preparation.

SECTION 1

INTRODUCTION

The study evolved as a result of the EPA air pollution control objectives. One of the major objectives has been the development of urban air quality simulation (AQS) models[1]. Currently many models are being developed[2] and several will be applied to the RAPS data base. A set of AQS models will eventually be used to determine the environmental impact including the health risk of all proposed new construction, such as, manufacturing plants, shopping centers, roadways, etc., on a given total urban complex. Of course, impact studies are currently required for all large projects and many are availabe for this purpose. However, all the routinely usable models are relatively simple and are usually applicable on the microscale rather than on the meso or urban scale. As the scale increases in magnitude the model complication increases rapidly in a very non-linear fashion.

The nature and complexity of the modeling problems have been discussed and outlined (Johnson, 1972)[3]. He also identified the important research needs. The most important identified need was an adequate data base for validating both existing and future models. The RAPS program was designed primarily to meet this need. The initial RAPS program was described in a companion paper (McCormick, 1972)[4]. This paper identified the need for area averaged measurements and outlined the original plan to use a laser to make area wide measurements. The detailed RAPS measurement plans were subsequently described (Pooler 1974)[5] and the measurement techniques and the data collected has been reviewed (Schiermeier 1978)[6].

The original area measurement plan was to use a laser with two turning mirrors to trace a triangular laser path around the monitoring station. The height of the path and the precise form would be determined in the field. It was suggested that the laser path measurements be made at three typical sites such as; downtown, urban, and suburban. It would have been desirable to collect the data continuously over some extended period (2 weeks) at each site.

The original objective of the study reported here was to meet this challenge and collect data suitable for storage in the RAPS data bank. The collection of such data was a goal throughout the three year study period. However, it was known from the start that the laser program might not develop rapidly

enough and area averaged data would have to be collected using conventional monitors as we have reported here.

It should be emphasized that the collection of data with conventional point monitors at a cluster of points inside the grid area is a significant departure from the proposed spatially integrated measurements. The proposed measurements could have been compared directly with the model calculations. The information collected can only advise the modeler on how he might interpret the point measurements.

During the RAPS program a large share of the total project effort was directed towards the development of the laser system. Due to problems with frequency drift and calibration neither laser system would function unattended. However, a limited amount of CO data was collected by MIT Lincoln Laboratories for storage in the RAPS data bank.

Following the completion of the RAPS program considerable effort has been devoted to the continuing development of both laser systems. At the present time (Jan. 1979) it is felt that the fundamental problems of frequency stability and multimoding of the diode laser have been solved. A continuing effort is being directed towards solving the non-uniform energy distribution in the CO_2 laser. In the event of a future RAPS program the collection of valid area averaged data seems almost certain.

The studies being reported here were all conducted inside a basic 2.8 km grid area and have been termed sub-grid studies. However, they belong to the general class of air pollution studies termed microscale. Microscale studies are usually restricted to distances of no more than few feet to approximately one kilometer. The purpose of the studies has been to determine the pollutant variability at RAMS sites (Fig. 1) utilized by the RAPS program.

Pooler[5], in an overall description of the program, recognized that the RAPS fixed point monitors located at 25 stations throughout the St. Louis metropolitan area could measure the pollutant concentration only at given points. However, atmospheric modeling can only predict the average concentration over grid volumes with bases of no less than 4 km^2 extending to the inversion height. Hence, there was a need to either determine the monitoring station bias or directly measure the volume average.

Specifically, the studies have addressed the following proposition: Given an air quality simulation model which will predict the average concentration in a defined volume:

(1) What are the spatial and temporal characteristics of

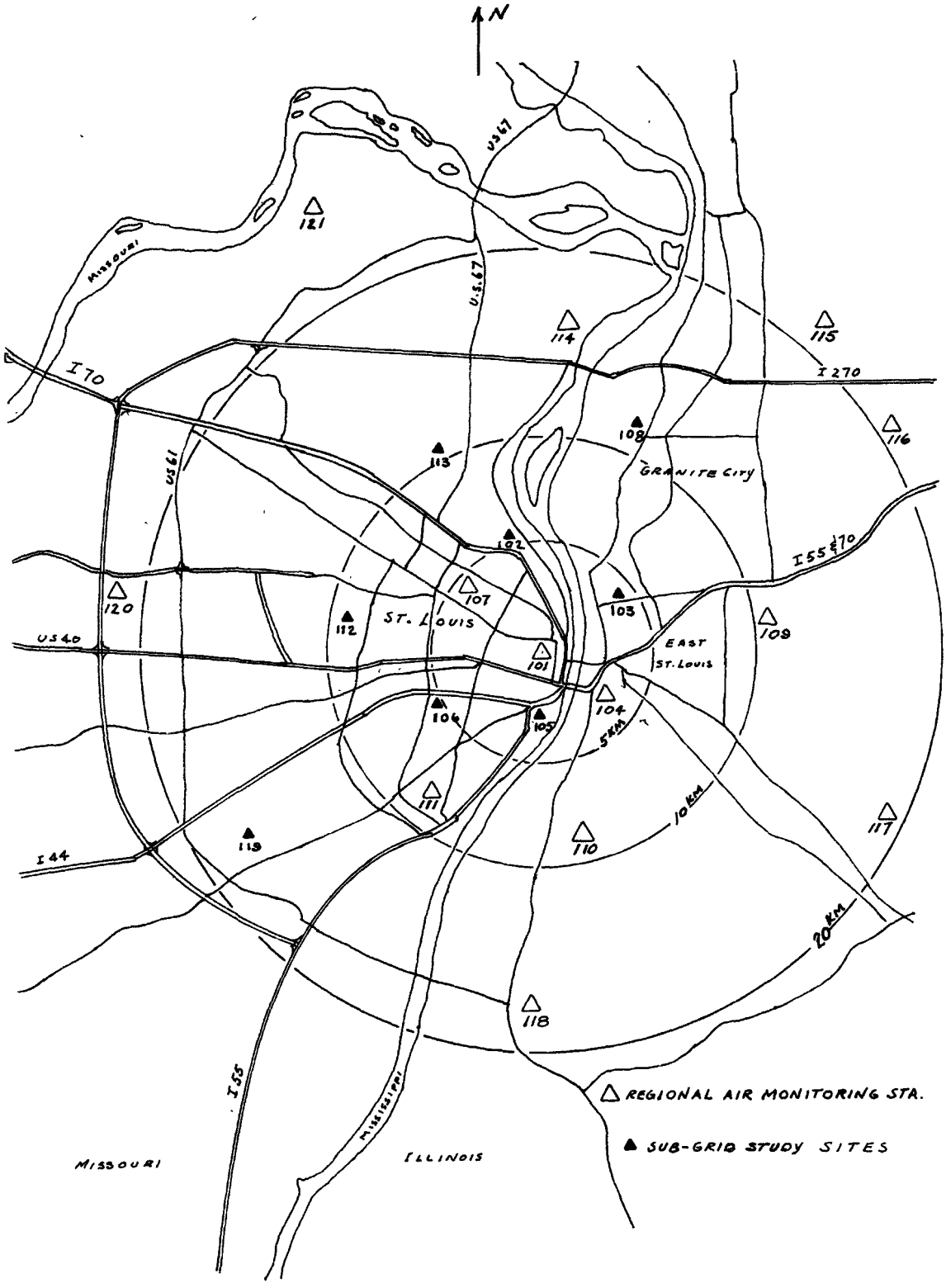

Figure 1. Regional Air Monitoring System Site Locations.

pollutant concentrations inside the grid volume?

(2) How accurately can a point measurement made at a specific location, for the purpose of verifying the model, represent the volume wide concentration?

(3) Can a calibration factor be applied to a point measurement to estimate more accurately the volume average?

The objective of the studies described in this report has been to answer the posed questions. The methodology and techniques employed during the study depended on the instrumentation both available and under development. Concurrent EPA sponsored programs were directed toward the development of new air monitoring instrumentation. The EPA sponsored developments which were evaluated for use in meeting the study objectives were a tuneable diode laser system developed by MIT Lincoln Laboratory,[7] a CO_2 laser system developed by the General Electric Company,[8] and gas filter orrelation spectrometers developed by both Ford Aeronutronic and Science Applications, Inc. In addition, several commercially developed portable monitors were evaluated and used for the study.

The studies were performed in St. Louis concurrently with the RAPSsummer intensive studies of 1974-1976. These time periods were chosen since many of the RAPS ancillary services such as meteorological information and helicopter data were not available at other times. The summer intensive periods also presented an opportunity to compare results with other investigators.

The 1974 studies were primarily ozone measurements made at six selected RAMS sites (Figs. 2-7). These measurements indicated good correlation between the RAMS measurements and the area averages determined with the portable monitors.

During the second year, an effort was made to include measurements of more pollutants and, as a consequence, the measurements were confined to two stations, 105 an inner city site (Fig. 4) and 108 a rural site (Fig. 6). The ozone area measurements again showed good correlation with the RAMS measurements, but the carbon monoxide data correlated poorly. The efforts to measure SO_2 and NO/NO_x on an area wide basis were unsuccessful and were dropped from further consideration.

The measurements made during the final year 1976 were limited to carbon monoxide. The measurements made the previous year at RAMS sites 105 and 108 were repeated. The measurements confirmed the previous year's results. Additional studies were made at two roadway sites and some helicopter data was obtained.

The conclusions and recommendations are presented in the following two sections. A description of the overall study is given in Sections 4 and 5. The data which has been tabulated according to the pollutant measured and the RAMS site, has been summarized by best fit linear equations given in the results. The discussion represents an attempt to relate this study to the overall air pollution measurement problem.

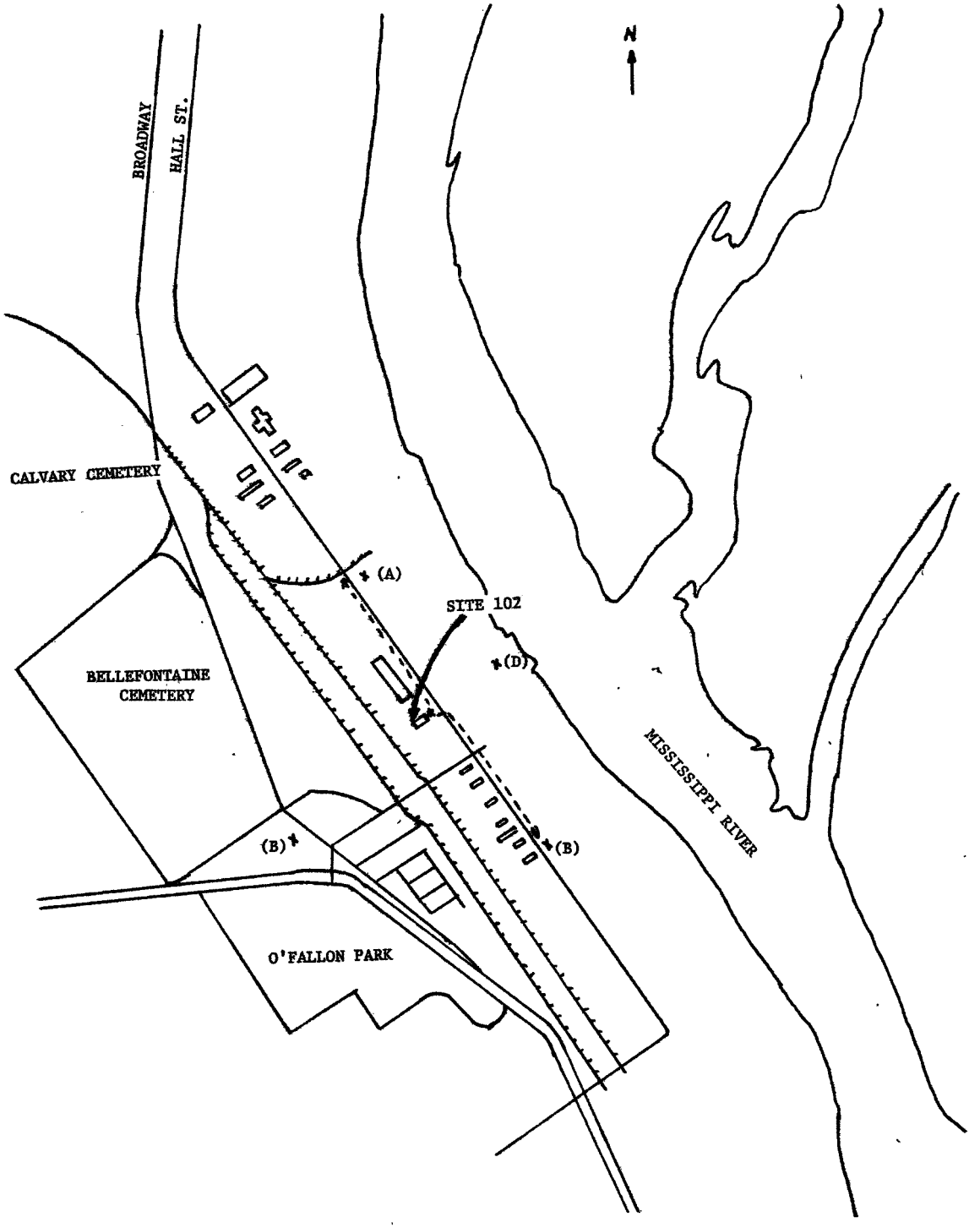

Figure 2. Regional Air Monitoring Site 102.

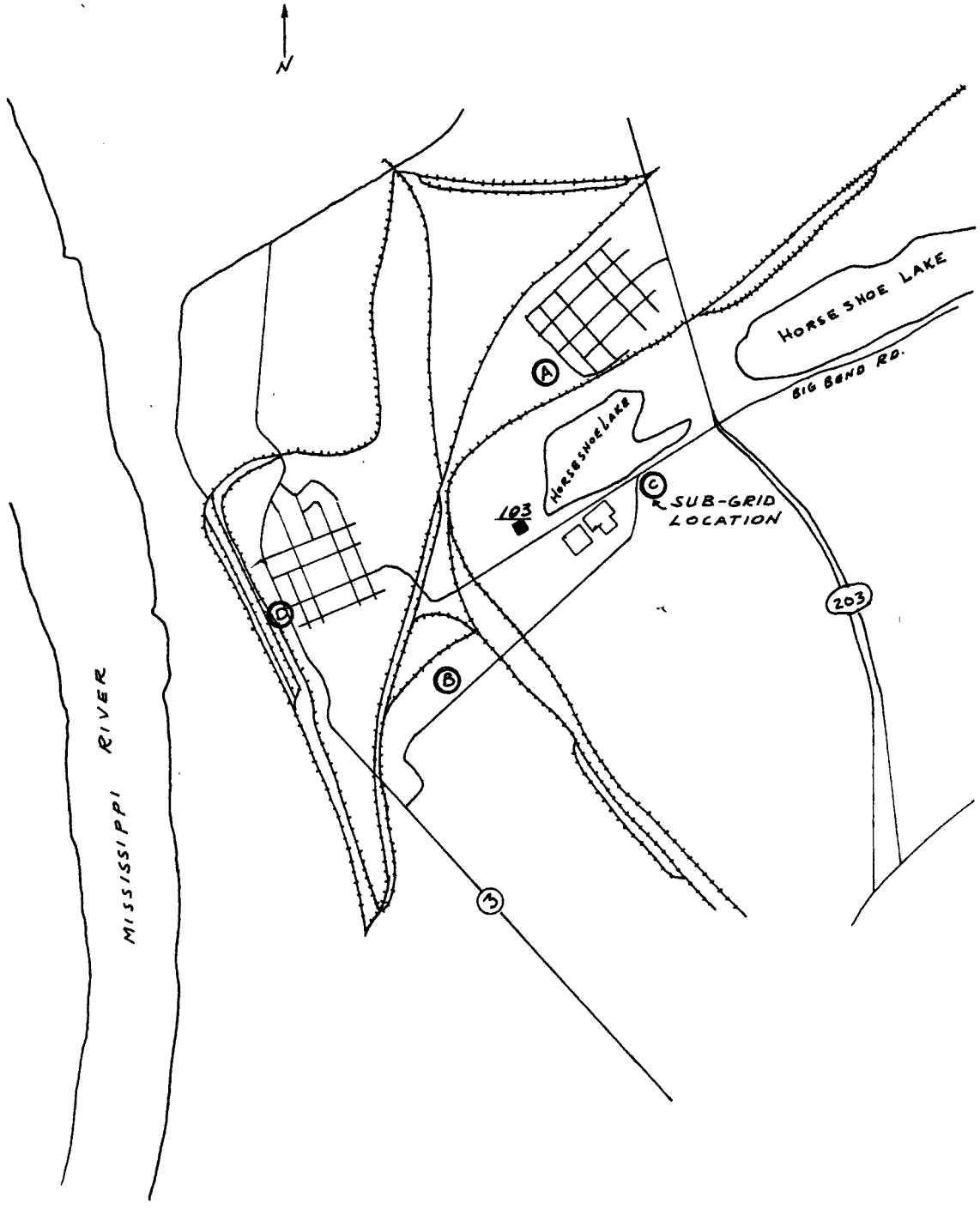

Figure 3. Regional Air Monitoring Site 103.

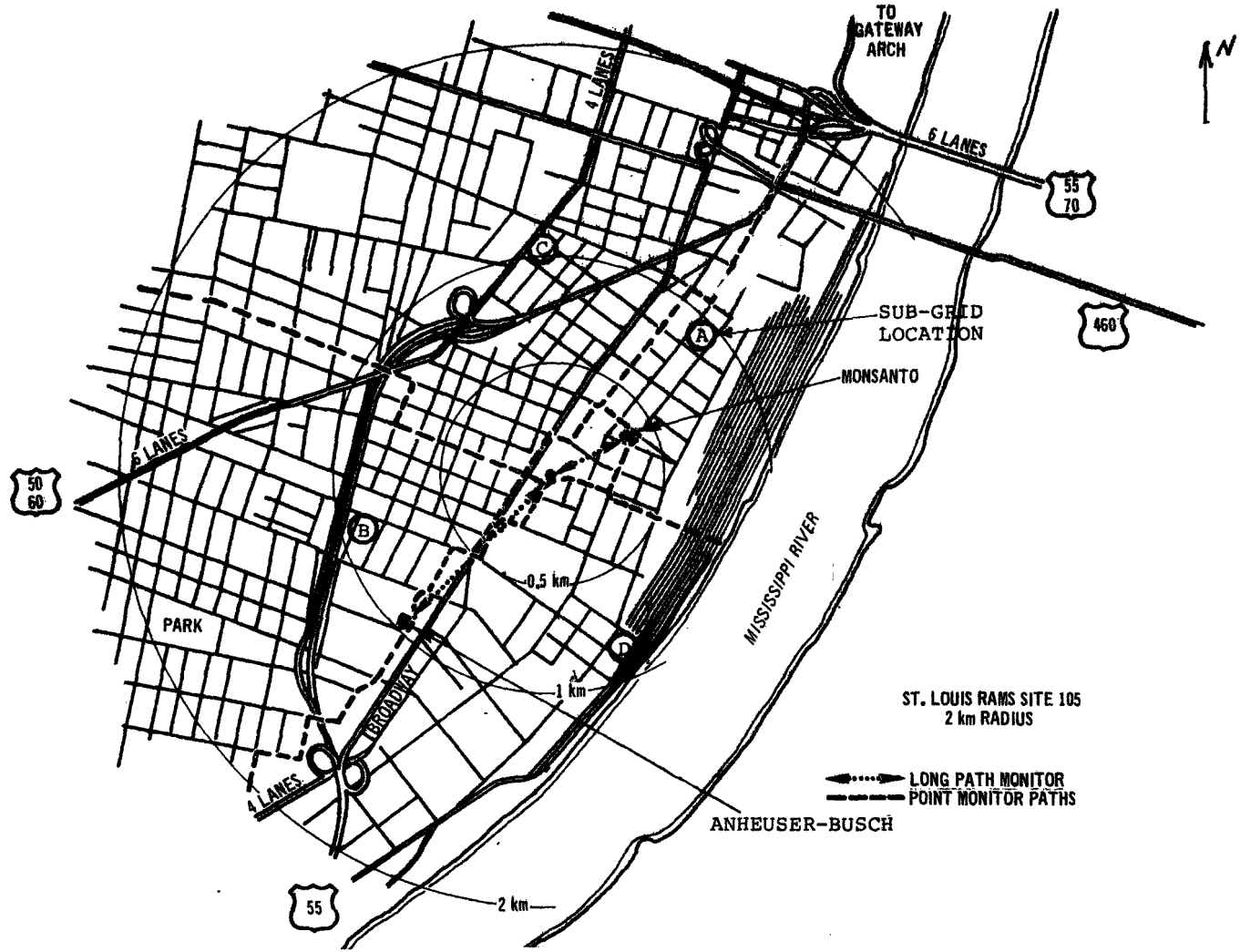

Figure 4. Regional Air Monitoring Site 105.

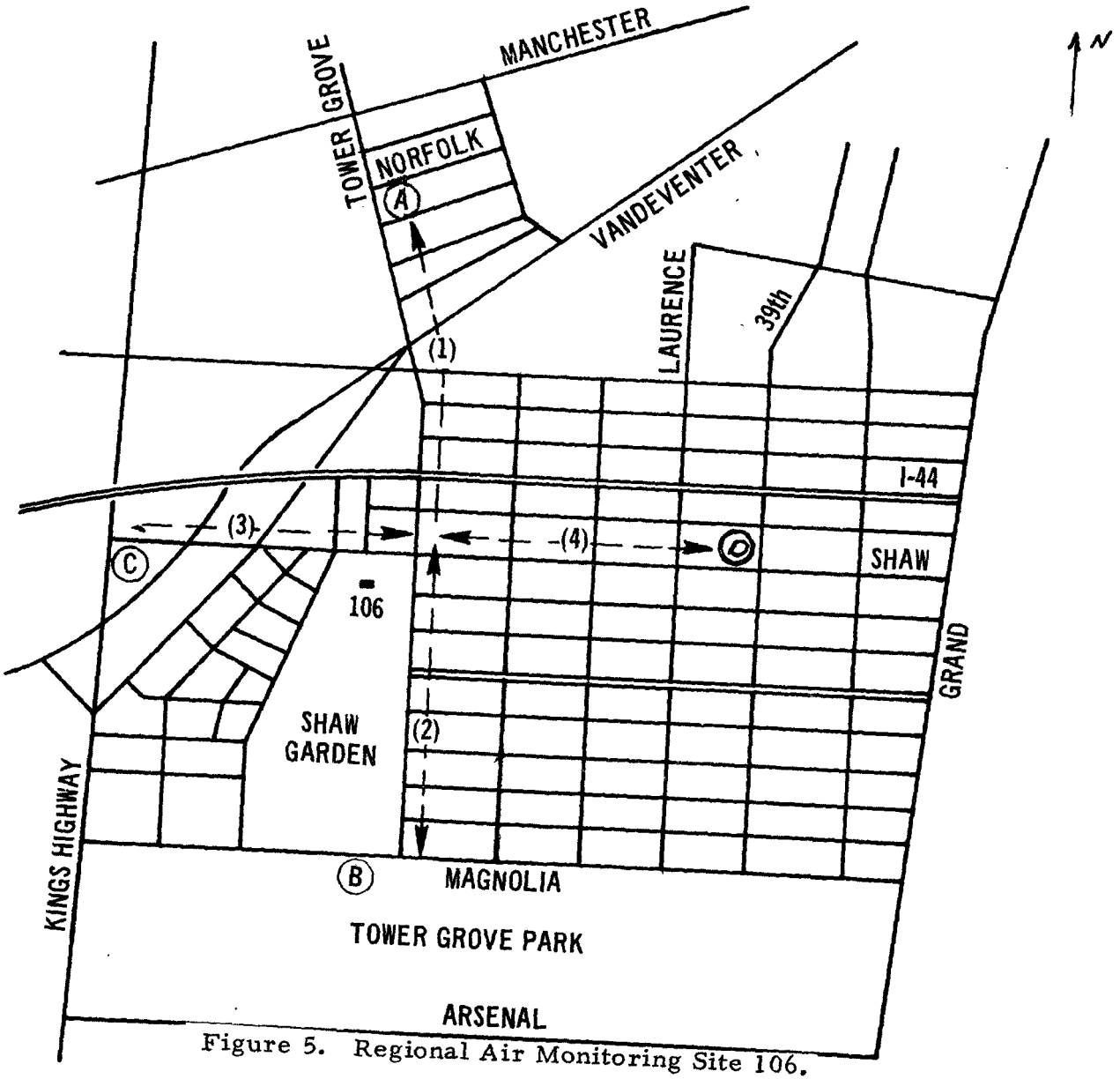

Figure 5. Regional Air Monitoring Site 106.

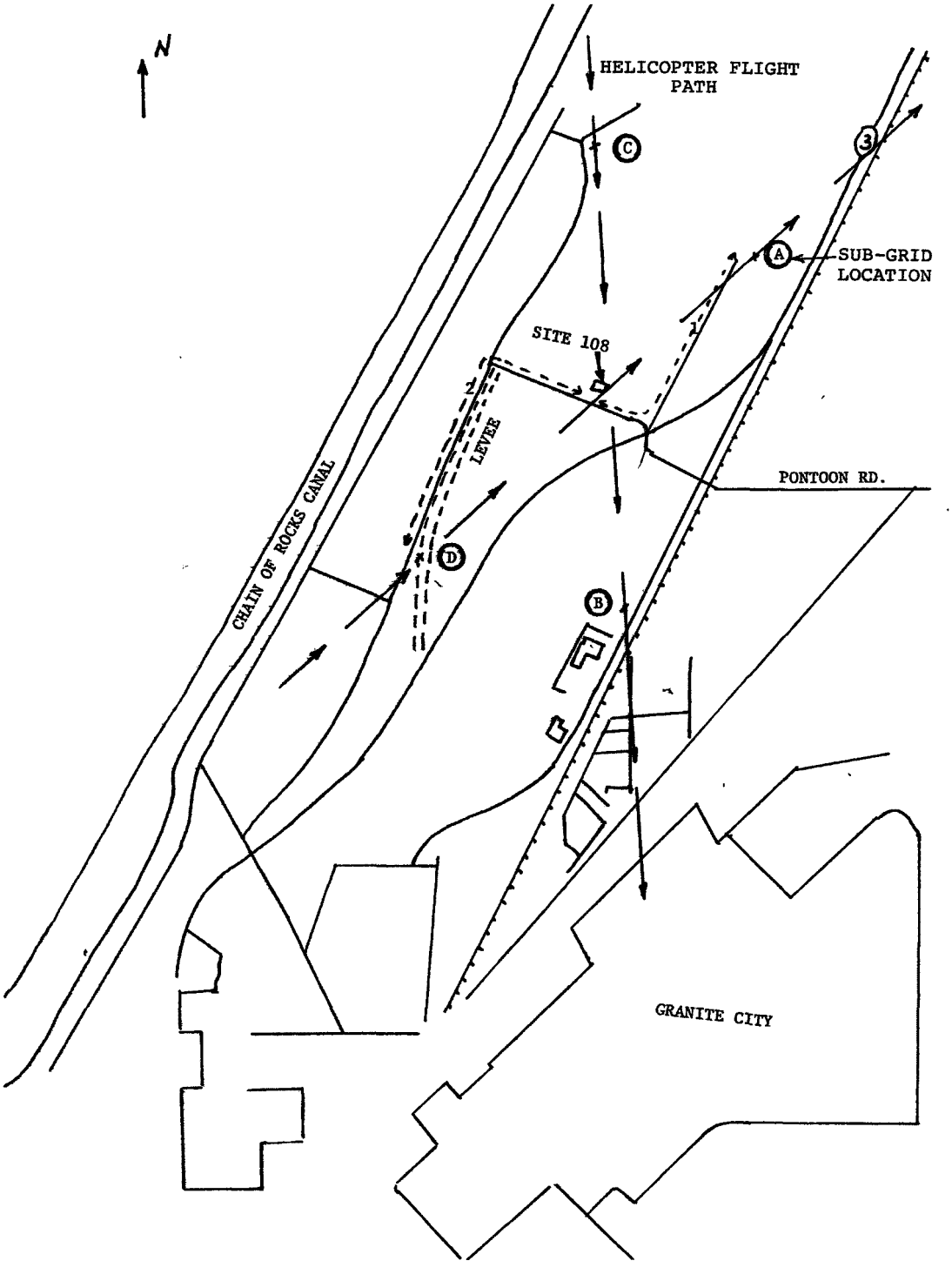

Figure 6. Regional Air Monitoring Site 108.

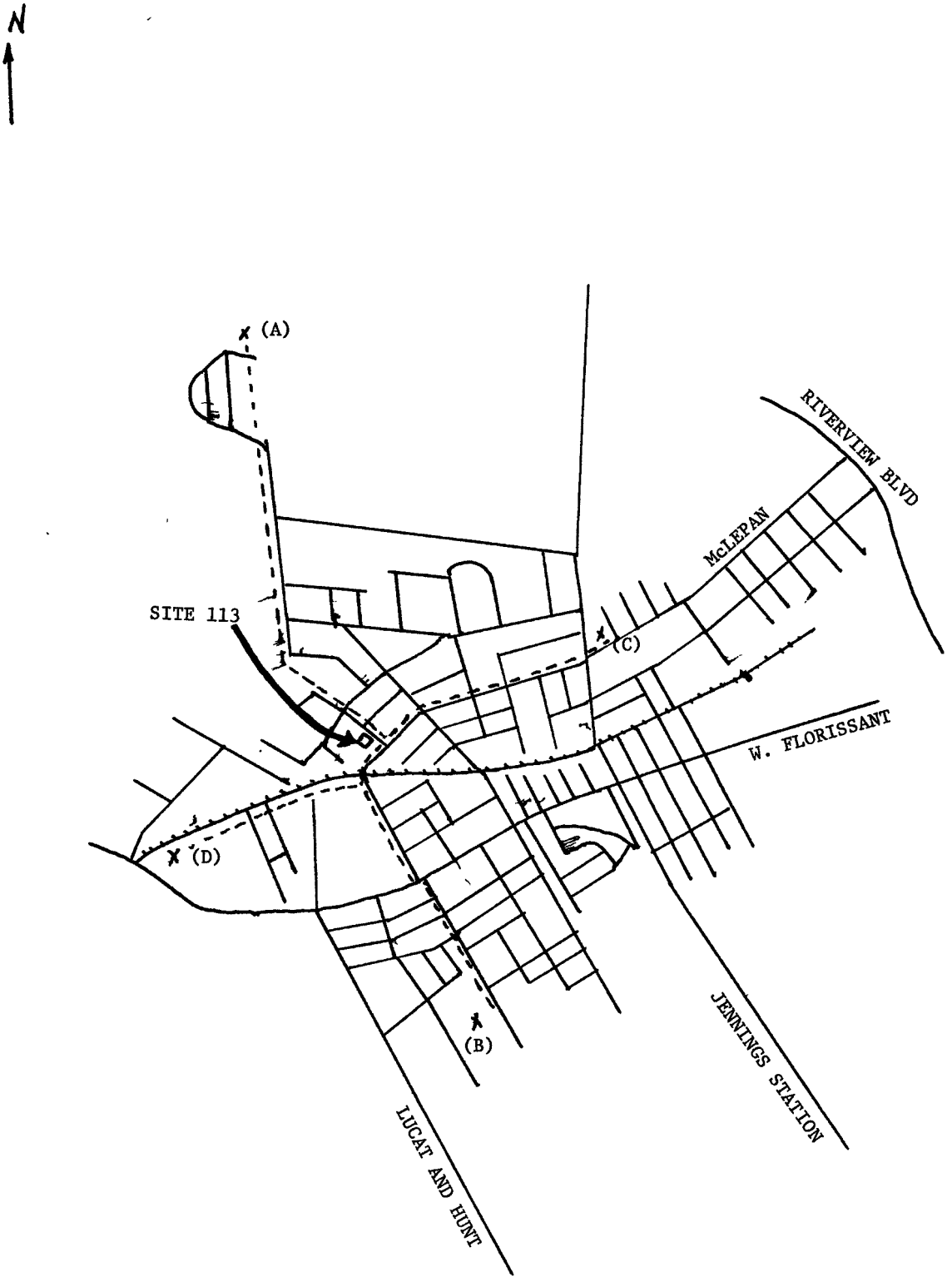

Figure 7. Regional Air Monitoring Site 113.

SECTION 2

CONCLUSIONS

MICROSCALE VARIATIONS

The microscale variations in the ambient concentration of air pollutants are dominated by local sources, usually automobile traffic. The temporal and spatial variations can be large. The temporal fluctuation in the CO concentration was measured to be as much as two orders of magnitude in 30 seconds and the spatial variation was measured to be as large as one order of magnitude over a distance of 100 meters. On the other hand, the ozone concentrations at rural stations have been measured to be constant within 2% over a distance of 50 km. The magnitude of the temporal and spatial variation inside the grid area depends on the pollutant, the sources inside the grid area, the location of the monitor with respect to the sources, and the meteorological conditions at the time the measurements are made.

AREA AVERAGES

The measurements of ozone concentrations at six RAMS sites established that whenever the ozone concentration reached summer values of 50 ppb to 200 ppb, the station measurements represented the area averages within 10%. Correction factors within the 10% range were determined for each measured site.

The CO measurements were made at two sites. One, an inner city site, RAMS 105, and the other a close rural site RAMS 108. These measurements established two facts: (1) The RAMS reported CO concentrations have a high probability of being low due to undersampling the data. The values measured during the study were on an average low by 50%. (2) The coefficient of variations of the station measurements from the measured area averages were 15% for the rural station and 60% for the inner city station.

LONG PATH MONITORS

Considerable effort was devoted to the evaluation of both the long path ozone and long path carbon monoxide monitors. Data taken in test runs of the two systems showed good agreement between point monitor readings and long path monitor rea-

ding, demonstrating the feasibility of making long path measurements. Monitoring of CO at the RAMS sites 105 and 108 with the diode laser system was successfully accomplished during the 1975 summer intensive period[10] with less extensive monitoring periods in summers 1974 and 1976. Monitoring of O_3 at the RAMS site 103 with the CO_2 laser based system occurred during the 1974 summer intensive. However, the system "zero" prevented any systematic data collection.

For both systems, long path monitoring was limited to single path averages instead of the area monitoring originally envisioned.

SECTION 3

RECOMMENDATIONS

DATA SAMPLING

This study has shown that the RAMS often reported, as a result of under-sampling the data, low CO values. It is imperative that whenever an air monitoring station is to be established, a determination should be made that the data sampling rate is twice the highest frequency appearing in the data. This can be done by either selecting a sufficiently high sampling rate or integrating the original data to eliminate the high frequency components.

STATION SITE SELECTION

This study has shown that the concentrations measured by an air monitoring station are strongly affected by its location relative to local sources. If the data collected is to be characteristic of the urban area, then the station should be sited 100 meters and preferably 200 meters away from any local source.

LONG PATH CO LASER MONITOR

The long path CO monitor development should be continued in order to demonstrate the capability of making routine field measurements. This will require further development of the monitor itself and the design and implementation of a demonstration study. The demonstration study could be one of the following: a roadside emission survey to verify existing models, an area emission study to verify existing emission inventories, a shopping center emission study, or an airport emission survey.

LONG PATH OZONE LASER MONITOR

The monitor which is currently under development should be evaluated to determine its effectiveness, and the feasibility of applying the same technique to other pollutant gases.

SECTION 4

PREPARATIONS

MONITOR SELECTION

The pollutant variability study was designed to answer basic questions regarding the variability inside a given grid area. In the initial consideration of the methodology to be employed in the conduct of the study, monitoring consideration was given to all of the criteria pollutants: that is, all pollutants for which maximum dosage levels have been established. The pollutants that fall into this classification are ozone, carbon monoxide, sulphur dioxide, nitric oxide, and non-methane hydrocarbons. The criteria pollutants are also the pollutants for which various monitors have been developed and are continuing to be developed. It was, of course, desirable to use the most modern techniques available and to measure as many of the pollutants as possible. Carbon monoxide, non-methane hydrocarbons, and nitrogen oxides are primary pollutants contained in auto emission. Carbon monoxide is considered to be a non-reactive compared to the other pollutants and is certainly the most abundant. Hence, its measurement was considered mandatory. However, at the beginning of the program no satisfactory portable instrument was available.

Ozone

Satisfactory portable monitors of ozone have been developed. An AID Model 560 monitor was used satisfactorily in a previous study and for that reason it was selected for this study. Two monitors were obtained. The total weight of the monitor and an Esterline-Angus Model T171B recorder mounted on a backpack was less than 35 pounds (Fig. 8). The monitor had ample sensitivity and fast response. The fundamental problem, which was common to all the portable monitors, was sensitivity to temperature changes. The monitor contains an uncooled photomultiplier tube and the electronics and gas flow rates are temperature dependent. A first order correction for temperature change was made by calibrating before and after each daily data collection period.

A long path laser monitor for ozone was under development at the beginning of the study and the eventual use of the monitor for area averaged measurements was a possibility. The monitor was tested in St. Louis during the first year of the study.

Figure 8. Portable Ozone Monitor on Back-pack.

Carbon Monoxide

The method selected for measurement was to collect air samples in 90 liter Tedlar bags attached to backpacks. The bags were returned to the RAMS laboratory for chromatographic analysis. The bags selected were 5 mils thick, which were satisfactory compared to 2 mil bags used by other investigators. However, only a limited amount of data could be collected using this technique. If the bags had to be stored for more than four hours before analysis the data was subject to question either due to diffusion into or out of the bag. Fortunately, as a result of an EPA contract to Ford Aeronutronic, a gas filter correlation monitor[11] became available during the second year of the study. This monitor was used in conjunction with the bag samples to obtain data.

A long range possibility for measuring CO was a long path laser monitor being developed by MIT Lincoln Laboratory[7] for EPA. It was not considered that this development would be ready for use during the first year of the study, but it would be available for on-site testing in St. Louis and would perhaps be available during the second or third year to make area averaged measurements. A limited amount of long path data collected during the second year was incorporated into the RAPS data bank.

Sulphur Dioxide

The monitor selected to measure sulfur dioxide was a Meloy Model 165A. The unit weighs 50 pounds and operates satisfactorily in the laboratory. However, as a portable unit there are several problems: temperature sensitivity, limited battery life, limited hydrogen supply, and long warmup time. The combination of limited battery life and hydrogen supply coupled with the long warmup time made the monitor difficult to use, but the temperature sensitivity made it impossible on hot days.

Nitric Oxide

Prior to the beginning of the second year a portable chemiluminescent monitor for NO, NO_x became available. The monitor, a McMillan Model 2200, was initially tested in the laboratory and found to be operable, but it never performed satisfactorily in the field due to multiple failures of the acid storage battery selected to meet the power requirements.

Non-methane Hydrocarbons

As a result of the leakage problem experienced when collecting CO in bags and transporting them to a laboratory for analysis, no consideration was given to measuring non-methane hy-

drocarbons.

In summary, the monitors selected for the study were:

Ozone:	AID Model 560
Carbon Monoxide:	First year bag sample and laboratory analysis Second and third year, Ford Aeronutronic GFC
Sulfur Dioxide:	Meloy Model 165A.

RECORDER SELECTION

An Esterline-Angus Model T171B portable chart recorder was used in a 1973 long path evaluation test and found to be satisfactory. A second identical unit was purchased prior to the 1974 study for use with the second ozone monitor. Two Hewlett-Packard Model 680 strip chart recorders were obtained. One was attached to the RAMS ozone monitors and one was attached to the CO monitor.

Prior to the final selection of the portable strip chart recorder for data collection, some thought was given to the use of a magnetic tape recorder. This would have several obvious advantages: elimination of jammed paper drives, torn paper, and the irregularity in the flow of the ink. The disadvantage at that time was that a separate, bulky instrument was required for play back and no convenient space was available. Hence, the decision was made to use the strip chart recorders.

CALIBRATION STANDARDS

The calibration procedures and the selection of standards are probably the most important aspects of any air pollution study. Specifically, the calibrations should be traceable to NBS and the procedures should follow FPA reference methods or their equivalent as outlined in the Federal Register Vol. 36, No. 228, Nov. 25, 1971. For most of the pollutants, it was necessary to provide both a primary laboratory standard as well as a secondary field standard.

Ozone

The primary ozone calibration selected for the first year's study was the KI technique which is the current EPA reference method. An ultraviolet ozone generator, manufactured by South States Industries, was used as the secondary standard. The generator was originally calibrated at EPA-NERC-RTP in June 1974 and re-calibrated upon arriving at St. Louis in July 1974. These two calibrations agreed to within

1%. The generator output was calibrated in St. Louis on two later occasions. These last two calibrations were found to be significantly lower than the first two calibrations. However, if a decrease in ozone generator output of 1% for each 100 hours of operation was assumed, the agreement between all the calibrations was within 3%.

During the second year, the ozone generator was calibrated[12] by a dynamic gas phase titration of O_3 with NO. The NO used in this titration was a standard reference material (SRM) obtained from the NBS. This method is listed as an EPA equivalent to the KI technique. The advantage for field operations was that no extra equipment was required and the results seemed to be more repeatable and were directly traceable to NBS.

Carbon Monoxide

The primary standard selected for the first year was a set of three span gas concentrations of CO in nitrogen obtained from Scott Research Company. The gas concentrations were checked by infrared absorption spectroscopy at EPA-RTP prior to the summer study and again in St. Louis by gas chromatography.

The procedure was unsatisfactory due to discrepancies between the various analyses. The conclusion was that the cylinder material was reacting with the CO to change the concentrations. This was based on the fact that all the concentrations were decreasing and the smaller the concentration the higher the percentage change. During the following years, NBS made available an SRM, CO in nitrogen, which was used. The SRM CO in N_2 concentration (94 ppm-v) was dynamically diluted with Scott Ultrapure air to obtain a seried of calibration points. The flow rates were measured with calibrated bubble meters.

Sulfur Dioxide

The primary, as well as the secondary, method selected for SO_2 calibration was to use calibrated permeation tubes in a dynamic calibration system. The tubes used during the first year were calibrated on Cahn/Ventron Recording Electro Balance System Model R-100 at EPA-NERC-RTP. These were installed in a Bendix Dynamic Calibration System Model 551446.

At the beginning of the second year SRM permeation tubes became available for use as primary sources and commercial tubes were obtained as secondary standards.

Nitric Oxide

The SRM, NO in nitrogen, obtained for the ozone calibration was also used for the nitric oxide calibration. The SRM was dynamically diluted with Scott Ultrapure grade air to obtain the calibrating mixture. The calibrating procedure was to measure the flow with a bubble meter and rotometer in series, then to remove the bubble meter and adjust the rotometer to the original reading.

Nitrogen Dioxide

The calibrating method selected for NO_2 was an SRM permeation tube furnished by NBS.

COOPERATIVE ARRANGEMENTS

RAPS Staff

This study was one of many carried out in connection with the overall RAPS program. During the five year period covering the entire study, a permanent staff was assigned to St. Louis to oversee the collection of data from the 25 RAMS sites as well as to assist the field investigators. Prior arrangements were made with the staff for the following: (1) assistance in selecting sites, (2) obtaining permission to locate laser reflectors on private property, (3) granting permission to use space inside the RAMS to locate monitors and recorders, (4) arranging with the prime contractor Rockwell International to increase the available power, phone service, and parking facilities at the laser monitoring sites, (5) providing a laboratory service of making gas chromatographic measurements of collected air samples, and (6) providing requested output data from the RAMS.

RAPS Helicopter

The RAPS Helicopter support consisted of two helicopters outfitted with a complete set of air pollution monitoring instruments. These helicopters were normally based in Las Vegas, Nevada and were sent to St. Louis for the summer intensive studies of 1974-1976. The purpose of the helicopter measurements was to add a third dimension to the data being collected by the 25 ground-base stations. Hence, the usual routine was to collect data on a regular schedule over many of the ground stations. However, a limited amount of time was made available for cooperative measurements with individual investigators. Prior to each year's study, we made a request for simultaneous data collection over the sites we were investigating. Two or three data collection periods were arranged during each summer period.

MIT Lincoln Laboratory

The MIT Lincoln Laboratory was responsible for the development of diode laser CO monitor which was originally tested during the RAPS program. We undertook to evaluate the performance of this system with the expectation that the data could eventually be used to make area averaged measurements around the monitoring sites. Numerous sets of simultaneous measurements were made using the diode laser the GFC monitor located in the laser van, and bag samples collected in the area. The van was a convenient field location for the GFC monitor throughout the study period.

General Electric Company

The GE Company under contract to EPA had built a CO_2 laser to measure ozone. We undertook to evaluate the performance of this laser system during the 1974 summer study. We selected the site for the evaluation study and also used that as one of the pollutant variability sites. Arrangements were made to carry out a series of comparison measurements on many different occasions during the summer period.

Aerospace Corporation

Under contract to EPA, the Aerospace Corporation developed a pulse fluorescence NO_2 monitor which was tested during the RAPS program. We arranged for the laboratory space required to carry out their evaluations and provided air sampling bags and a backpack sampler for the collection of air samples.

Ford Aeronutronic

A contract was awarded to Ford Aeronutronic to design and build a GFC CO monitor. This monitor was brought to St. Louis for testing at the end of the 1974 period. Data was collected for about one week and comparisons were made with the Lincoln Laboratory monitor as well as with bag samples measured by gas chromatography at the RAPS center.

SITE SELECTION

In order to implement the study it was necessary to select the monitoring sites, determine the monitoring paths, and field calibrate the monitors.

The choice of sites was limited to the Regional Air Monitoring System (RAMS) sites in the St. Louis area. The area map (Fig. 1) indicates the locations of 21 of the 25 RAMS sites. The four remote stations are beyond the borders of the map. The stations are located on three concentric rings centered on the downtown area plus one station near the center and four remote stations 40 km away in the general direction

of the cardinal compass points. The six stations on the inner ring, with the exception of 103 in the stockyard area, are inner city locations. The six stations on the center ring, are near-suburban locations while the eight stations on the outer ring are far-suburban locations.

As soon as the site locations were finalized, a survey was made to select three sites suitable for testing the long path laser systems being developed by EPA and also suitable for the pollutant variability study. The basic requirement for the long path testing was that an unobstructed one kilometer path at ground level be available, and for the pollutant variability study a variety of sites was required. In addition to the three sites selected to meet the long path laser system requirements, an additional three sites were selected for the pollutant variability study. It was expected that the inner city stations would have the greatest variability. Two were found, 103 and 105, from which one kilometer line of sight paths were possible. The third long path site was located on the second ring. This site, 108, was ideal for testing purposes because a levee ran across one edge of the site. A retroreflector could be placed on the levee at varying distances from the station. Another advantage of the sites was the proximity to industrial plumes which could produce a large variability. The three additional sites selected for the pollutant variability study consisted of 102 and 106, in the inner ring and 113 in the center ring. The remaining inner city sites were eliminated for security reasons.

PERSONNEL AND FACILITIES

The personnel required to calibrate and move the monitors in 1974 were two college students supplied under a task order to Rockwell. The facilities needed to set up and store the equipment were furnished by St. Louis University, Department of Chemistry. St. Louis University provided about 250 square feet of laboratory space and the spectrometer used for the KI determination of ozone.

During the last two years, three college students, employed by the University of Michigan, performed the tasks of calibrating and moving the monitors as well as carrying out some of the data reduction. St. Louis University again provided the required laboratory space.

SECTION 5

METHODOLOGY

MONITORING PATHS

Many details of the methodology employed were developed in the field as the project developed. The original concept for conducting the study was to hand carry portable monitors and recorders over previously selected, orthogonal paths approximately one kilometer long, leading away from the fixed monitoring site.

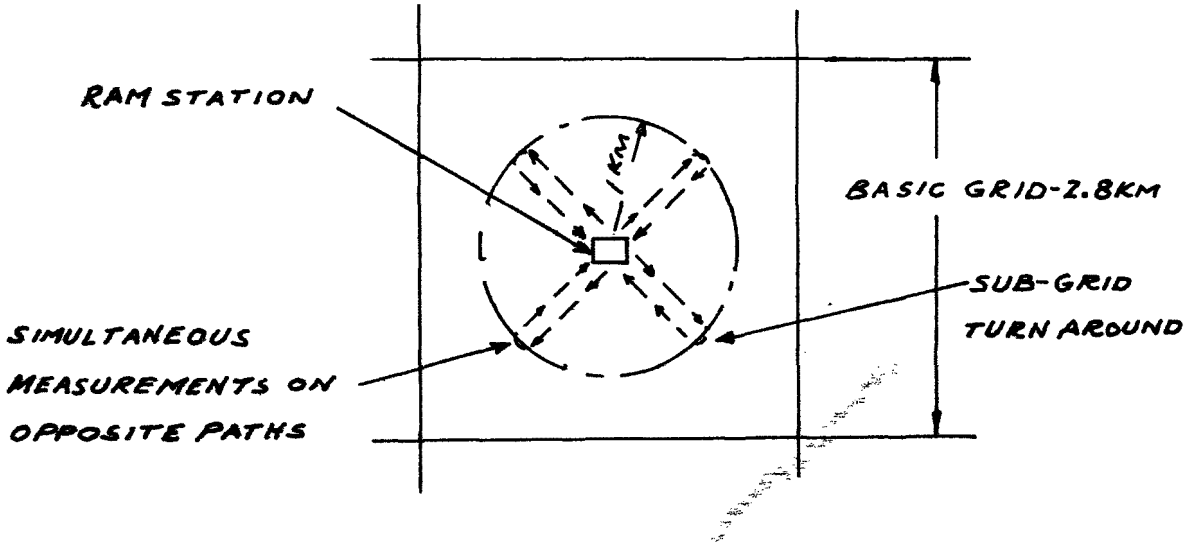

Figure 9. Sub-grid Data Collection by Back-packing Portable Monitors.

The data collected by the portable monitors were averaged and the average value was compared with the average measurement reported by the fixed station monitor during the same time interval. This was the procedure which we expected to follow throughout the study. However, the procedure was altered during the study due partly to the sites selected.

Geodetic survey maps were obtained for each station and paths were initially laid out on the maps (Figs. 2-7). The selected paths were inspected to determine if the monitors

could be safely carried along the paths. Occasionally there were obstructions or blocked streets not noted on the maps. One path was eliminated because the neighborhood was badly deteriorated. Before attempting to take data, trial runs were made to establish satisfactory walking speeds. The two people carrying the monitors used watches and noted their times at major street crossings and at the turn-around point.

Prior to the collection of data at any of the selected sites, preliminary testing was carried out in the vicinity of St. Louis University.

During the previous evaluation of a long path system[13], the monitor and recorder were hand carried. However, it was determined that it would be more satisfactory to strap the monitor and recorder to a backpack (Fig. 8). It was also determined from preliminary tests that more consistent results could be obtained if sample inlets were placed at a height of 10 feet, which corresponds closely to the position of the gas inlet on the RAMS stations.

As soon as a reasonable configuration of the instrument package was complete, data were recorded while both instruments were moved along the same path (Fig. 10). The average difference between the monitors was 5%, and the standard deviation of the individual instrument signal from the average value was 30%. A similar test was performed near site 106 after the completion of a data set (see Fig. 11). In this case the difference between monitors was 9%, and the standard deviation was 15%. These differences were probably due to the drifting of the zero and the sensitivity of the monitors.

Another part of the preliminary testing involved determining the length of the recordings, synchronizing the recordings and walking speeds, and selecting the paths to be traveled. The area around St. Louis University, shown in Fig. 12, was treated as if it were a RAMS site to be investigated. The paths traveled are noted by numbers on Fig. 12. After taking data for a few days, it became obvious that by walking along the streets the data was biased by the traffic[14]. Hence, in order to obtain a better area average, some of the measurements had to be taken at points away from the streets. An attempt was made to assess the average land use of the area by the use of maps, observations from the top of a 15-story building, and driving around the area. Finally, an experiment was performed to determine the changes in the readings as the monitors were moved away from the street. Subject to the prevalent wind conditions, the measurements which were made at points adjacent to the street were as low as 30% of the ambient level. By moving the monitors 100 feet from the street, the readings were at least 90% of the ambient

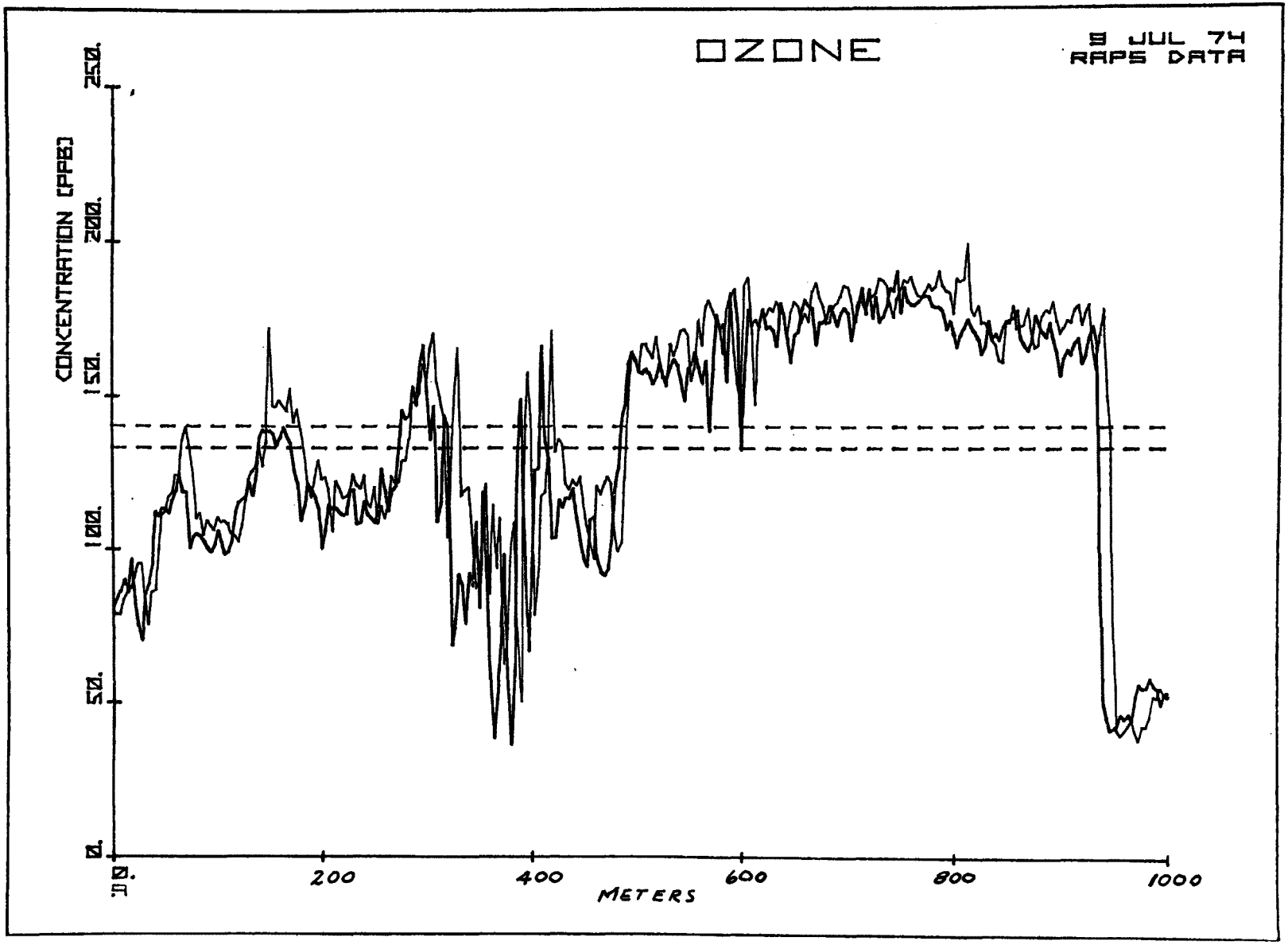

Figure 10. Side by Side Comparison Around St. Louis University.

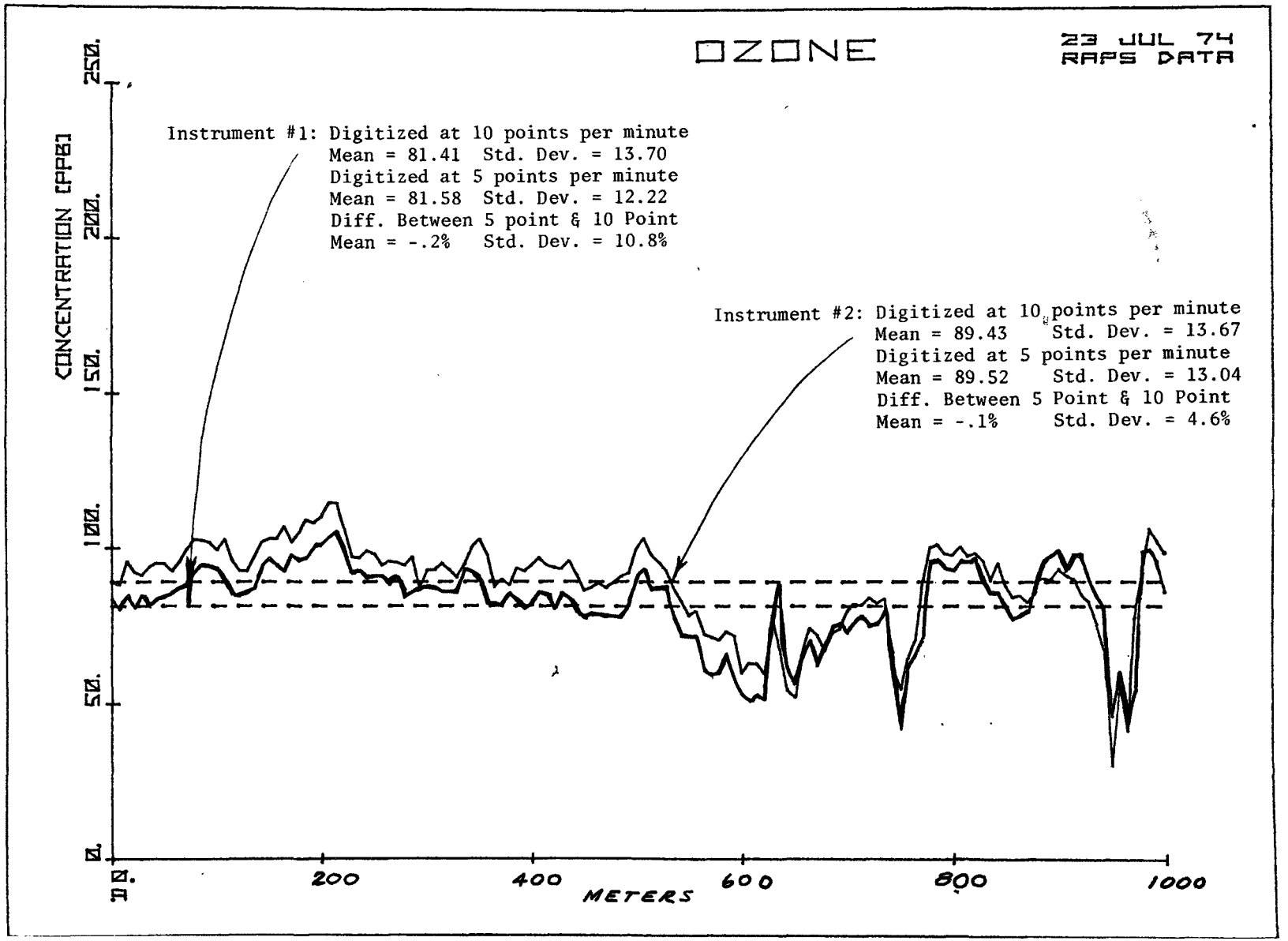

Figure 11. Side by Side Comparison Near Site 106.

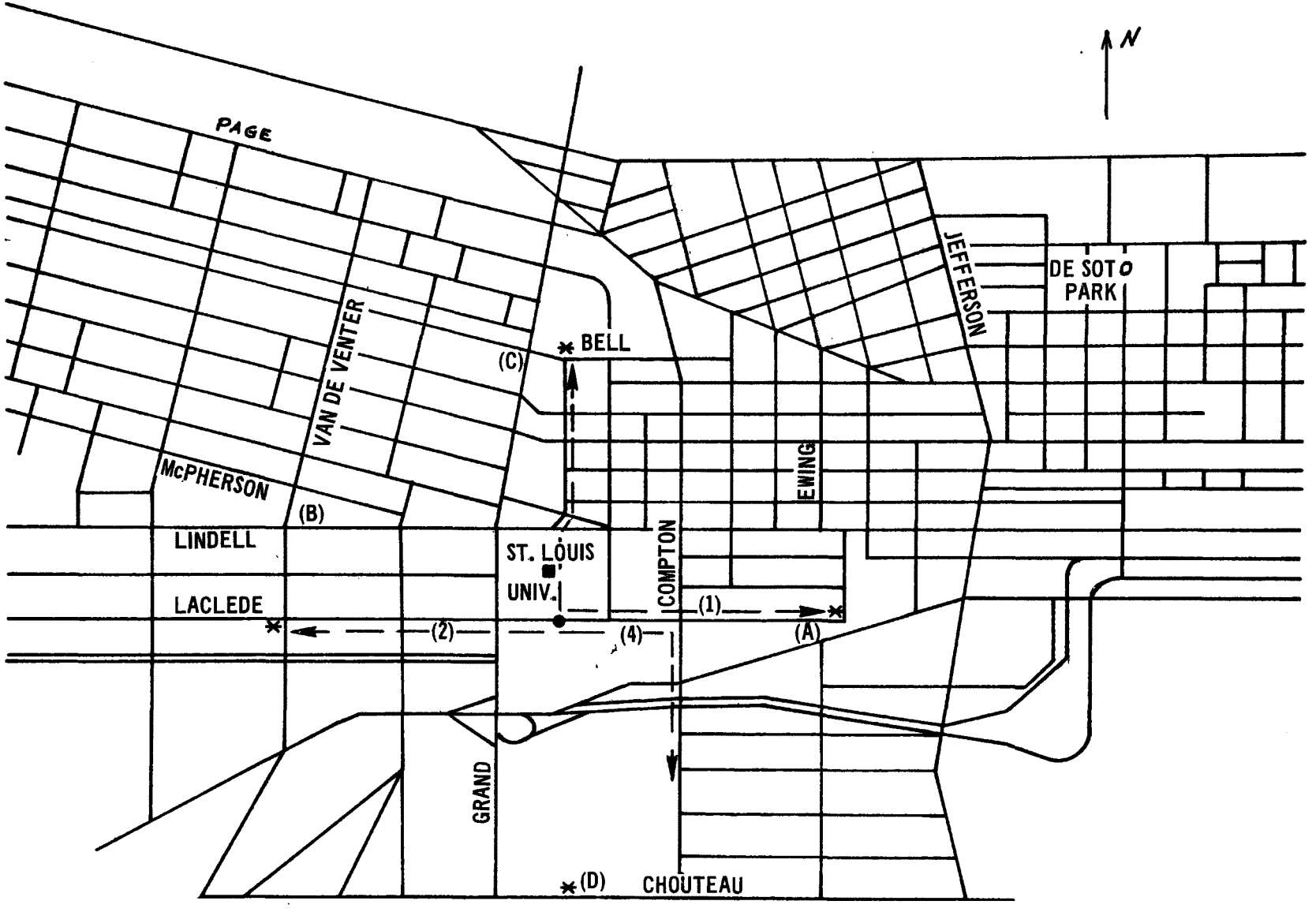

Figure 12. Area plot Around St. Louis University.

level. At points 200 feet from the street, the street effects were not noticed. The same experiment was repeated each year and in no case were the effects from roadway observed at distances greater than 100 meters.

As a result of these tests an alternate data collection technique was developed.

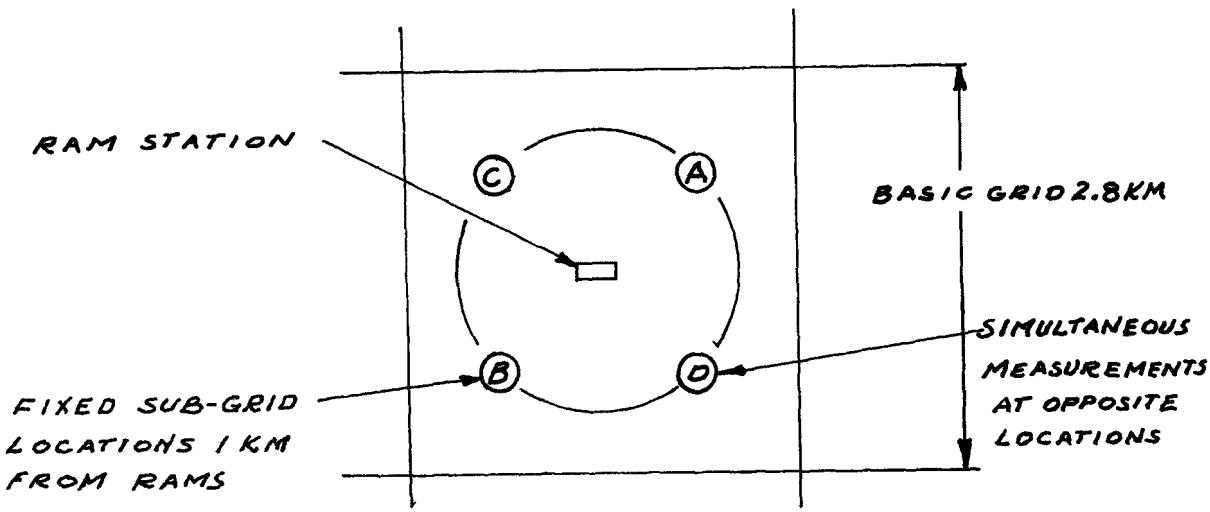

Figure 13. Sub-grid Data Collection by Fixed Location.

After surveying the area, four fixed points, all located approximately 1 km from the RAMS station or central reference point were selected. These points are designated on Fig. 13 and all the site maps by the letters A,B,C and D. The measurement procedure was to take data simultaneously at A, B and the RAMS station, and then to move the monitors as rapidly as possible to positions C&D and record a second simultaneous set of data.

The operating procedure in the case of using a monitoring path (Fig. 9) was to have the two monitor backpackers start at RAMS station, walk in opposite directions to the edge of the grid, turn around, and return. With a little practice it was possible for two people to walk at approximately the same rate. A second traverse would then be taken in a direction orthogonal to the original traverse. The total averaged data was then compared with the data collected at the station during the same interval.

At each site at least one set of data was collected while walking the monitor or bag sampler along selected paths. However, the bulk of the data was collected at the sub-grid monitoring locations. Data was recorded for fifteen to twenty minutes at each location. One or two complete data sets were taken during the morning, and one complete set was taken during the afternoon. Occasionally, rain or other unforeseen factors prevented a data set from being taken.

HELICOPTER SUPPLEMENTAL DATA TECHNIQUES

A limited amount of helicopter data was collected every year. The measurements were made at 103 in 1974 and at 108 in 1975 and 1976. The collection procedures were the same in both cases with two exceptions. During 1974 only ozone was measured and the helicopter performed a mission for another project while the monitors were being moved. This resulted in an excessive waiting time for the portable monitors.

The collection procedure was to locate the portable ozone monitors and the CO bag collectors at positions A and B while the helicopter made three passes overhead at heights of 60, 215, and 460 meters. The monitors were then moved to C and D and three more passes were made. The purpose in taking the data was to investigate the ability of RAMS to represent pollution in a three dimensional area (see Table 1).

On August 12, 1975 a special effort was made to collect data from two sites. Morning and afternoon sets were collected at urban site 105 and a midday set was collected at site 108 in conjunction with a helicopter run. The three data sets are reasonably representative of the data collected during the study and demonstrate the difference in variability between a rural and an urban site.

FIELD CALIBRATIONS

Field calibrations must be carried out in a minimum of time and often under adverse conditions. Hence, the techniques selected emphasized convenience rather than accuracy.

Ozone

The calibration instrument was an ultraviolet ozone generator which could be adjusted with a simple sleeve setting. This required a clean air supply for operation and had to be left set up in our laboratory space at St. Louis University (SLU). The daily procedure was to calibrate the portable monitors at SLU. The monitors were then taken to the RAMS site and simultaneous recordings of the RAMS monitor and the portable monitors were made at the station inlet. The data

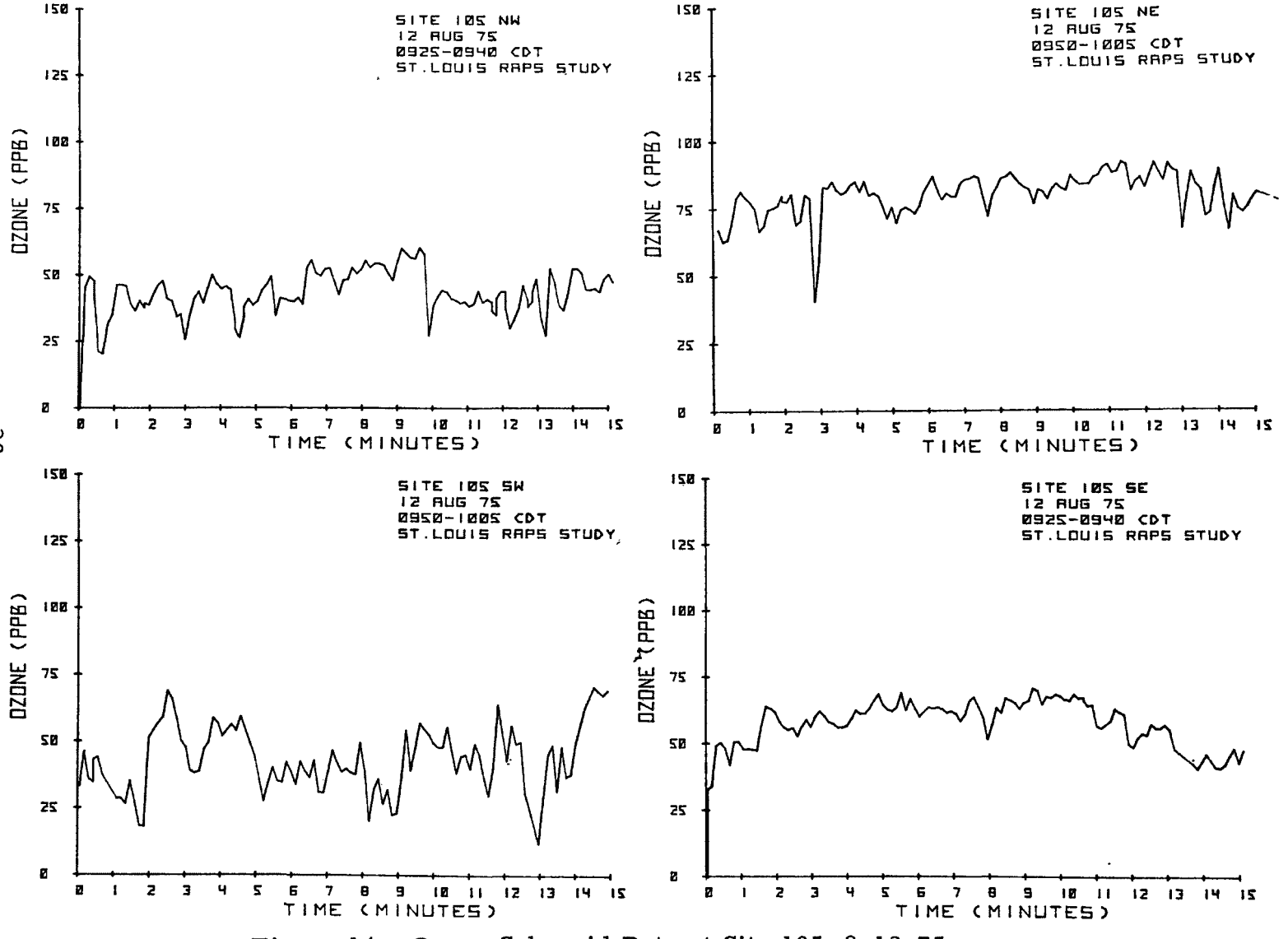

Figure 14. Ozone Sub-grid Data at Site 105 8-12-75 a.m.

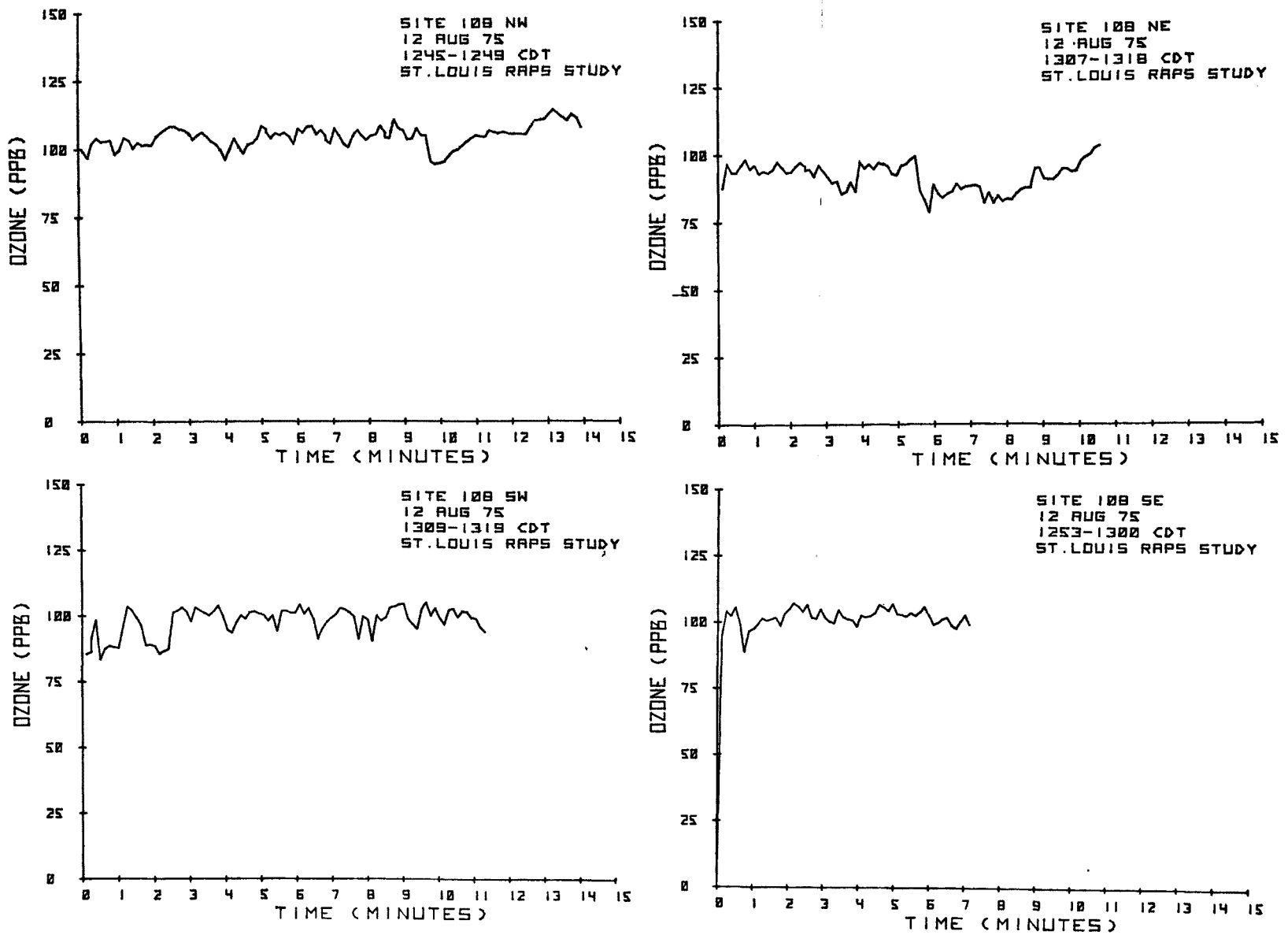

Figure 15. Ozone Sub-grid Data at Site 108 8-12-75 noon.

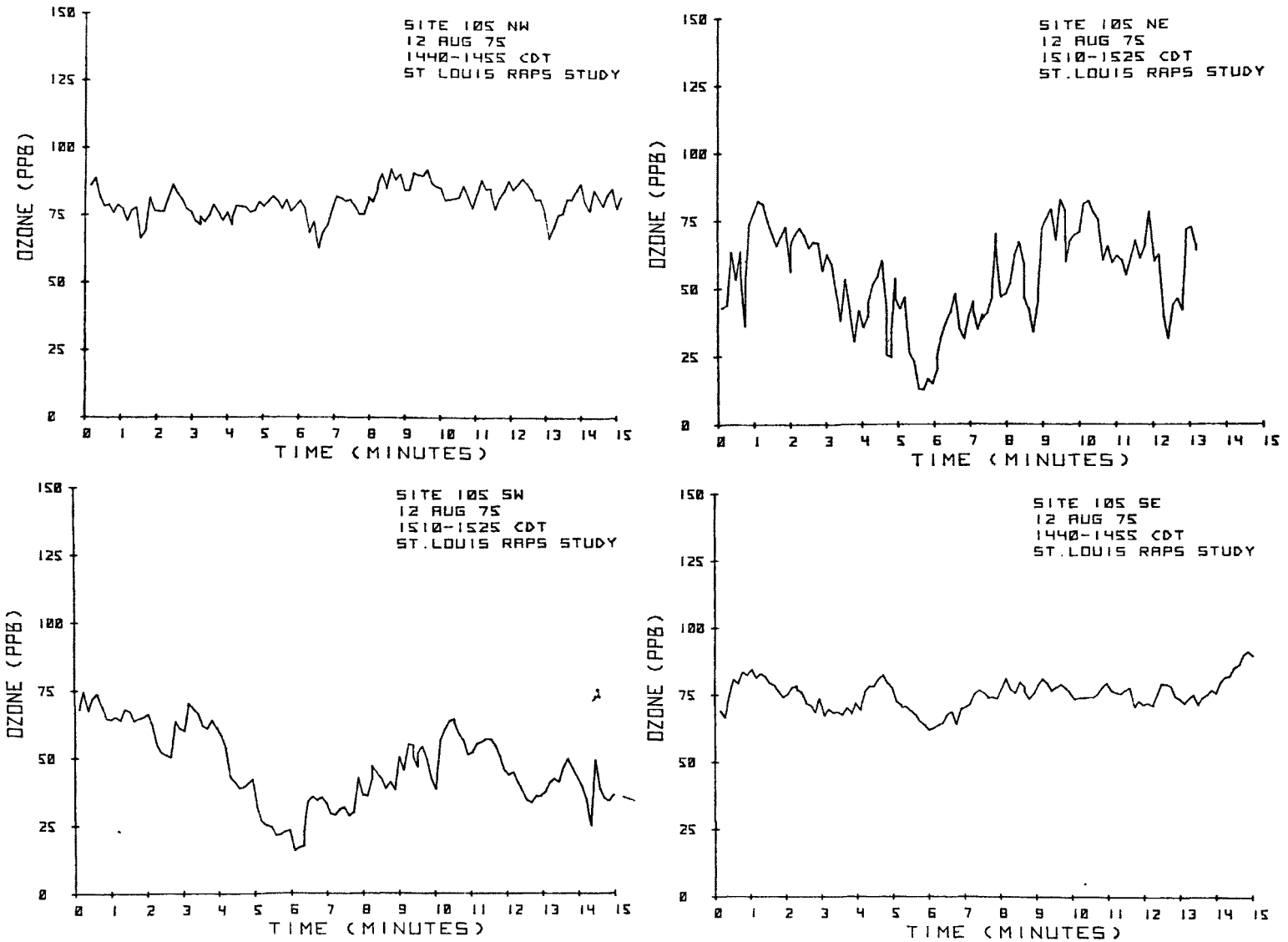

Figure 16. Ozone Sub-grid Data at Site 105 8-12-75 p.m.

set for the day was collected after which another simultaneous set was recorded. The portable monitors were then returned to SLU and a final claibration using the ozone generator was performed. This procedure was required in order to account for the drift in the portable monitors during the day.

Carbon Monoxide

The procedure developed after the first year was to periodically (every 4 weeks) perform a 5 point calibration of the monitor by the dynamic dilution of the SRM obtained from NBS. Then, immediately following the calibration, the monitor was used to measure the concentrations of newly mixed field calibration gases. The field calibration gas was stored in small cylinders about 17 inches high, which were easily handled by one person. The normal daily procedure was to make a twice daily check of the monitor with one span gas and one zero gas. Several gases were available for zeroing the monitor: Scott Ultrapure Air, Linde Prepurified Argon, and Linde High Purity Helium. All of these produced zero values within the noise figure of the GFC monitor (20 ppb-v).

DATA COLLECTION PROCEDURES

The data collection procedure followed throughout the study was to collect at least 10 complete data sets at each site over a period of one week. The daily procedure was to perform two zero and span calibrations of the ozone monitors at SLU and one or two zero and span calibrations of the GFC monitor located in the Lincoln Laboratory van parked adjacent to one of the RAMS stations. While the monitors were being calibrated, the Tedlar bags used to collect the air samples were flushed with helium and evacuated.

The equipment taken to the site to be studied consisted of four backpacks: two each had an ozone monitor and recorder and two each had an air sampling pump and Tedlar bag. Data was collected by both ozone monitors and an air sample was collected at the RAMS inlet monitor. The monitors and the air sampling systems were then taken to the sub-grid locations, or were backpacked along the selected paths as previously outlined. The monitors were returned to the station and the six air samples collected were analyzed. This completed one data set. Usually two, and sometimes three, data sets were collected at each site per day. At the end of the day, additional ozone data were collected at the station manifold. The laboratory calibrations of the ozone generator and the CO monitor were performed once a month.

DATA REDUCTION PROCEDURE

The analog data recorded on strip charts was digitized at 10 points per minute, calibration corrections based on the difference between the morning and afternoon calibrations were applied to each data set, and the mean and standard deviation from the average of the data set was calculated. Further analysis of the data required that the RAMS data be correlated with the sub-grid or portable monitor data. This was done by fitting straight lines to data pairs consisting of the RAMS data and the sub-grid data taken at corresponding times. A straight line was fitted to the data set from which were obtained values for the slope, intercepts, and their standard deviations. The correlation between the RAMS and the sub-grid measurements was also determined, then the relationship between the RAMS and the average of the four sub-grid measurements was established. The standard deviation calculated for each data set was adjusted by a ratio derived from Student's t distribution based on the number of data points used and an 80 per cent confidence limit. Thus, each data set was summarized by a best fit linear equation with 80% confidence limits.

SECTION 6

RESULTS

1974 OZONE

During 1974 the pollutant variability study was confined to ozone measurements although it was originally intended that SO_2 and CO measurements should also be made. The sample pump failed in one of the two SO_2 monitors. Because of the delays and problems in making the measurements only a few exploratory measurements were taken. As previously explained the technique of collecting bag samples and returning them to the laboratory for analysis was not satisfactory because of the limited number of samples and the possible contamination.

1975 OZONE AND CARBON MONOXIDE

During this study a maximum effort was made to increase the number of pollutants and to take more data at a given site. This required a compromise on the number of sites. Data was taken at two sites only, 105 and 108. These were also the sites selected for testing the long path laser system. A few ozone data sets were collected at site 108 by walking along the orthogonal paths, but most were collected at the sub-grid locations.

The CO data was obtained by collecting a bag sample while ozone was being measured, and usually within a half hour the sample was measured with the GFC monitor which was located in the Lincoln Laboratory van parked adjacent to the RAMS.

Two calibrated SO_2 monitors were taken into the field for data collection. However, during the first day of the study the outside temperature reached 98°F and it was immediately apparent that the monitors would never operate in this environment. Hence, the SO_2 measurements were dropped from further consideration. Enough data were collected in 1974 to indicate that most of the time the concentration was below the monitor noise level (10ppb) but whenever a plume appeared it was quite high, hundreds of ppb.

The ozone and CO data were collected for a period of two weeks at each station site. The ozone data were essentially in agreement with that collected in 1974. Since there was no statistical difference between corresponding sets, it

was considered that the study objective had been reached. The CO data indicated that the station was reading low and for this reason more data was collected.

A further indication that there was a discrepancy in the CO data was the conclusion of a separate quality assurance study[9] which showed low CO measurements. At the end of the 1975 study, the GFC monitor was placed in several RAMS station manifolds where the GFC and the station Beckman 6800 gas chromatograph were compared. The data is contained in a separate report[10] which describes the GFC CO monitor application.

1976 CARBON MONOXIDE

The primary objective of the 1976 study was to repeat the CO variability measurements at stations 105 and 108 in order to determine the cause of the low CO values reported by RAMS. The procedure in making these measurements was altered in that a bag sample was collected on the roof of the RAMS simultaneously with the collection at the sub-grid locations. Thus, for each data set there were five bags-one colleced for 1/2 hour on the station roof, and four 15-minute collections at each sub-grid location.

This data demonstrated that there was a difference between the bag sample collected on the roof and the RAMS measurement. It was suspected from the Quality Assurance Study that a sampling problem existed in the RAMS CO measurements. The RAMS CO measurements are made on samples collected during a 2 second interval every five minutes. Hence, signal fluctuation periods shorter than five minutes are not observed. This can lead to an appreciable error if the data is not averaged over a sufficiently long period.

In order to determine the possible signal variation, it was decided to conduct a small roadside study. This was done at two locations in the St. Louis area. One study was conducted on Grand Avenue near St. Louis University, and all the others on Page Road near the EPA-RAPS laboratory. The GFC monitor was set up with the sample cell open and data were collected at intervals of 25 meters away from the roadway. The data set collected has been included in the separate report[16] which describes the GFC monitor applications. An example of the roadside data is shown in Fig. 17.

DATA PRESENTATION

The results of the study are summarized by a set of best fit linear equations fitted to all the data collected at each test site. This data and further analyses of the data are discussed in published paper[17].

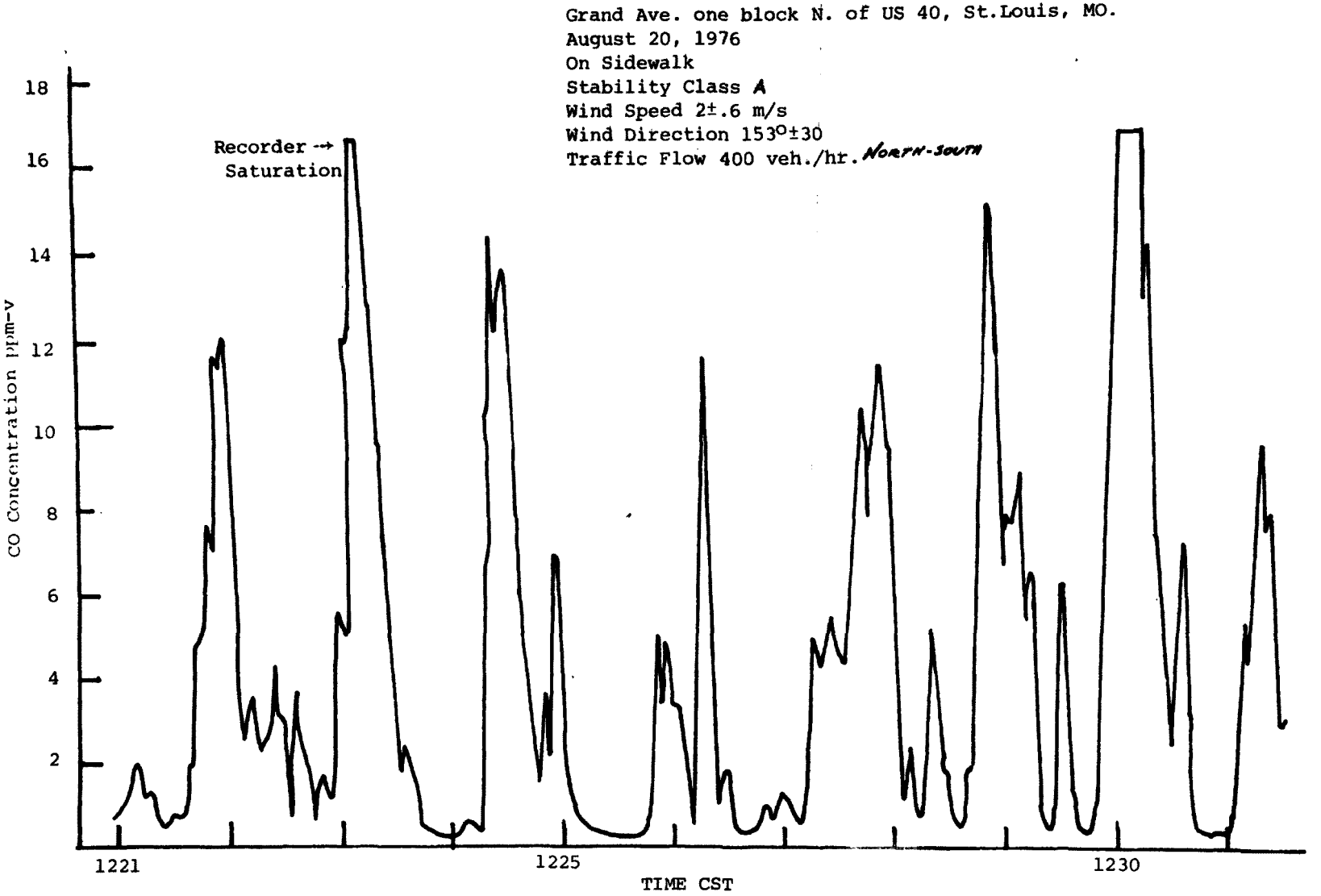

Figure 17. Grand Avenue CO Concentrations August 20, 1976.

Ozone

The results of the ozone data collection are given by six equations, one from each site studied (see Table 1). The number of data points for each set is indicated beside each equation. Each point represents the average of 15-20 minutes of concurrent data. The data from four of the stations was collected in 1974 and the data from the other two was collected during 1974 and 1975. A single example of how well a given equation fits the data is given in Fig. 18 for RAMS 113, a suburban site. The average slope for all the data sets is 0.99 and none of the sets are statistically different from 1.0.

TABLE 1. RAMS MONITOR OZONE CONCENTRATION-

Related to Area Concentration.

Variations represent 80% confidence limits

Station	No. of Points
RAMS 102 = 1.14(±.17) area av. -1(±11)	14
RAMS 103 = 0.86(± .06) area av. +4(±4)	13
RAMS 105 = 0.88(± .10) area av. +4(±6)	52
RAMS 106 = 1.07(± .08) area av. +2(±8)	32
RAMS 108 = 0.98(± .07) area av. +2(±4)	58
RAMS 113 = 1.00(± .26) area av. +1(±27)	20
AVERAGE = 0.99	

Carbon Monoxide

The CO data was analyzed by the same technique as the ozone data, linear regression by the method of least squares, and determining the correlation coefficient. The basic objective was to determine the relationship between the RAMS station monitor and the area average. This relationship is expresses by equations 1 and 2 listed in Table 2. The very poor correlation

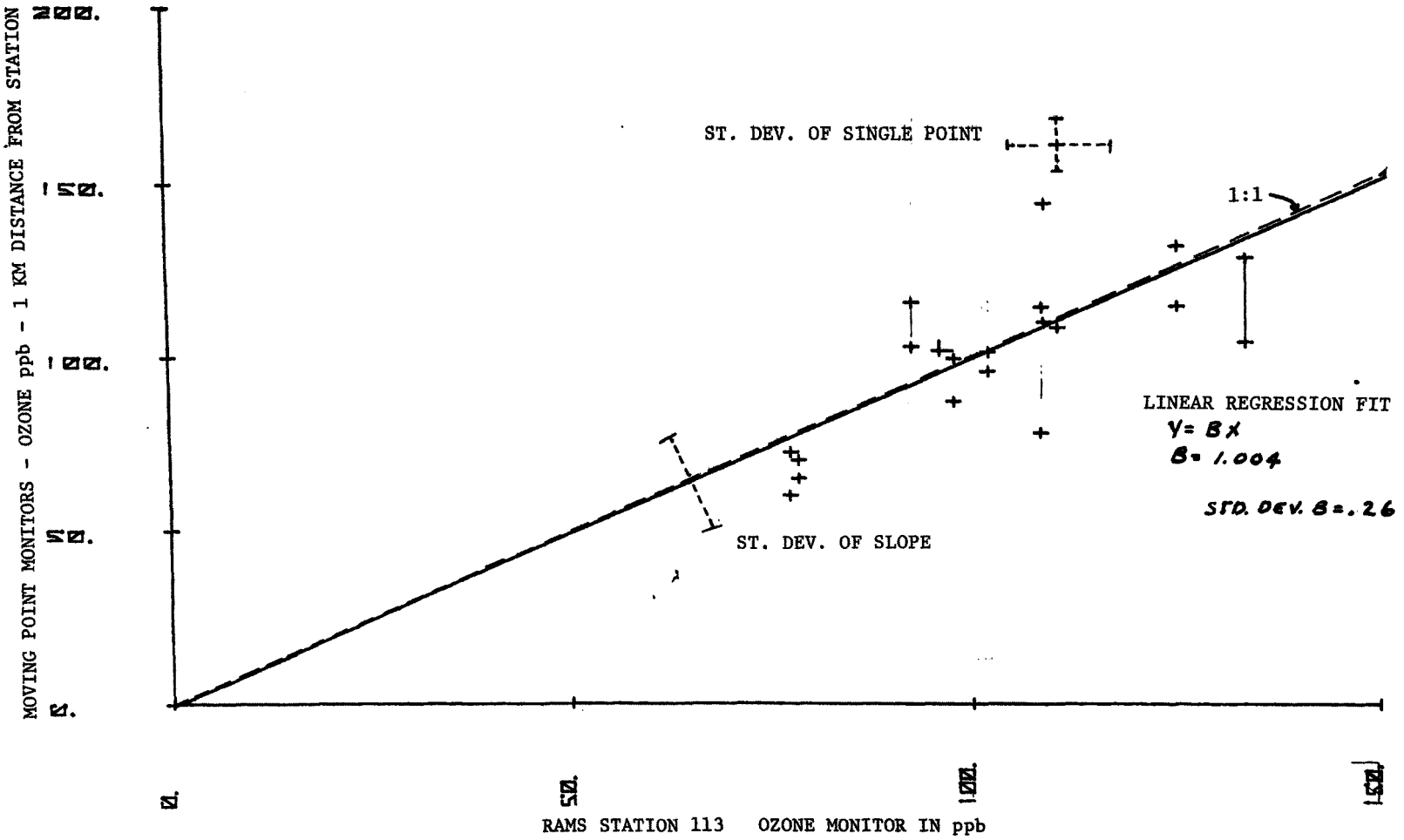

Figure 18. Ozone Correlation Plot RAMS Station 113.

TABLE 2. RAMS MONITOR CO CONCENTRATION RELATED TO $\overline{AREA}$ CONCENTRATION.

Variations represent 80% confidence limits.

Equation No.	Correlation Coefficient (r)	$\%\bar{D}$	$S_{\%\bar{D}}$	No. of Pairs
(1) RAMS 105 = .07(±.07) $\overline{AREA}$ + .5(±.12)	.10	-36	34	70/40
(2) RAMS 108 = .8 $\overline{AREA}$ - .11	.82	-38	21	27
(3) BAG 105 = .35 $\overline{AREA}$ +.66	.75	-1.5	17	40
(4) BAG 108 = .94(±.06) $\overline{AREA}$ + .004(±.03)	.94	-5.0	11	33
(5) RAMS 105 = .29 (BAG 105) + .28	.20	-35	30	10
(6) RAMS 108 = .86 (BAG 108) - .11	.88	-35	21	9

shown in equation 1 was one of the reasons for collecting bag samples at the station while the area average measurements were being made.

The relation between the bag measurements and the area averages are expressed by equations 3 and 4. The correlation is much better, particularly at site 108. These equations express the basic site variability during the measurement period.

The variability between the RAMS monitor measurements and the bag measurement technique are expressed by equations 5 and 6 which relate the monitor measurements to the measurement of the bag samples collected on the station roof.

It is apparent from an examination of equation 1 that this technique of analyzing the data is not completely satisfactory. Hence, it was suggested that the data pairs be examined by determining the present difference (%D = Y-X/Y+X/2 · 100) and calculating $\%\bar{D}$ and $S\%\bar{D}$. These values are listed with the equations in Table 2.

It can be seen that the correlation between the RAMS monitor and the area average is much better at site 108, a rural station, than at site 105 an urban station. However, the percent difference between the fixed monitor and the area average is nearly the same at both sites. We have attributed this to the data sampling technique used in connection with the station monitors.

Helicopter Measurements

The only helicopter data significant to this study were collected in 1975. These data are summarized in Table 3. This indicates that the ozone concentration is very uniform over the entire grid area and that it reaches a maximum at about 60 meters and drops at higher altitudes. The values on the ground are slightly lower and more variable, as might be expected.

The CO concentraitons show much more variation and some of the concentrations are much higher than the ground level values. This might be due to a plume from a factory in Granite City or it might be temperature drift of the CO analyzer. Because of the limited amount of data no analysis was attempted.

PROBABLE SOURCES OF ERROR

One of the major sources of error is uncertainty in the calibration of the portable monitors and the station monitors. Much of the uncertainty in these calibrations was reduced during the 1975 and 1976 study by using SRM's as calibration standards for all monitors.

There is a measureable drift in the zero and sensitivity of the portable ozone monitors with temperature. Much of this error was corrected by measuring the sensitivity of the monitors before and after the data set each day. The temperature drift was measured in an environmental test chamber and over the temperature range from 0°C to 35°C, one monitor changed 10% and the other 20%. However, on some days during the 1974 study larger drifts were noted. This was probably due to absorbed solar radiation in addition to the high air temperature.

The drift in sensitivity of the CO monitor was largely corrected by operating the monitor in a temperature stable environment, namely, the Lincoln Laboratory van. The CO monitor was tested in an environmental chamber and a sensitivity drift of 0.3% per degree C was measured.

The RAMS CO monitor samples CO once every five minutes. Data collected by the Philco-Ford GFC[11] has shown that the concentration of CO can fluctuate with a period of less than 5 seconds (Fig. 17). When this happens the RAMS values will not accurately represent the CO concentration. The data collected in that study and subsequent studies shows that the typical RAMS measurement is low.

The typical low average reading is due to the fact that the average does not cover a sufficiently long sampling period. The minimum averaging period can be determined from the sampling theorem which states that two samples are required per period of the highest frequency to be represented. If the highest frequency of the concentration fluctuation is 5 seconds then a sample is required every 2.5 seconds. During the 5 minute (300 second) interval between RAMS measurements 300/2.5 = 120 samples are required. In order to accumulate 120 samples the data must be averaged for 120 x 5 minutes = 600 minutes or 10 hours. The concentration is normally not constant nor is it averaged over such a long period. The user should be aware that the typical measurement will be low, but an occasional measurement will be very high.

TABLE 3. INTENSIVE STUDIES WITH HELICOPTER SUPPORT RAMS SITE 108

Date	Time(CST)	Position	$(O_3)_{ppb}$ S=10ppb	$(CO)_{ppm}$ S=.15ppm	Measurement system
8-7-75					
	11:45-12:05	NW	54	0.38	Bag Samples
		SE	46	0.87	Measured by GFC
		RAMS	59	0.29	-Beckman 6800
		Helicopter at 60M	60	1.0	Andros measurement
		Helicopter at 215M	60	1.5	In helicopter
		Helicopter at 460M	60	2.0	Error not known
8-7-75					
	12:10-12:25	NE	63	0.47	Bag Samples
		SW	54	0.64	Measured by GFC
		RAMS	60	0.30	-Beckman 6800
		Helicopter at 60M	60		
		Helicopter at 215M	60		
		Helicopter at 460M	60		
8-12-75					
	11:52-12:05	NW	89	0.41	Bag Samples
		SE	86	1.03	Measured by GFC
		RAMS	89	0.3	-Beckman 6800
	11:52-53	Helicopter at 60M	99	1.2	Bag Samples
	11:54-56	Helicopter at 215M	96	1.06	Measured by
	11:57-58	Helicopter at 460M	93	1.15	Beckman 6800
8-12-75					
	12:08-12:20	NE	79	0.64	Bag Samples
		SW	89	0.42	Measured by GFC
		RAMS	87	0.3	-Beckman 6800
	12:12-13	Helicopter at 60M	95	2.45	Bag Samples
	12:14-15	Helicopter at 215M	93	0.89	Measured by
	12:16-20	Helicopter at 460M	92	0.91	Beckman 6800

SECTION 7

DISCUSSION

In general, the correlation between area averages and RAMS values is greater at rural than it is at urban sites. This is not surprising; rural sites contain considerable fewer sources of pollution than do urban sites. Consequently, the pollutant in the rural sites is more evenly distributed than it is in an urban area.

The correlation of O_3 RAMS data with the area average measurement is greater than the correlation of CO RAMS data with the area averages. This is probably due to the differences in the method by which the pollutants are produced.

Ozone occurs naturally and is also a widely dispersed secondary pollutant. It seems that a relatively uniform concentration could be spread across an entire air mass. In any event it is dispersed on a macroscale. These variations within the urban area are due to titration with NO which is dispersed on a microscale. The higher the total ozone concentration, the less is the effect of local sources on the concentration. Carbon monoxide is a primary pollutant and is not so evenly dispersed, especially, in urban areas. Under conditions when the background CO is low, for example, during the passage of a cold front, most of the measured pollution is from local sources. If we define local sources to be those no more than 100 meters away, then there will be little correlation between sub-grid locations 1 kilometer apart.

During the course of this study, a large number of measurements were made of the ambient concentrations of both ozone and carbon monoxide. In addition, a significant portion of the RAPS data base collected during the same time periods was examined. The primary observations to be noted is that the variability in pollutant concentration id difficult to correlate with any single factor. In fact, the variation is dependent on many factors making it nearly impossible to develop simple relationships between any single factor such as wind speed, wind direction, or source strength and the pollutant concentration.

RELATION TO SIMILAR STUDIES

The variability data which was collected during this study was averaged over relatively short time intervals (10 min. to 30 min.). These times are short compared to any model which

will be applied to the RAPS data base. Also the number of samples were limited and all were collected during the summer daylight hours. Hence, the measured correlation between the monitoring station and the area wide averages cannot be applied as corrections, but noted as a probable error. However, such data has proved useful in other similar studies. Examples of such studies are "An Urban Survey Technique for Measuring the Spatial Variation of Carbon Monoxide Concentrations in Cities" by Wayne Ott[14], "The Areal Representiveness of Air Monitoring Stations--Fresno Study Phase I" by State of California Air Resources Board[18], and "Selecting Sites for Carbon Monoxide Monitoring" by F.L. Ludwig and J.H.S. Kealoha[19].

CO STUDIES

Ott performed a CO survey of the San Jose urban area (13 square mile grid) over a six month period by collecting bag samples which were analyzed for CO and compared with a permanent stationary monitor. The primary question which he sought to answer was, "How representative was the station monitor?" This was essentially the same question we asked regarding the individual stations in the St. Louis RAPS network. Ott's survey extended over a six-month period from October through March compared to our summer investigation of St. Louis. The San Jose area was divided into 9 squares whereas we used 4 squares. In each case the sample collections were made at fixed sites inside the squares. The basic procedure in both cases was to collect two or more simultaneous samples including the monitoring station at the selected locations over an extended time period.

We each performed an almost identical supplementary experiment in order to try to determine the "street effect" (Ott's terminology). Data was collected on a sidewalk near a very busy street and the sampling point was moved back 25 feet at a time until the "street effects" were no longer observed. Ott reported that the "street effects" disappeared after 200 feet and we reported that they disappeared after 100 meters. We were able to make the measurements with a portable monitor, whereas Ott had to have the bag sample analyzed. Hence, our sensitivity must have been greater which makes the agreement very impressive. These results are in agreement with an analysis of Los Angeles monitoring data which showed a correlation between the monitored value and the distance of the monitor from the street.

Our measurement of the "street effect" was done by placing the monitor on the sidewalk along a busy street as compared to Ott's technique of walking along the street. A sample of our results is shown in Fig. 17. We believe that this confirms Ott's conclusion that the measured CO consists of two components, "urban background," the area between the spikes, and

"street effects," the area under the spikes.

Our conclusion is that the "urban background" is CO which has dispersed until it reached the inversion and dispersed back to the surface, or else dispersed downwards after an initial plume rise. The contributions from individual sources are no longer identifiable. The "street effects" or spikes on our records are due to intercepting the initial plume as it is exhausted from the individual automobile or a cluster of automobiles. It appears that there is an initial plume rise or buoyancy which normally prevents the initial plume from being detected at ground level more than a few hundred feet from the source. This effect has been identified as a reason for the disagreement between some gaussian plume models and field measurements (Chock)[20]. It has also been suggested that near mid-day, particularly in the summer, a street temperature higher than the surroundings may contribute to the effect.

A typical inversion height at mid-day during the summer will be several thousand meters and the urban background may be very low (less than 0.5 ppm) so that most of the total monitored CO is due to "street effects" Under these circumstances two monitors only 500 meters apart may monitor CO from completely different sources. We believe this explains the complete lack of correlation of much of the CO data collected at RAM site 105.

There have been numerous microscale studies directed towards measuring the distribution of CO such as, the St. Louis street canyon[21], the San Jose street canyon[22], the Oak Park shopping center[23], and the New York submerged roadway[24]. These studies have a common characteristic in that they tried to establish an average CO distribution in a limited area over a limited time period. This is difficult task in that a dynamic situation is being described by static measurements. Rather than stable gradients, many individual plumes move in a turbulent fashion through the area with order of magnitude concentration variations. In all of these cases the total concentrations are high and the "urban background" component is relatively low which is a different condition than the measurements that we have reported.

OZONE STUDY

The results of our ozone study show that there is no statistical difference between the RAM point measurements and the portable monitor area-wide measurements. These results can be compared with a Fresno study done by the California Air Resources Board to determine the representiveness of a single monitoring station located near the city center for a surrounding 64 square mile area. Ozone was measured from June 22, 1976 to Nov. 30. 1976 at 20 locations throughout the area. A pattern of mean regression slopes for the maximum hour concentrations

were drawn. This analysis showed the maximum concentration gradient to be 5% over 1/2 mile. This is less than a statistically significant difference for our experiment. This agreement regarding the microscale variation of ozone adds weight to our conclusion that RAM ozone measurements should be representative of the surrounding area.

RELATIONSHIP TO SITE SELECTION

A result of this study is a recommendation that monitoring stations be sited 100 meters off a roadway in order to minimize "streets effects." Ott made a similar recommendation and followed with a paper suggesting several types of locations depending on the data desired. Ott's suggestions were used by Ludwig and Kealoha (L and K) in the development of criteria for the selection of CO monitoring sites.

It was suggested by L. and K. that the measurement scales which may span 7 orders of magnitude from less than one meter to 40,00Km (the earth's circumference) be divided into seven categories each spanning approximately one order of magnitude.

The proposed categories and the approximate scales as well as the standard meteorological turbulence scales are shown in Fig. (19).

The discussion by L. and K. of the seven proposed scales concluded that only the three shown by the solid hatching should normally be considered as monitoring sites. It can be seen that each of these categories is included in each of the three meteorological scales. Hence, for the purpose of this discussion the meteorological nomenclature will be used.

As can be seen in Fig. (19) there is a close relationship between the spatial and time variations of either atmospheric turbulence or pollutant concentration. We have tried to illustrate the scale of the spatial variation in Fig. (20) and the temporal variation in Fig (21).

Referring to Fig. (20) which illustrates the relative size of the three scales it should be noted that any station located inside the urban plume will monitor pollutant concentrations on all three scales. The magnitude of the microscale CO contribution (0.5 ppm to 50 ppm) will depend on the monitor location relative to the local sources (less than 1 km away). The mesoscale or urban CO contribution (0.1 ppm to 20 ppm) will depend on the inversion height, wind speed, and wind direction. The macroscale or synoptic CO contribution (0.05 ppm to 0.5 ppm) will depend on the origin of the air mass. An artic high may have traveled 1000's of kilometers over uncontaminated areas and have contributions below the global CO background level

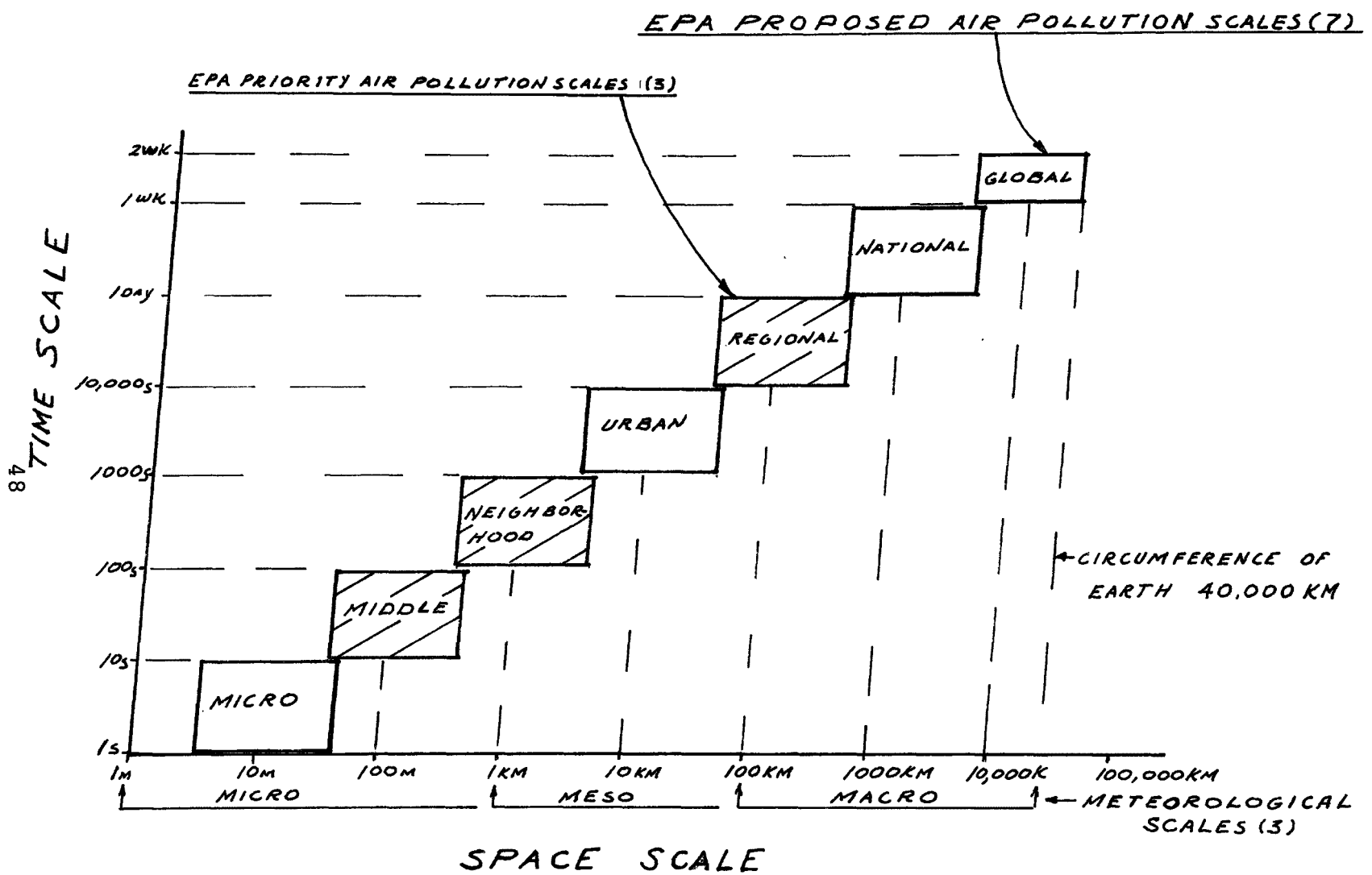

Fig. 19 Space and Time Scale Correlation

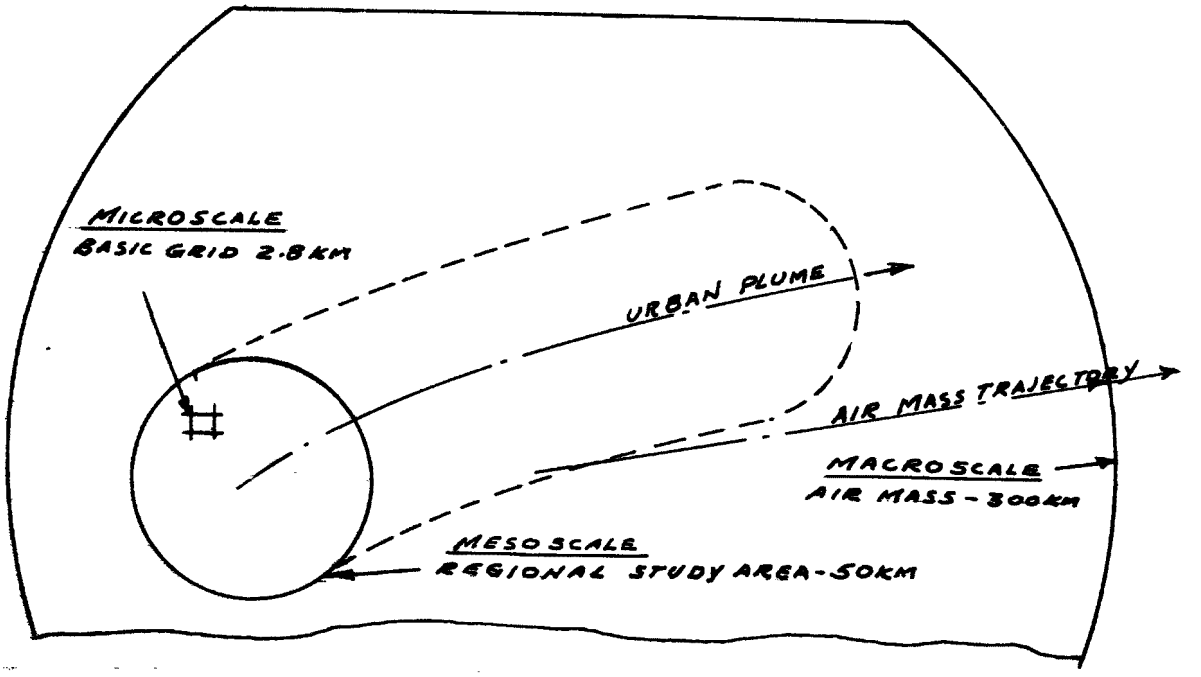

Figure. 20. Pollutant Area Scale Comparison.

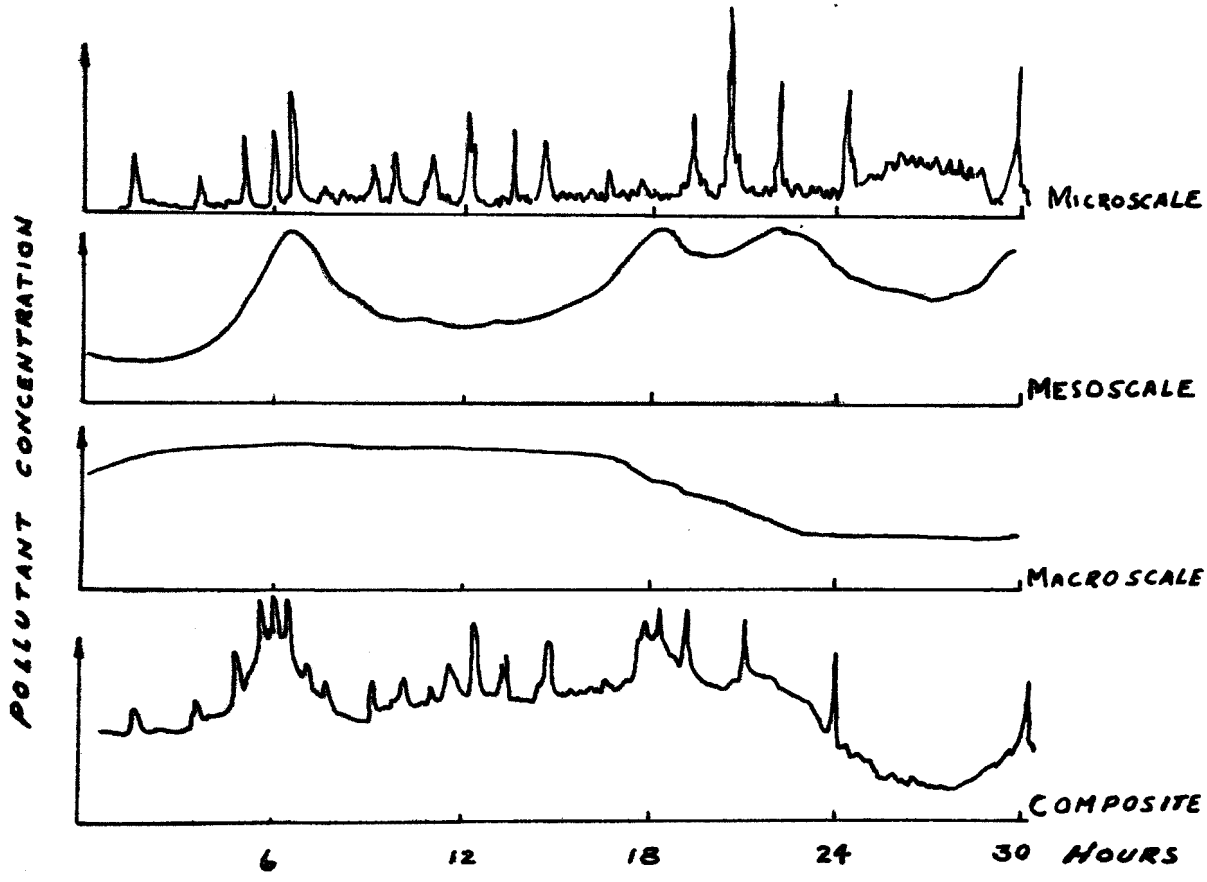

Figure 21. Pollutant Variation vs. Time Comparison.

(0.16 ppm). Of course, it is possible to be located on the backside of a stagnant high and measure fairly high CO concentrations (0.5 ppm).

An illustration of the time variation in the pollutant concentration is shown in Fig. (21). If we assume that the monitors used will follow the time variations in the concentrations and that these variations are faithfully recorded, then it would be possible to apply filtering to the data in order to determine each of the three components separately.

The ability to separate the measurements into components would increase the usefulness of the data. Models designed to measure either microscale or mesosclae effects could be verified directly without spurious interferences. Also, the problem of station siting would be simplified and probably the number of stations required to obtain satisfactory data would be reduced.

If other studies such as the one reported here were to be made, it would be appropriate to compare and examine only the highest frequency components. On the other hand, if comparisons were to be made between stations on a regional basis as in the RAPS, then the mesoscale or midfrequency variations should be examined. In the case of ozone transport studies, the macroscale or low frequency portions of the signal should be examined.

SUGGESTIONS

RAPS DATA BANK

Most of the monitoring instruments used in the RAPS network were capable of responding to microscale variations. However, the data sampling, averaging, and readout process may have obscured the microscale components. A careful examination of the data should be made to determine if filtering can be applied. If filtering is possible, a selected set of filtered data should be tested for model verification.

FIELD TESTING

The most effective means of testing the filtering technique would be by application to an existing data collection network. The monitors to which the technique could be readily applied are the continuous reading fast response instruments such as the ozone and NO_x chemiluminescence monitors. If additional network data collection channels are available, the data could be passed through filters and collected on separate channels. Otherwise, the data can be collected in digital form and mathematical filtering applied to obtain the desired out-

put signals.

It is felt that the possible benefits to be gained by using filtered data requires the testing of the technique.

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15. SUPPLEMENTARY NOTES

16. ABSTRACT

As part of the Regional Air Pollution Study (RAPS), a series of studies were carried out in St. Louis during the summers of 1974, 1975, and 1976 primarily to determine the sub-grid concentrations of ambient air pollution. One primary pollutant gas, CO, and one secondary pollutant gas, ozone, were chosen to be representative. Methodology for determining sub-grid concentration variations of these gases are discussed.

Portable monitors and the collection and analysis of bag samples were used to determine pollutant concentrations. In some cases the monitors were moved along selected paths while the measurements were made; in other cases the monitors were placed at selected sub-grid locations. The data were collected at six sites during the first year, and at two sites during the final two years. Both urban and rural sites were selected. All the data were collected during daylight hours generally between 10:00 a.m. and 4:00 p.m.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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