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Vertical Gradients of Pollutant Concentrations and Deposition Fluxes at the Cathedral of Learning

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Table of Contents

List of Figures

List of Tables

Introduction

Numerous studies have shown that air pollutants can cause deterioration of sensitive materials (Sherwood et al., 1990). This problem is particularly important for buildings and monuments, where materials are chosen for structural support as well as for their aesthetic value. Several types of deterioration have been documented, including discoloration, erosion of material, and changes in the physical and chemical make-up of the surface that lead to weakening of the structure and reduce aesthetic appeal.

Unfortunately, our understanding of the processes responsible for the deterioration is extremely limited. Such understanding is needed to assist in developing control strategies that minimize the damage and to help in designing new structures that will be less vulnerable to damage.

This research program has focused on a 42-story building that has been exposed to high levels of air pollutants over several decades. The building, known as the Cathedral of Learning, is a National Historic Landmark on the University of Pittsburgh campus. The building was constructed of Indiana limestone between 1929 and 1937, and is located in the densely populated Oakland area of Pittsburgh. Two sides of the Cathedral have extensive soiling; furthermore, the stone is eroded in several places. Since the time of construction, there have been numerous air pollutant sources within a few kilometers of the building. These include steel manufacturing plants that employ coke ovens and blast furnaces, a coal-burning steam heating plant, heavy motor vehicle traffic, coal-burning railroads and riverboats, and a large number of domestic coal combustion sources such as home furnaces.

The overall goal of this program is to improve our understanding of the processes responsible for air pollutant damage to the Cathedral of Learning. The work being conducted to achieve this goal includes field experiments at the Cathedral, laboratory experiments in a wind tunnel, and computer modeling. Efforts over the past year have focused on a few specific components of the overall goal with somewhat focused objectives.

First, we sought to determine whether the airborne concentrations of certain pollutants vary with height on the building. The pollutants of interest include SO_4^{2-}, NO_3^-, and carbon particles, as well as total particle number and SO_2 and HNO_3 gas. This information can provide insight on present-day pollution sources affecting the building as well as pathways for delivery of pollutants to the building surface. Second, we investigated whether dry deposition of SO_2 varies with height. This can provide information on the processes of deposition responsible for the observed damage. Third, we identified several key factors affecting air pollutant damage and investigated these factors through undergraduate projects.

Report Organization

This report summarizes the work conducted during the period October 1, 1995 to September 30, 1996. The report is organized into two sections, a main body which includes discussions of the chemical species data, and appendices. A standard organization scheme is followed in the main body of the report. We begin with a background section, followed by a description of the experimental procedure. We then present a summary of the data and interpret the results. Finally, we list the findings of this phase of the program and discuss future work plans.

Appendix A contains tables of original airborne concentration and deposition data. Brief summaries of these data, sufficient to allow interpretation of the most important findings, are included in the main body of the report. Appendix B contains carbon airborne concentrations for the period 3/18/94 through 6/27/95. Because chemical analyses had not been completed, these data could not be presented in the 1995 report for this project (Etyemezian et al. 1995). Appendix C describes a study of rain washoff of material deposited on the walls of the Cathedral. For this part of the project, carbon particles were applied at several hundred locations on the Cathedral, and observations were made of the gradual washoff of these deposits over time. Appendix D presents a protocol ‘for simultaneously measuring vertical wind speeds at five locations near the Cathedral walls. Appendix E describes a comparison of SO_2 data obtained at the Cathedral with similar data from the Allegheny County Bureau of Air Pollution Control at locations around the city. Finally, Appendix F summarizes a pilot study on using uranine as an indicator of surface wetness on the walls of the Cathedral.

Experimental

Vertical gradients of pollutant concentrations and deposition fluxes were measured by sampling at varying elevations on the Cathedral. Three locations were chosen for sampling, the South-facing 5th floor patio, the East-facing 16th floor patio, and the patio on the roof (Figure 1).

The vertical gradient experiments were conducted on four separate occasions from the period of 11/20/96 to 8/21/96. The experiments were scheduled so that representative sets of data were obtained during the different seasons of the year (Table 1). Each set of experiments included four sampling periods of one week each. Airborne concentrations of $S0_4^{2}$ and $N0_3$ particles as well as SO_2 and HNO_3 gases were measured. Airborne concentrations of elemental and organic carbon particles were measured during the fall and winter experiments only. For the spring and summer experiments, Nuclepore polycarbonate membrane filters were used in place of the carbon measurements to obtain samples for scanning electron microscopy analysis (SEM). Laser particle counters were used to provide real-time data for number concentrations of particles with diameter> 0.5 µm and> 5µm. Each set of experiments also included two 2-week measurements of SO_2 deposition fluxes.

All sampling was conducted using identical sets of sampling equipment at each site, two replicate sets for airborne concentrations and four sets for deposition fluxes. Airborne concentrations were measured on patios on the fifth floor, sixteenth floor, and roof of the Cathedral. Deposition flux and laser particle counter measurements were conducted on the fifth floor and sixteenth floors only.

Airborne Concentrations of Chemical Species

Air samplers were placed on supports 1.5 m above the surface of the patios. Concentrations of anions were measured using multistage Teflon filterpacks (Savillex Corporation) with 47 mm diameter filters. Each filterpack included a Teflon Zefluor filter (Gelman P5PL047, ljim pore size) followed by two back-to-back nylon Nylasorb filters (Gelman 66509). This was followed by two sets of potassium carbonate impregnated cellulose filters (Whatman 1441-047, ashless), each set consisting of two back-to-back filters. The Teflon filters were used to sample SO42 and NO particles, while the nylon and cellulose filters were used to sample HNO_3 and SO_2, respectively. An orifice maintained the flow at 1 liter per minute.

Stainless steel filter holders (Millipore XX50-047-l0, open faced) were used with 47 mm diameter quartz fiber filters (Pallflex 2500 QAT-UP) to measure carbon. An orifice maintained the flow at 3 liters per minute. These same filter holders were used with polycarbonate membrane filters (Costar Nuclepore PC-MB-47mm, 0.4 µm pore size) for SEM analysis. A metering valve (Hoke 1656 G4YA) was used to maintain the flow at 0.2 liters per minute through the membrane filters. For all filter sampling systems, a dry test meter (Singer DTM-115) was used to obtain accurate flow rates at the beginning and end of each sampling run.

The Teflon, nylon, quartz, and Nuclepore filters were used as received from the manufacturer without washing. The cellulose filters were immersed in a solution consisting of 76 ml deionized water (D.I. water), 24 ml glycerin, and 15 g K_2C0_3. The filters were then dried on a hot plate covered with clean aluminum foil. Dry filters were placed in clean polyethylene bags (Clean Room Products 6 MIL-0406), heat sealed, and stored in a dessicator. One batch of cellulose filters was prepared at the beginning of each of the four sets of sampling experiments and used throughout that set.

Filterpacks and associated tubing were washed using three rinses with deionized (D.I.) water, one rinse with Optima grade methanol, 30 minute sonication in a D.I. water bath, and two subsequent rinses with D.I. water. All procedures after washing such as drying, loading, assembly, and unloading of the filterpacks were performed inside a laminar flow hood. Filters were handled only with clean Teflon-coated tweezers. Assembled filterpacks were placed in clean polyethylene bags. Field blanks of all filters were prepared in an identical manner as the samples. Air was drawn through the blanks for 3-8 minutes prior to each sampling period.

When unloading the filterpacks, the same contamination control procedures were observed. The Teflon, nylon, and cellulose filters were placed in clean 30 ml polypropylene bottles. The two sets of back-to back cellulose filters were placed in separate bottles, and each set was analyzed individually. The quartz fiber and polycarbonate membrane filters were unloaded into clean 47 mm polypropylene petri dishes. With the exception of the polycarbonate membrane samples, all filters were frozen each season, starting in fall 1995 and ending in summer 1996, four sets of concentration data were obtained, each representing a one week average. Laser particle counters on the 5th and 16th floors were used to measure particle concentration gradients in two size ranges, >0.5 µm and >5 µm. To estimate the dependence of SO_2 deposition velocities on location, a total of 9 surrogate surfaces were deployed on the 5th and 16th floors. The surrogate surfaces were exposed for two week periods.

The concentration measurements indicated that there were no significant vertical gradients for any of the pollutants measured. Emissions from local sources, motor vehicles and a coal-fired steam plant, were either too small or too well dispersed to cause differences in concentrations of elemental carbon or SO_2 among the sampling sites. Laser particle counts qualitatively agreed with this finding for the >0.5 µm particle size range. Although not reflected in the chemical data, on average, >5 µm particle counts were 30% higher on the 5th floor than on the 16th floor.

Pollutant levels exhibited some seasonal dependence. HNO_3 gas and $S0_4^{2-}$ particle levels were higher in the spring and summer while NO_3^- particle levels were higher in the fall and winter. Total NO_3 (HNO_3 and particulate NO_3) remained constant. This seasonal behavior was hypothesized to be caused by either artifact nitrate sampling or a meteorologically - related thermodynamic shift in favor of particulate SO_4^{2-} formation.

Unlike airborne concentrations, deposition of SO_2 to surrogate surfaces was spatially variable. At each sampling elevation, the highest deposition velocities were measured at locations that corresponded to the outside corners of the patios. Furthermore, of the four outer corner locations, 5a, Sf, 16a, and 16c, three were areas that had no soiling. This implied that rain washing was probably an important factor in determining the extent of soiling on the Cathedral wall surfaces. Archival photographs showing a decrease in soiling at the Cathedral with a corresponding decrease in Pittsburgh pollution levels supported this hypothesis.

Future Work

The characterization of rain delivery patterns to the Cathedral walls hinges on a better understanding of the air flow around the building. Because of its massive size, the presence of the Cathedral alters the upstream air flow profile. During rain storms, some parts of the building experience concentrated rain intensity whereas others are sheltered. To gain a better estimate of the degree to which this process occurs, we will attempt to model rain delivery patterns. This involves two major steps; the first is the estimation of the air flow patterns around the building. The second step is the incorporation of rain drop size distributions and a force balance into the model.

Other work that will be conducted includes continuing the analysis of the Nuelepore filters used during the vertical gradient experiments. Because the availability of the computer controlled scanning electron microscope is limited, samples will be analyzed over a period of time. The data from this effort should serve to improve our understanding of particle deposition dependence on size and chemical composition.

the remaining four were in areas that were free of soiling. To avoid exposure to rain, each aluminum plate was placed under a galvanized aluminum rainshield (Figure 2). Locations SB and SC were adjacent and were placed under one larger rainshield.

Results

Chemical analysis results for airborne concentration and surrogate surface field blanks are summarized in Table 2 and Table 3, respectively. Airborne concentrations of NO, SO_4^{2-}, and carbon particles as well as SO_2 and HNO_3 gases are shown in Figures 3 and 4 and Tables 4a-f. Results of SEM analyses of the polycarbonate membrane filters will be presented in a subsequent report. Measured vertical deposition fluxes and deposition velocities appear in Figures 5 and 6 and Table 5. A summary of laser particle counts is given in Table 6. Results of chemical analyses of individual samples appear in Appendix A.

Airborne Concentrations of Chemical Species

Each set of experiments consisted of four consecutive one-week airborne concentration measurements. Sampling was continuous throughout this period except for approximately three hours each week for changing samples. Averages and standard deviations of concentrations were based on the two side by side replicate samplers. When one of the replicate samplers malfunctioned, the concentration was obtained from a single sample. The standard deviation for a single sample was approximated by the concentration multiplied by the average coefficient of variation (COV) for all samples for which replicates were available. The COV was calculated as the standard deviation divided by the average concentration. Each sample was blank-corrected by subtracting the average mass of analyte found on field blanks from the mass of anályte found on the sample. Average values of field blanks for each type of filter used in these experiments are footnoted in the tables in Appendix A.

SO_2 concentrations were based on the chemical analyses of both the nylon and cellulose filters, since the nylon filters tended to remove some SO_2 before the airstream reached the cellulose filters. Experiments in the fall of 1995 showed that two sets of cellulose filters may be needed to capture all of the SO_2 at high concentrations. Therefore, a second pair of cellulose filters was added downstream of the first set for the latter part of the fall experiments and all remaining runs.

Like the other airborne concentration data presented here, the standard deviations of elemental carbon concentrations reflect the variability between two side by side replicate airborne concentration samplers. However, only 10 of the 48 samples and 5 of the 19 field blanks had replicate chemical analysis. Therefore, the standard deviations of the mass of carbon on each filter (Appendix A) had to be approximated by the average COV of the samples for which replicate chemical analyses were performed.

Laser Particle Counts

The averages and standard deviations for laser particle counts for particle diameters >0.5 µm and particles >5 µm are shown in Table 6. On several occasions, one or both LPCs for later analysis. The quartz fiber filters were shipped frozen to the Desert Research Institute for analysis by the thermal optical reflectance method (Chow et al., 1993).

The Teflon, nylon, and cellulose filters were analyzed by ion chromatography. Extractions were performed in a laminar flow hood. The upstream faces of the Teflon filters were wetted with 1 ml Optima grade methanol and 29 ml of D.I. water were subsequently added to the sample bottle. Thirty ml of 0.003 M sodium hydroxide were added to the bottles containing the nylon filters. Thirty ml of 0.05% hydrogen peroxide solution were added to the bottles containing the cellulose filters. All sample bottles were sonicated for 45 minutes. After sonication, Teflon-coated tweezers were used to remove the nylon and Teflon filters from their sample bottles. The filters were discarded. The cellulose filters remained immersed in the extract solution.

Ion chromatography analysis was generally performed within two or three days of the extractions. Extract solutions were refrigerated in order to maintain sample integrity. Analyses were performed on a Dionex 4500i ion chromatograph using a 4mm AS4A anion column. Samples and standard solutions for calibrating the instrument were manually injected. After each injection, the syringe was rinsed with D.I. water several times. A standard solution was analyzed at least once every two hours. All sample handling procedures occurred in a laminar flow hood.

Laser Particle Counters

Two TSI model 3755 laser particle counters (LPC) were used in these experiments. The LPC's were mounted with the nozzle side facing down at a height of 1.5 m above the patios. A laptop computer was used to log particle count data on a two minute basis. Some data were not properly logged during sampling periods due to clogging of the inlet with large particles. High particle concentrations measured by the LPC had to be corrected for double counts in accordance with the manufacturer's recommendations.

Vertical Deposition Sampling

Dry deposition of SO_2 was measured on 125 mm potassium carbonate impregnated cellulose filters (Whatman 1441-125, ashless). Four of these filters were mounted on a thin Teflon-coated aluminum plate. Flat Teflon rings (inner diameter = 105mm) were placed on top of the filters. Labeling tape was used to fasten the rings to the aluminum plate. The fully assembled plates with filters were transported to the Cathedral in a polyethylene tray encased in a clean bag. Field blanks were exposed for approximately ten minutes in an identical manner as the samples. As with the airborne concentration filters, all loading, unloading, and drying of equipment was performed on a clean surface in a laminar flow hood. Extraction and ion chromatography analyses were conducted in the same manner as for the airborne concentration cellulose filters except that 120 ml of H_2O_2 extraction solution was used for each filter.

Nine aluminum plates were exposed simultaneously in each deposition sampling period. The samples were placed at six locations on the 5th floor and three locations on the 16th floor (Figure 1). Five of these locations were areas where visible soiling was present, while nearby coal-fired steam plant does not cause differences in SO_2 levels between the three sampling locations.

Seasonal differences in airborne concentrations are more dramatic than vertical gradients. NO3~ particle levels are higher in the fall and winter than they are in the spring and summer, whereas the converse is true for SO_4^{2}- particles and HNO_3 gas. Total NO_3 (HNO_3 and NO^{3-} particles) remains constant throughout the year. Two explanations are offered:
1. Because of higher temperatures, the evaporation of ammonium nitrate aerosol from the Teflon filters occurs to a greater extent in the spring and summer (Hering et al., 1988). This results in underestimates of NO^{3-} and overestimates of HNO_3 concentrations. 2. During spring and summer, relative humidity and temperature conditions shift gas-particle equilibria in favor of SO42~, thereby displacing NO into the gas phase.

In the >0.5 µm size range, particle counts by LPC agree well with the chemical data. For this size range, the average percent difference between particle counts on the 5th and 16th floors is 2%. If the precision of the instruments is taken into account (10%), this difference is not significant. The LPC data also indicate that >5 µm particle counts are, on average, 30% higher on the 16th floor than on the 5th floor. Since this difference is not reflected in the chemical data, it is unlikely that large fractions of SO42~, NO3~, or carbon mass are associated with the additional particle counts on the 16th floor.

There is considerable spatial variability in SO_2 deposition within each patio. The highest deposition velocities on the 16th floor correspond to locations 16a and l6c. On the 5th floor, the largest values are at 5a and Sf. Furthermore, the relative magnitudes at one location with respect to another location do not change seasonally. For example, on the 5th floor, at locations 5d and Se measurements of fluxes and deposition velocities are consistently lower than at location 5a.

The higher deposition velocities at locations 5a, Sf, l6a, and l6c are probably a result of turbulent eddies caused by flow separation and recirculation zones at the outside corners of the 5th and 16th floor patios. The higher deposition at these four locations cannot be reconciled with the observed soiling patterns. Locations Sf, 16a, and 16c are on parts of the building where there is no visible soiling. Location Sa is inside a 0.5 m heavily soiled indent on the wall. The portion of the wall immediately outside the indent and closer to the outer corner of the patio is clean. These observations suggest that surface rain washing and pollutant deposition must be considered as competing processes. Archival photographs of the Cathedral (Etyemezian et al., 1995) have shown a gradual decrease in surface soiling corresponding to a decrease in Pittsburgh pollution levels (Davidson, 1979).

Conclusion

The primary objective of this phase of the program was to determine if there were vertical gradients in pollutant concentrations or deposition fluxes at the Cathedral of Learning. Measurements of airborne concentrations of $5O_4^{2-}$, NO_3^-, and elemental carbon particles as well as HNO_3 and SO_2 gases were conducted at the 5th floor, 16th floor, and roof. For each season, starting in fall 1995 and ending in summer 1996, four sets of concentration data were obtained, each representing a one week average. Laser particle counters on the 5th and 16th floors were used to measure particle concentration gradients in two size ranges, >0.5 µm and >5 µm. To estimate the dependence of SO_2 deposition velocities on location, a total of 9 surrogate surfaces were deployed on the 5th and 16th floors. The surrogate surfaces were exposed for two week periods.

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Future Work

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Other work that will be conducted includes continuing the analysis of the Nuclepore filters used during the vertical gradient experiments. Because the availability of the computer controlled scanning electron microscope is limited, samples will be analyzed over a period of time. The data from this effort should serve to improve our understanding of particle deposition dependence on size and chemical composition.

In addition to the primary objectives for future research, several undergraduate projects are also being pursued. The measurements of vertical air flows near the walls of the Cathedral and the construction of a computer database are continuing. Because of the success of a previous project, two additional photodocumentation projects have been initiated. In the first project, photographs are being taken of areas of the Cathedral walls where soiled and unsoiled surfaces are adjacent. The documentation of the current locations of these interfaces will be used as a reference point for evaluating the movement of the boundary between soiled and unsoiled areas. The second project involves procuring archival photographs of other local buildings that have undergone similar changes in environmental conditions, a period of heavy pollution followed by a gradual decrease. Comparing these photographs may allow us to detect area-wide trends with respect to these buildings becoming gradually cleaner.

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Table 1. Sampling Schedule at The Cathedral of Learning[a]

Fall 11/20195-12118/95

Date	11/20/95	11/27/95	12/4/95	12/11/95
Teflon, Nylon, and Whatman Filters	+	+	+	+
Quartz Filters	+	+	+	+
Nuclepore filter				
Surrogate Surfaces	+		+	-
Laser Particle Counters				

Winter 2/1/96-2/29/96

Date	2/1/96	2/8/96	2/15/96	2/22/96
Teflon, Nylon, and Whatman Filters	+	+	+	+
Quartz Filters	+	+	+	
Nuclepore filter				
Surrogate Suffaces	+	-	+	
Laser Particle Counters		+	+	+

Spring 5/14/96-6/12/96

Date	5/14/96	5/22/96	5/29/96	6/5/96
Teflon, Nylon, and whatman Filters	+	+	+	+
Quartz Filters				
Nuclepore filter	+	+	+	+
Surrogate Surfaces	+	-	+	-
Laser Particle Counters		+	+	+

Summer 7/24/96-8/21/96

Date	7/24/96	7/31/96	8/7/96	8/14/96
Teflon, Nylon, and Whatman Filters	+	+	+	+
Quartz Filters				
Nuclepore filter	+	+	+	+
Surrogate Surfaces	+	-	+	-
Laser Particle Counters	+	+	+	

[a] **“+“** indicates that a new set of experiments was initiated this week, “-“ indicates that exposures begun in the previous week were continued for a second week, and an empty cell indicates that no data were collected.

[b] No data past 8/16/96

Table 2. Analyte Mass on Airborne Concentration Field Blanks.

Sample	Zefluor		Nylasorb		Whatman		Whatman Backup		Quartz
	NO3 mass (μg)[a]	SO4 mass (μg)[b]	NO3 mass (μg)[c]	SO4 mass (μg)[d]	NO3 mass (μg)[e]	SO4 mass (μg)[f]	NO3 mass (μg)[g]	SO4 mass (μg)[h]	elemental carbon (μg)’
11/20/95-5a-blank	0.70	0.75	1.14	1.08	3.00	2.48			0[l]
I1/20/95-16a.blank	0.44	0.31	1.16	0.98	2.37	2.17			0[l]
11/20/95-42a-blank	0.98	0.90	1.34	1.24	1.20	2.32			0[l]
11/27/95-5b-blank	1.98	0.42	1.24	1.32	1.63	2.24			0[l]
1/27/95-16b-blank	1.18	0.50	1.51	0.98	0[k]	2.51			1.20
11/27/95-42b-blank	1.52	0.45	1.26	1.08	1.28	1.85			2.30
12/04/95-5a-blank	4.11	0.53	1.15	1.06	2.78	2.15			0[l]
12/04/95-16a-blank	4.13	0.61	1.22	1.13	3.69	2.29			0[l]
12/04/95-42a-blank	1.30	0.48	1.19	0.96	1.72	2.18			0[l]
12/11/95-5b-blank	1.08	0.69	0.77	0.75	2.62	1.96	1.65	2.45	0[l]
12/11/95-16b-blank	7.49	0.59	1.07	0.64	3.10	2.28	1.82	2.44	0.60
12/11/95-42b-blank	0.64	0.64	0.93	0.75	1.89	2.27	0[k]	2.18	1.50
02/01/96-5a-blank	1.51	0.64	0.64	0.66	1.85	2.91	1.82	2.77	0[l]
02/01/96-16a-blank	0.69	0.66	0.70	0.79	1.06	2.74	2.11	2.68	0[l]
02/01/96-42a-blank	1.78	0.53	0.73	0.75	0[k]	2.55	1.47	2.72	1.10
02/15/96-5b-blank	0.31	0.84	0[j]	0.78	1.89	2.02	1.96	2.30	0[l]
02/15/96-16b-blank	0.50	0.87	0.39	0.89	1.44	1.98	1.53	2.37	0[l]
02/15/96-42b-blank	0.24	0.88	0.59	0.79	1.01	2.31	0[k]	1.93	
02/22/96-5a-blank	0.48	0.86	0.24	0.77	1.78	2.11			
02/22/96-16a-blank	0.27	0.91	0[j]	0.75	1.91	2.19			0.00
02/22/96-42a-blank	0.55	0.94	0.48	0.82	0[l]	1.90			0.00
05/14/96-5a-blank	0.41	0.29	0.26	0.24	0[k]	0[k]	0[k]	0[k]	
05/14/96-16a-blank	0.39	0.36	0.24	0.22	0[k]	0[k]	0[k]	0[k]	
05/14/96-42a-blank	0.43	0.24	0.29	0.30	1.07	0[k]	0[k]	0[k]	
05/22/96-5b-blank	0[j]	0[j]	0[j]	0[j]	1.29	0[k]	1.15	0[k]	
05/22/96-16b-blank	0[j]	0[j]	0[j]	0[j]	3.70	0[k]	1.76	0[k]	
05/22/96-42b-blank	0[j]	0[j]	0[j]	0[j]	1.38	0[k]	0[k]	0[k]	
05/29/96-5a-blank	0.76	0[j]	0[j]	0[j]	0[k]	0[k]	2.83	0[k]	
05/29/96-16a-blank	0.59	0[j]	0[j]	0[j]	3.02	0[k]	4.03	0[k]	
05/29/96-42a.blank	0.64	0[j]	0[j]	0[j]	0[k]	0[k]	3.42	0[k]	
06/05/96-5b-blank	0[j]	0[j]	0.38	0.30	0[k]	0.92	0[k]	0[k]	
06/05/96-16b-blank	0[j]	0[j]	0[j]	0.24	1.41	0[k]	0[k]	0[k]	
06/05/96-42b-blank	0[j]	0[j]	0[j]	0.31	0[k]	0[k]	0[k]	0[k]	
07/24/96-5a-blank	0[j]	0.23	0[j]	0[j]	0.92	0[k]	0[k]	0[k]	
07/24/96-16a-blank	0[j]	0[j]	0[j]	0[j]	1.32	0[k]”	1.57	0.99	
07/24/96-42a-blank	0[j]	0[j]	0[j]	0[j]	0[k]	0[k]	0[k]	1.22	
07/31/96-5b-blank	0.90	0.31	0[j]	0[j]	1.63	1.92	0[k]	0[k]	
07/31/96-16b-blank	0[j]	0[j]	0[j]	0[j]	0[k]	0[k]	0[k]	0[k]	
7/31/96-42b-blank	0[j]	0.23	0[j]	0[j]	1.11	0[k]	1.19	0[k]	
08/07/96-5a-blank	1.33	0.70	0.38	1.41	1.99	2.22	2.66	1.33	
08/07/96-16a-blank	1.49	0.90	0.52	2.05	2.52	1.95	1.65	1.73	
08/07/96-42a-blank	0.65	0.65	0.53	1.68	1.52	2.05	1.36	1.58	
08/14/96-5b-blank	0[j]	0[j]	0[j]	0[j]	0[k]	0[k]	0[k]	1.27	
08/14/96-16b-blank	0[j]	0[j]	0[j]	0[j]	0[k]	1.14	0[k]	0[k]	
08/14/96-42b-blank	1.55	0[j]	0[j]	0[j]	0[k]	0[k]	0[k]	0[k]	

[a] Average NO_3 mass found on Zefluor filters was 0.92 ± 1.36 pg.

[b] Average SO_4 mass found on Zefluor filters was 0.43 ± 0.30 pg

[c] Average NO, mass found on Nylasorb filters was 0.47 ± 0.48 pg

[d] Average SO., mass found on Nylasorb filters was 0.59 ± 0.52 pg.

[e] Average NO, mass found on Whatman filters was 1.42 ± 1.00 pg.

[f] Average SO_4 mass found on Whatman filters was 1.39 ± 1.00 pg.

[g] Average NO, mass found on Whatman backup filters was 1.19 ± 1.02 pg

[h] Average SO_4 mass found on Whatman backup filters was 1.03 ± 1.00 pg

[i] Average carbon mass found on quartz filters was 0.4 ± 0.6 pg

[j] IC detection limit of 1 ppb.

[k] IC detection limit of 3 ppb.

[l] Carbon mass detection limit 0.6 μg

Table 3. Analyte Mass on Whatman Surrogate Surface Field Blanks.

Sample	NO3 mass (µg)[a]	SO4 mass (µg)[b]	Sample	NO3 mass (µg)[a]	504 mass (µg)[b]
11/20/95-5a-1-blank	1.80	2.90	05/14/96-5d-1-blank	2.77	2.63
11/20/95-5a-2-blank	1.72	1.40	05/4/96-5d-2-blank	2.50	2.72
11/20/95-5a-3-blank	2.24	1.32	05/14/96-5d-3-blank	2.61	2.83
11/20/95-5a-4-blank	1.54	1.07	05/14/96-5d-4-blank	2.55	2.66
11/20/95-16a-1-blank	1.74	2.30	05/14/96-16a-1-blank	2.11	2.77
11/20/95-16a-2-blank	2.06	2.08	05/14/96-16a-2-blank	2.09	2.72
11/20/95-16a-3-blank	2.07	2.19	05/14/96-16a-3-blank	2.11	2.82
11/20/95-16a-4-blank	1.73	1.93	05/14/96-16a-4-blank	2.40	2.66
12/04/95-5b-1-blank	1.31	0[c]	05/29/96-5b-1-blank	4.82	2.69
12/04/95-5b-2-blank	0[c]	0.96	05/29/96-5b-2-blank	4.88	2.66
12/04/95-5b-3-blank	0[c]	0[c]	05/29/96-5b-3-blank	4.07	2.68
12/04/95-5b-4-blank	0[c]	0[c]	05/29/96-5b-4-blank	4.32	2.69
12/04/95-16b-1-blank	0[c]	0[c]	05/29/96-16b-1-blank	6.62	2.82
12/04/95-16b-2-blank	0[c]	0[c]	05/29/96-16b-2-blank	4.74	2.76
12/04/95-16b-3-blank	0[c]	0[c]	05/29/96-16b-3-blank	5.33	2.85
12/04/95-16b-4-blank	0[c]	0[c]	05/29/96-16b-4-blank	5.71	2.88
02/01/96-5c-1-blank	1.40	3.86	07/24/96-5d-1-blank	3.63	4.64
02/01/96-5c-2-blank	1.48	3.67	07/24/96-5d-2-blank	3.76	4.63
02/01/96-5c-3-blank	2.92	5.92	07/24/96-5d-3-blank	3.59	4.52
02/01 /96-5c-4-blank	1.26	3.15	07/24/96-5d-4-blank	3.81	4.53
02/01/96-16c-1-blank	1.48	2.77	07/24/96-16a-1-blank	3.63	4.53
02/01/96-16c-2-blank	1.62	2.86	07/24/96-16a-2-blank	3.31	4.66
02/01/96-16c-3-blank	1.63	3.01	07/24/96-16a-3-blank	3.30	4.63
02/01/96-16c-4-blank	1.69	2.89	07/24/96-16a-4-blank	3.43	4.55
02/15/96-5a-1-blank	3.14	4.73	08/07/96-5c-1-blank	0[c]	0[c]
02/15/95-5a-2-blank	3.19	4.99	08/07/96-5c-2-blank	0[c]	0[c]
02/15/96-5a-3-blank	3.22	5.25	08/07/96-5c-3-blank	0[c]	0[c]
02/15/95-5a-4-blank	3.35	5.14	08/07/96-5c-4-blank	0[c]	0[c]
02/15/96-16a-1-blank	3.51	3.98	08/07/96-16b-1-blank	0[c]	0[c]
02/15/96-16a-2-blank	4.67	3.43	08/07/96-16b-2-blank	0[c]	0[c]
02/15/96-16a-3-blank	4.49	3.63	08/07/96-16b-3-blank	0[c]	0[c]
02/15/96-16a-4-blank	4.80	3.57	08/07/96-16b-4-blank	0[c]	0[c]

[a] Average NO$_3$ mass on vertical Whatman filters was 2.38 ± 1.64 µg

[a] Average SO$_4$ mass on vertical Whatman filters was 2.53 ± 1.66 µg

[a] IC detection limit of 4 ppb.

Table 4a. SO_4^{2-} Particle Concentrations.

Sample	**Exposure Time (hr)**	**5th floor SO4 particle conc. (μg/m^3)**	**5th floor std dev. of SO4 particle conc. (μg/m^3)**	**16th floor SO4 particle conc. (μg/m^3)**	**16th floor std dev. of SO4 particle conc. (μg/m^3)**	**Roof SO4 particle conc. (μg/m^3)**	**Roof std dev. of SO4 particle conc. (μg/m^3)**
11/20/95	165	2.45	1.35	2.48	1.34	4.58	0.85
11/27/95	168	4.23	0.17	4.41	0.38	4.45	0.32
12/4/95	168	2.64	0.06	2.76	0.14	3.11	0.06
12/11/95	170	4.22	0.02	3.96	0.47	4.03	0.29
2/1/96	173	4.66	0.19	4.64	0.27	3.35	0.27
2/8/96	163	3.54	0.25	3.13	0.39	3.46	0.08
2/15/96	169	6.61	0.13	7.13	1.12	7.79	0.03
2/22/96	167	5.09	0.86	4.94	0.50	5.33	0.43
5/14/96	192	6.69	0.72	7.47	0.47	6.35	0.30
5/22/96	164	4.17	0.09	4.51	0.38	3.i3	0.76
5/29/96	173	4.36	0.15	5.78	0.47	4.98	0.20
6/5/96	168	8.89	0.76	5.67[a]	0.48	7.36	0.26
7/24/96	166	7.32	1.94	6.64	0.11	6.55	0.11
7/31/96	171	11.37	0.04	12.58	0.01	12.79	0.60
8/7/96	166	8.66	0.18	7.94	0.00	8.09	0.00
8/14/96	167	12.25	0.45	12.11	0.39	11.65	0.33

[a] Because of a power failure, the 16th floor samples were only exposed for 131 hours.

Table 4b. NO_3 Particle Concentrations.

Sample	**Exposure Time (hr)**	**5th floor NO4 particle conc. (μg/m^3)**	**5th floor std dev. of NO4 particle conc. (μg/m^3)**	**16th floor NO4 particle conc. (μg/m^3)**	**16th floor std dev. of NO4 particle conc. (μg/m^3)**	**Roof NO4 particle conc. (μg/m^3)**	**Roof std dev. of NO4 particle conc. (μg/m^3)**
11/20/95	165	1.82	1.38	1.76	0.91	3.19	0.50
11/27/95	168	3.38	0.03	2.68	0.29	3.56	0.12
12/4/95	168	3.09	0.05	2.69	0.10	3.16	0.02
12/11/95	170	4.28	0.07	4.24	0.47	3.96	0.29
2/1/96	173	5.67	0.37	5.35	0.33	3.86	0.17
2/8/96	163	3.48	0.16	2.97	0.12	3.38	0.14
2/15/96	169	4.14	0.29	3.25	0.69	3.10	0.01
2/22/96	167	2.21	0.43	2.01	0.17	2.21	0.23
5/14/96	192	0.74	0.12	0.73	0.07	0.64	0.10
5/22/96	164	1.50	0.15	1.62	0.18	1.19	0.37
5/29/96	173	0.75	0.14	1.13	0.06	0.99	0.09
6/5/96	168	0.78	0.09	0.35[a]	0.04	0.51	0.06
7/24/96	166	0.69	0.20	0.66	0.04	0.75	0.01
7/31/96	171	0.88	0.03	0.98	0.01	0.83	0.05
8/7/96	166	0.55	0.05	0.57	0.00	0.50	0.01
8/14/96	167	0.66	0.09	0.65	0.04	0.58	0.03

[a] Because of a power failure, the 16th floor samples were only exposed for 131 hours.

Table 4c. HNO$_3$ Gas Concentrations.

Sample	Exposure Time (hr)	5th floor HNO3 gas conc. (μg/m^3)	5th floor std dev. of HNO3 gas conc. (μg/m^3)	16th floor HNO3 gas conc. (μg/m^3)	16th floor std dev. of HNO3 gas conc. (μg/m^3)	Roof HNO3 gas conc. (μg/m^3)	Roof std dev. 0 HNO3 gas conc. (μg/m^3)
11/20/95	165	1.12	0.12	1.95	0.50	1.35	0.21
11/27/95	168	1.90	0.04	2.04	0.17	1.88	0.24
12/4/95	168	1.15	0.09	1.34	0.04	1.13	0.09
21i1/95	170	0.58	0.02	0.98	0.04	0.72	0.02
2/i/96	173	1.6i	0.15	1.79	0.15	1.03	0.01
2/8/96	163	1.20	0.12	1.23	0.23	0.88	037
2/i 5/96	169	2.80	0.03	3.44	0.65	3.28	0.00
2/22/96	167	1.34	0.32	1.59	0.18	1.77	0.25
5/i 4/96	192	4.17	0.41	4.40	0.17	4.18	O.2i
5/22/96	164	3.04	0.13	3.61	0.30	2.68	0.57
5/29/96	173	313	0.07	4.35	0.80	3.15	0.04
6/5/96	168	5.96	0.49	3.58[a]	0.30	4.42	0.07
7/24/96	166	4.56	0.79	4.41	0.02	3.84	0.01
7/31/96	171	5.19	0.52	6.67	0.28	8.18	0.18
817/96	166	3.41	0.06	3.22	0.01	3.29	0.02
8/14/96	167	5.51	0.06	5.49	0.14	5.29	0.05

[a] Because of a power failure, the 16th floor samples were only exposed for 131 hours.

Table 4d. Total NO3 Concentrations[a].

Sample	Exposure Time (hr)	5th floor Total NO3 conc. (μg/m^3)	5th floor std dev. of Total NO3 conc. (μg/m^3)	16th floor Total NO3 conc. (μg/m^3)	16th floor std dev. of Total NO3 conc. (μg/m^3)	Roof Total NO3 conc. (μg/m^3)	Roof std dev. of Total NO3 conc. (μg/m^3)
11/20/95	165	2.92	1.39	3.68	1.04	4.52	0.55
11/27/95	168	5.25	0.05	4.69	0.34	5.41	0.28
12/4/95	168	4.22	0.10	4.01	0.11i	4.27	0.09
12/11/95	170	4.85	0.07	5.21	0.47	4.66	0.29
2/1/96	173	7.25	0.40	7.11	0.36	4.87	0.17
2/8/96	163	4.67	0.20	4.18	0.25	4.25	0.40
2/15/96	169	8.90	0.29	6.84	0.94	6.33	0.01
2/22/96	167	3.53	0.54	3.58	0.25	3.96	0.34
5/14/96	192	4.84	0.42	5.06	0.18	4.75	0.23
5/22/96	164	4.48	0.20	5.18	0.35	3.83	0.68
5/29/96	173	4.42	0.18	5.41	0.80	4.09	0.10
6/5/96	168	6.65	0.50	3.88c	0.30	4.86	0.09
7/24/96	166	5.18	0.81	5.01	0.05	4.53	0.02
7/31/96	171	5.98	0.52	7.54	0.28	8.92	0.18
8/7/98	168	3.91	0.08	3.73	0.01	3.73	0.02
8/14/96	167	6.08	0.11	6.06	0.14	5.79	0.06

[a] Total NO, concentration is based on NO, found on Zefluor filter and NO, found on Nylasorb filters.

[b] Because of a power failure, the 16th floor samples were only exposed for 131 hours.

Table 4e. SO_2 Gas Concentrations[a].

Sample	Exposure Time (hr)	5th floor SO2 gas conc. $(\mu g/m^3)$	5th floor std dev. of SO2 gas conc. $(\mu g/m^3)$	16th floor SO2 gas conc. $(\mu g/m^3)$	16th floor std dev. of SO2 gas conc. $(\mu g/m^3)$	Roof SO2 gas conc. $(\mu g/m^3)$	Roof std dev. a SO2 gas Conc. $(\mu g/m^3)$
11/20/95	165	24.27	9.36	31.73	7.06	36.21	0.66
11/27/95	168	27.70	3.26	33.48	0.53	27.74	1.38
12/4/95	168	30.56	1.48	34.41	2.17	35.16	0.37
2/11/95	170	23.80	1.51	26.45	2.42	26.22	2.65
211/96	173	31.96	5.32	33.22	2.16	23.84	0.99
2/8/96	163	15.95	0.81	14.05	0.78	14.36	1.39
2115/96	169	43.79	2.05	60.39	10.97	71.11	1.66
2/22/96	167	25.62	5.00	31.03	3.47	32.20	1.56
5/14/96	192	26.06	1.88	29.70	1.45	23.25	1.78
5/22/96	164	15.91	0.42	17.82	1.38	9.52	1.83
5/29/96	173	13.09	1.49	19.27	1.93	19.52	1.33
6/5/96	168	27.32	2.11	20.38[k]	1.59	20.59	2.38
7/24/96	166	15.97	3.16	13.41	3.23	15.93	0.84
7/31/96	171	17.31	1.18	22.90	0.19	26.08	2.63
8/7/96	166	20.12	0.94	20.33	0.67	16.34	0.41
8/14/96	167	19.78	0.49	20.44	0.30	21.37	0.34

[a] SO_2 concentration is based on SO_4^{-2} found on Nylasorb filters and SO42 found on Whatman filters.

[b] Because of a power failure, the 16th floor samples were only exposed for 131 hours.

Table 4f. Elemental Carbon Concentrations.

Sample	Exposure Time (hr)	5th floor elemental carbon conc. $(\mu g/m^3)$	5th floor std dev. of elemental carbon conc. $(\mu g/m^3)$	16th floor elemental carbon conc. $(\mu g/m^3)$	16th floor std dev. of elemental carbon cone. $(\mu g/m^3)$	Roof elemental carbon conc. $(\mu g/m^3)$	Roof std dev. of elemental carbon conc. $(\mu g/m^3)$
11/20/95	165	3.94	0.03	4.32	0.41	3.27	0.27
11/27/95	168	2.61	0.01	2.83	0.05	2.39	0.04
2/4/95	168	2.30	0.02	1.91	0.44	1.87	0.03
2/11/95	170	1.67	0.30	1.92	0.42	2.37	0.26
2/1/96	173	1.90	0.08	1.92	0.11	0.94	0.06
2/8/96	163	1.39	0.09	1.44	0.16	1.46	0.12
2/15/96	169	2.61	0.00	2.79	0.07	2.73	0.31
2/22/96	167	3.49	0.12	3.26	0.50	2.71	0.18

Table 5. SO2 Fluxes and Deposition Velocities.

Sample	Exposure time (hr)	SO2 flux (µg/cm$^{2/}$day)	SO2 flux std. dev. (µg/cm^2/day)	Average SO2 conc (µg/m^3)	SO2 conc std. dev. (µg/rn^3)	SO2 deposition velocity (cm/s)	SO2 deposition velocity std. dev. (cm/s)
11/20/95-5a	332	1672	43.3	26.0	5.0	0.74	0.19
11/20/95-5b	332	1606	75.7	26.0	5.0	022	0.20
11/20/95-Sc	332	1667	46.1	26.0	5.0	0.74	0.19
11/20/95-5d	332	1376	54.9	26.0	5.0	0.61	0.19
11/20/95-5e	332	1387	6.8	26.0	5.0	0.62	0.19
11/20/95-5f	332	2004	45.3	26.0	5.0	0.89	0.19
11/20/95-16a	332	2902	183.6	32.6	3.5	1.03	0.13
11/20/95-16b	332	2152	68.4	32.6	3.5	0.76	0.11
11/20/95-16c	332	2691	67.6	32.6	3.5	0.96	0.11
12/04/95-5a	338	1846	25.0	27.2	1.1	0.79	0.04
12/04195-5b	338	1725	76.8	27.2	1.1	023	0.06
12/04/95-5c	338	1748	79.0	27.2	1.1	024	0.06
2/04/95-5d	338	1622	100.8	27.2	1.1	0.69	0.07
2/04/95-5e	338	1579	26.2	27.2	1.1	0.67	0.04
2/04/95-5f	338	1817	401	27.2	1.1	0.77	0.04
2/04/95-16a	338	2481	86.6	30.4	1.6	0.94	0.06
2/04195-16b	338	1811	72.1	30.4	1.6	0.69	0.07
2/04/95-16c	338	2335	37.8	30.4	1.6	0.89	0.06
2/01/96-5a	336	1555	42.6	24.0	2.7	0.75	0.12
2/01/96-5b	336	1377	35.5	24.0	2.7	0.67	0.12
2/01/96-5c	336	1259	163	24.0	2.7	0.61	0.11
2/01/96-5d	336	1322	25.5	24.0	2.7	0.64	0.11
2/01/96-5e	336	1330	38.2	24.0	2.7	0.64	0.12
2/01/96-5f	336	2012	92.0	24.0	2.7	0.97	0.12
2/01/96-16a	336	1960	251.7	23.6	1.1	0.96	0.14
2/01/96-16b	336	1SS6	192.2	23.6	1.1	0.76	0.13
2/01/96-16c	336	1786	104.9	23.6	1.1	0.87	0.08
2/15/96-5a	336	2187	95.6	34.7	2.7	0.73	0.09
2/15/96-5b	336	1741	163.9	341	2.7	0.58	0.12
2/15/96-5c	336	1749	107.9	341	21	0.58	0.10
2/15/96-5d[3]	336						
2/15/96-5e	336	1833	82.2	34.7	21	0.61	0.09

Table 5. SO$_2$ Fluxes and Deposition Velocities (continued).

Sample	Exposure time (hr)	SO2 flux (μg/cm$^{2/}$day)	SO2 flux std. dev. (μg/cm^2/day)	Average SO2 conc (μg/m^3)	SO2 conc std. dev. (μg/m^3)	SO2 deposition velocity (cm/s)	SO2 deposition velocity std. dev. (cm/s)
02/15/96-5f	336	2060	281.2	34.7	2.7	0.69	0.16
02/15/96-16a	336	2977	202.0	45.7	5.8	0.75	0.14
02/15/96-16b	336	2003	284.5	45.7	5.8	0.51	0.19
02/15/96-16c	336	2890	211.4	45.7	5.8	0.73	0.15
05/14/96-5a	356	1319	38.7	21.0	1.0	0.73	0.05
05/14/96-5b	356	1381	28.2	21.0	1.0	0.76	0.05
05/14/96-5c	356	1392	69.5	21.0	1.0	017	0.07
05/14/96-5d	356	1266	35.9	21.0	1.0	0.70	0.05
05/14/96-5e	356	1349	25.7	21.0	1.0	0.74	0.05
05/14/96-5f	356	1524	117.0	21.0	1.0	0.84	0.09
05/14/96-16a	358	2378	200.4	23.8	1.0	1.16	0.09
05/14/96-16b	358	1352	116.2	23.8	1.0	0.66	0.10
05/14/96-16c	358	961	101.6	23.8	1.0	0.47	0.11
05/29/96-5a	341	1438	81.9	20.2	1.3	0.82	0.09
05/29/96-5b	341	1277	40.1	20.2	1.3	033	0.07
05/29/96-5c	341	1439	63.5	20.2	.3	0.82	0.08
05/29/96-5d	341	1131	38.6	20.2	.3	0.6S	0.07
05/29/96-5e	341	1135	67.5	20.2	.3	0.6S	0.09
05/29/96-5f	341	1S03	10.7	20.2	.3	0.86	0.06
05/29/96-16a	340	2327	99.8	19.8	1.2	136	0.08
05/29/96-16b	340	168S	92.9	19.8	1.2	0.98	0.08
05/29/96-16c	340	2318	49.6	19.8	1.2	1.35	0.07
07/24/96-5a	336	1037	31.9	16.6	1.7	032	0.11
07/24/96-5b	336	929	23.8	16.6	1.7	0.65	0.10
07/24/96-5c	336	974	42.2	16.6	1.7	0.68	0.11
07/24/96-5d	336	810	45.5	16.6	1.7	0.56	0.12
07/24/96-5e	336	887	32.S	16.6	1.7	0.62	0.11
07/24/96-5f	336	1097	33.2	16.6	1.7	016	0.11
07/24/96-16a	336	1412	45.5	18.2	1.6	0.90	0.09
07/24/96-16b	336	1263	27.4	18.2	1.6	0.81	0.09
07/24/96-16c	336	1034	96.9	18.2	1.6	0.66	0.13
08/07/96-5a	333	984	58.8	19.9	0.S	0.57	0.07

Table 5. SO_2 Fluxes and Deposition Velocities (continued).

Sample	**Exposure time (hr)**	**SO2 flux (μg/crn^2/day)**	**SO2 flux std. dev. (μg/cm^2/day)**	**Average SO2 conc (μg/m^3)**	**SO2 conc std.dev. (μg/m^3)**	**SO2 deposition velocity (cm/s)**	**SO2 deposition velocity std. dev. (cm/s)**
08/07/96-5b	333	879	48.9	19.9	0.5	0.51	0.06
08/07/96-5c	333	921	57.7	19.9	0.5	0.53	0.07
08/07/96-5d	333	800	25.0	19.9	0.5	0.46	0.04
08/07/96-5e	333	819	25.8	19.9	0.5	0.47	0.04
08/07/96-5f	333	1061	38.3	19.9	0.5	0.62	0.04
08/07/96-16a	333	1378	56.8	20.4	0.4	0.78	0.04
08/07/96-16b	333	1066	36.8	20.4	0.4	0.61	0.04
08/07/96-16c	333	1258	19.0	20.4	0.4	0.71	0.02

[a] Sample was lost during the exposure period.

Table 6. 5th floor and 16th Floor Laser Particle Count Averages for >0.5 µm and > µm Size Ranges.

Sampling Period	15th floor LPC >0.5 µm		16th floor IPC >0.5 µm		5th floor LPC >5 µm		16th floor LPC>5 µm	
	Average (part/cm^3)	Std. dev. (part/cm^3)	Average (part/cm^3)	Std. dev. (part/cm^3)	Average (part/cm^3)	Std. dev. (part/cm^3)	Average (part/cm^3)	Std. dev. (part/cm^3)
2/8/96	18.7E+0	17.1E+0	17.9E+0	15.2E+0	8.0E-3	7.9E-3	9.9E-3	8.5E-3
2/15196	20.0E+0	18.8E+0	20.6E-t-0	16.7E+0	22.4E-3	107.9E-3	38.1E-3	275.3E-3
2/22/96	25.0E+0	22.9Ei-0	22.0E+0	17.0E+0	188.5E-3	1.3E+0	137.4E-3	827.5E-3
5/22/96	10.8E+0	11.7E+0	12.5E-t-0	12.3E+0	7.1E-3	12.1E-3	15.6E-3	27.6E-3
5/29/96	11.5E+0	9.2E-t-0	13.3Ei-0	10.3E+0	5.7E-3	8.3E-3	8.4E-3	11.1 E-3
6/5/96	14.2E+0	11.6E+0	8.6E+0	9.2E+0	6.2E-3	11 .0E-3	5.0E-3	10.0E-3
7/24/96	12.1 E+0	10.2E-f0	14.8E+0	11.1E+0	2.3E-3	13.4E-3	4.1E-3	8.7E-3
7/31/96	21.6E+0	18.2E+0	23.0E+0	15.7E+0	2.4E-3	2.0E-3	4.9E-3	3.5E-3
8/7/96	19.4E+0	16.5E+0	24.6E+0	15.5E+0	3.0E-3	4.5E-3	11.1E-3	110.9E-3

Figure 1. Sampling Sites at the Cathedral of Learning.

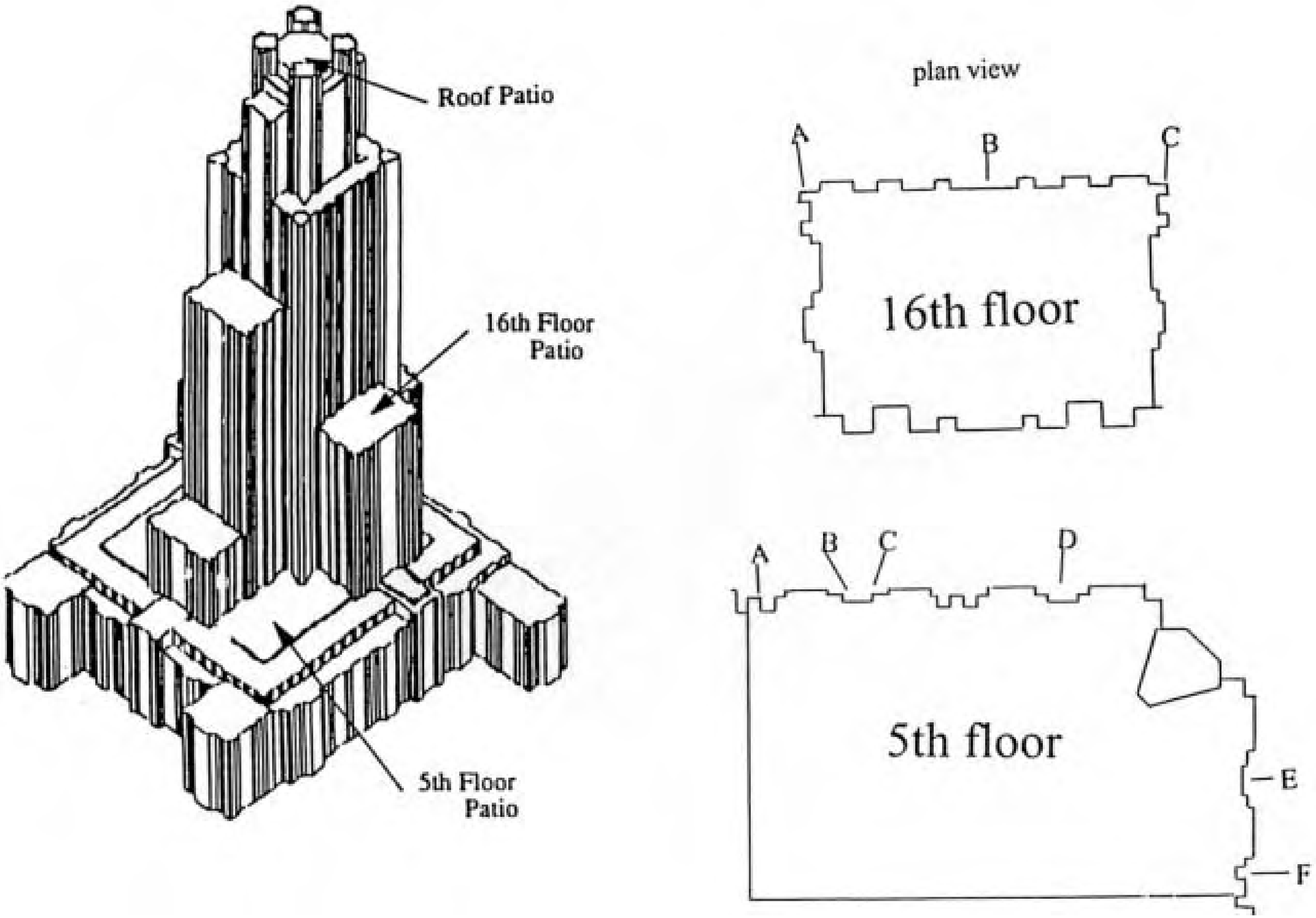


Figure 2. Schematic of a Vertical Deposition Sheet and Rainshield

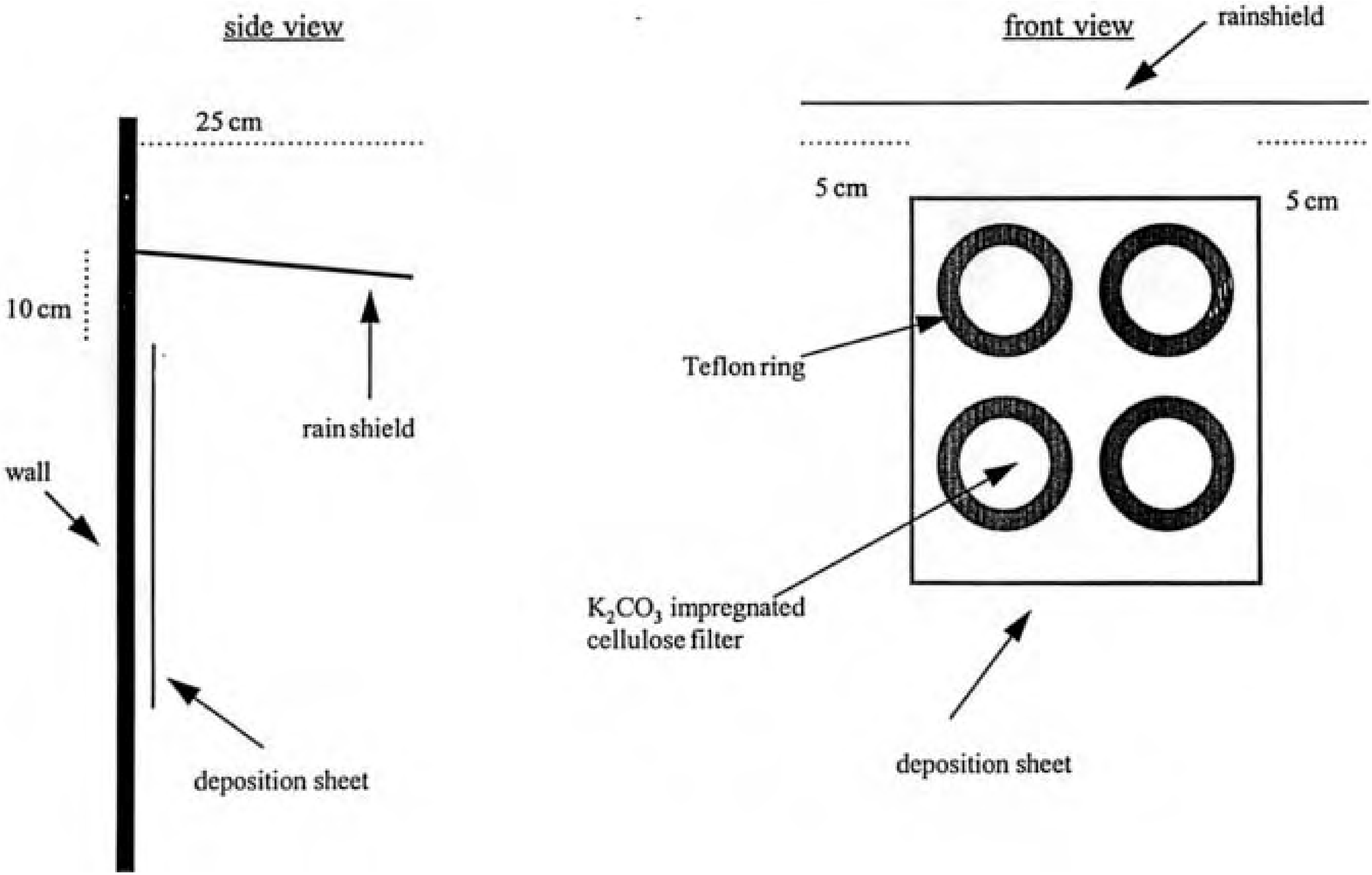


Figure 3. Concentrations Averaged Over All Four Seasons.

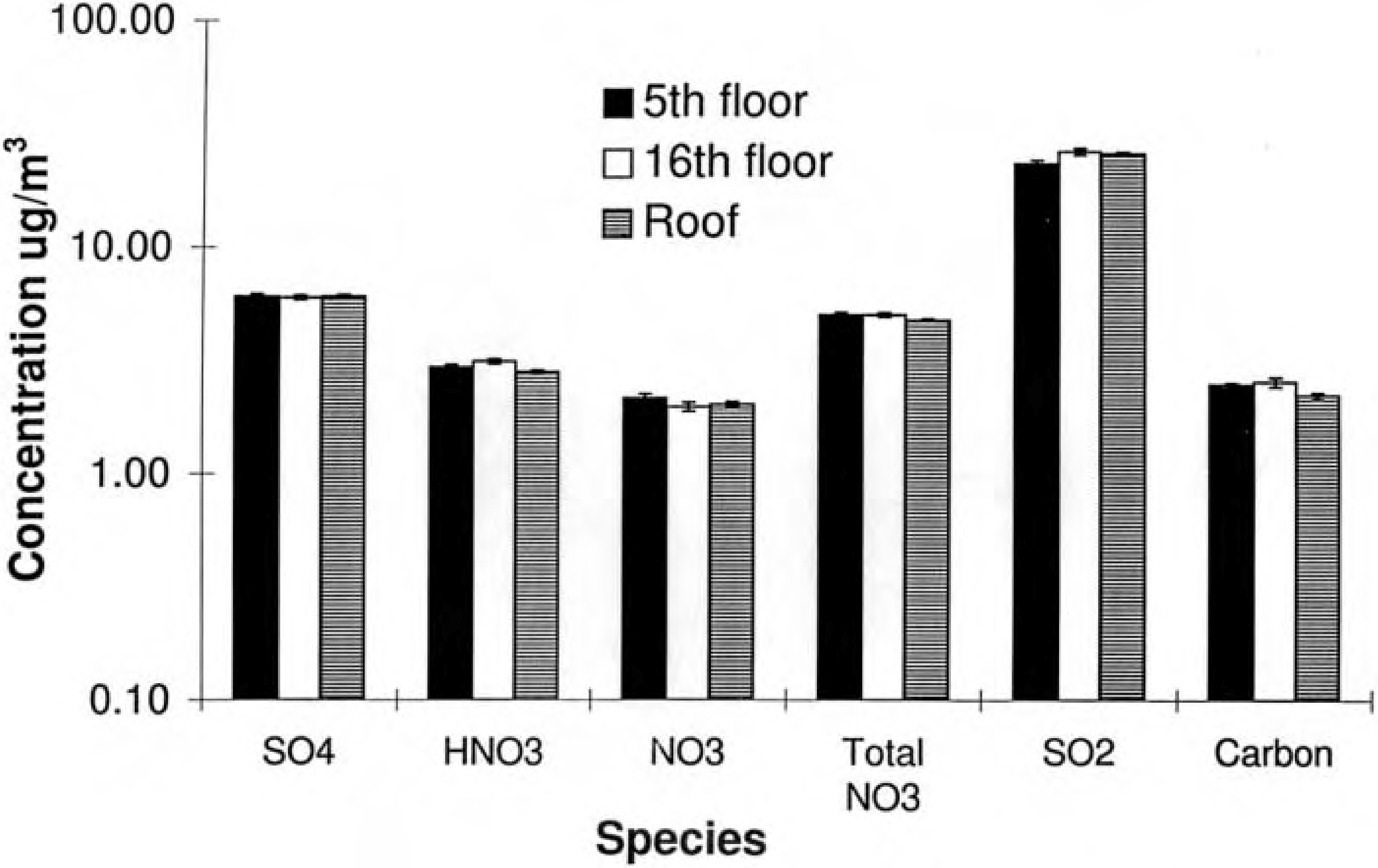


Figure 4. Seasonal Concentrations Averaged Over the Three Sampling Locations.

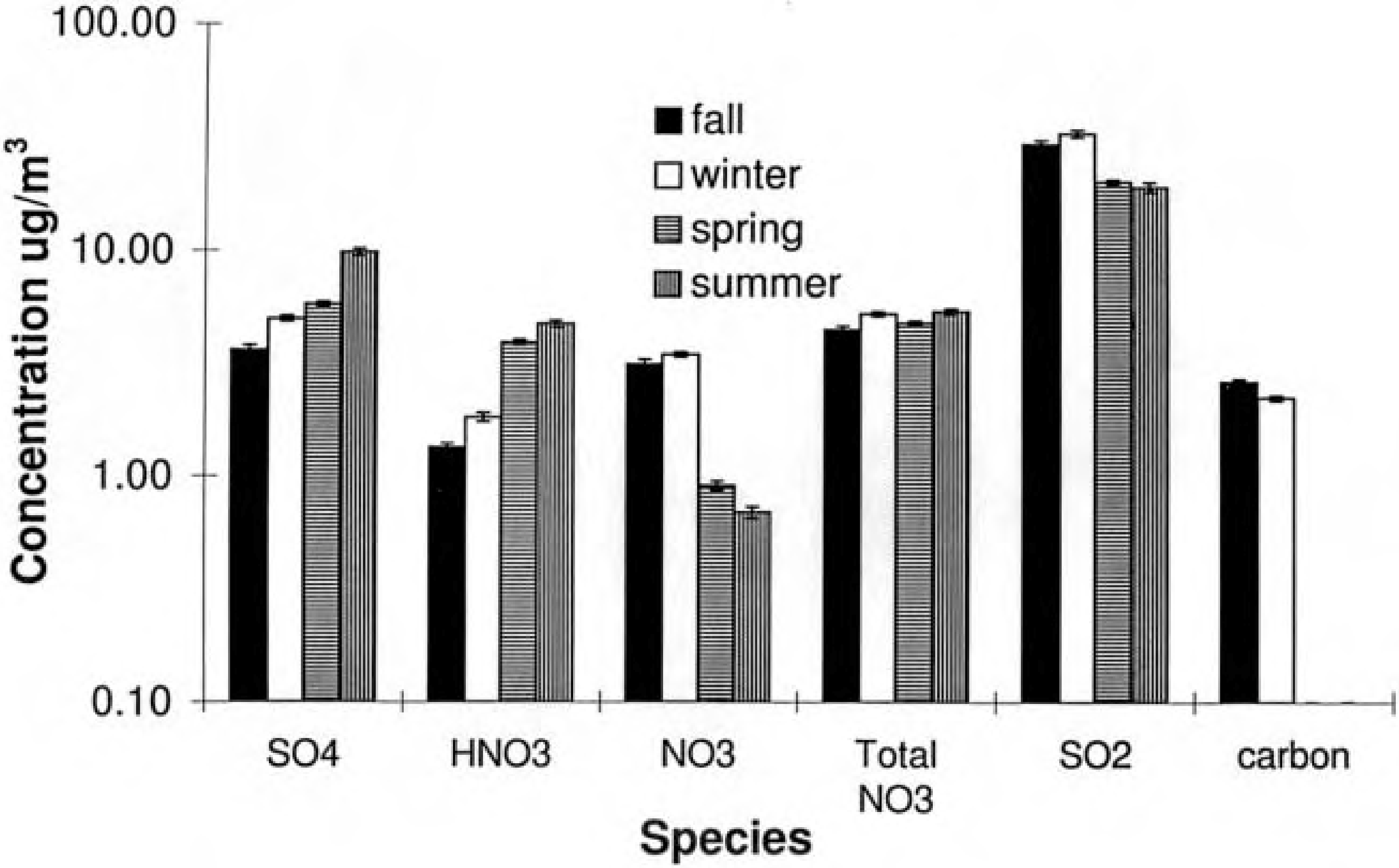


Figure 5. SO_2 Deposition Fluxes.

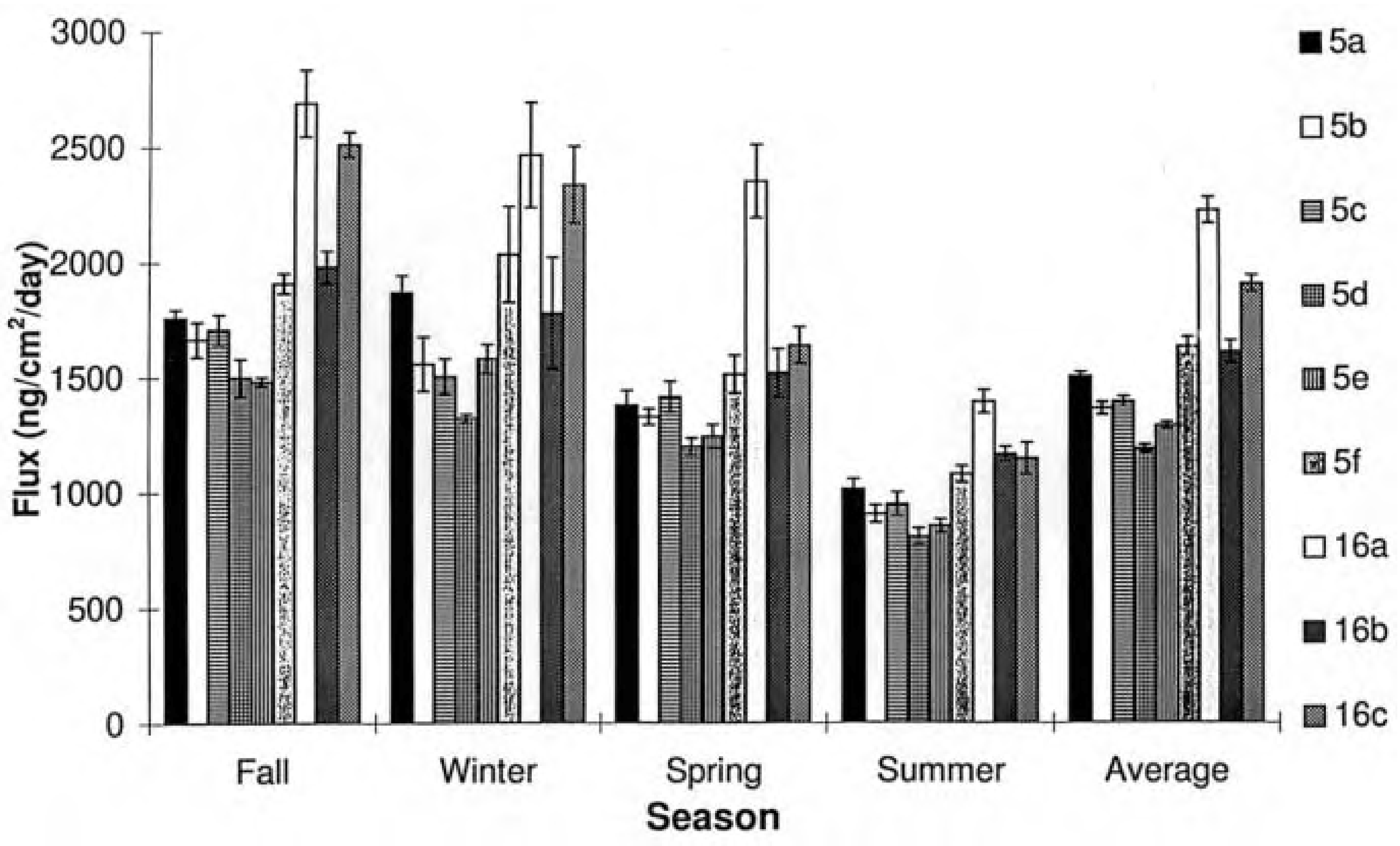
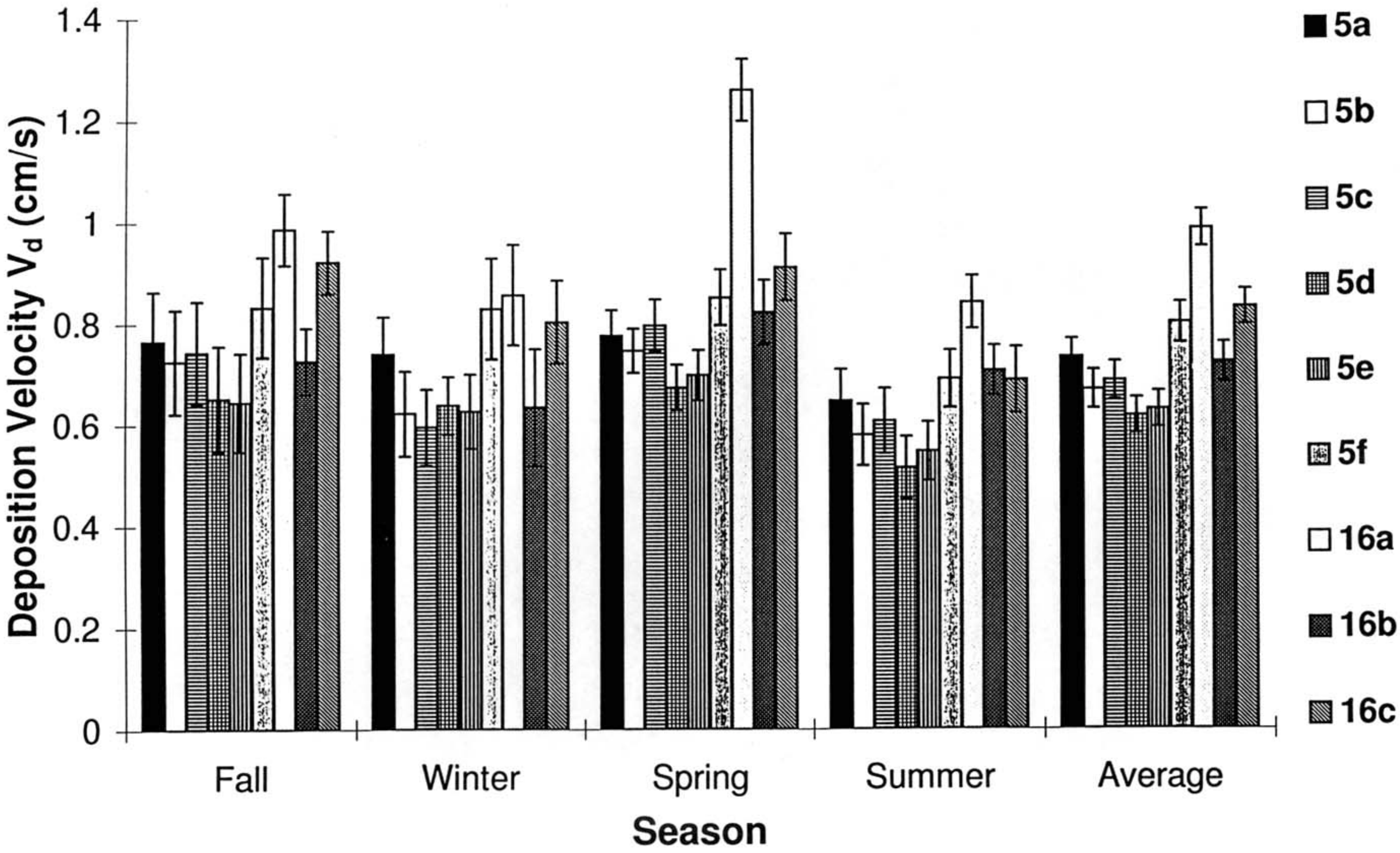


Figure 6. SO_2 Deposition Velocities.



Appendix A

Tables of Data for Airborne Concentrations and Vertical Deposition Fluxes

Table A.1. NO_3 Airborne Concentrations on Zefluor Filters.

Sample	Time (hr)	Flow rate (L/min)	NO_3 mass (μg)	NO_3 mass std. dev. (μg)[a]	Net NO_3 mass (μg)[b]	Net NO_3 mass std. dev. (μg)	NO_3 conc. (μg/m^3)	NO_3 conc. std. dev. (μg/m^3)	Ave NO_3 conc. (μg/m^3)	Ave NO_3 conc. std. dev. (μg/m^3)[C]
11/20/95-5a	165	0.83	7.85	0.42	6.93	1.42	0.85	0.17	1.82	1.38
11/20/95-5b	165	1.10	31.34	0.17	30.42	1.37	2.80	0.13		
11/20/95-16a	166	0.33	4.58	0.10	3.66	1.36	1.11	0.41	1.76	0.91
11/20/95-16b	166	0.78	19.60	0.76	18.68	1.55	2.40	0.20		
11/20/95-42a	169	0.99	29.22	1.68	28.30	2.16	2.83	0.22	3.19	0.50
11/20/95-42b	169	0.90	33.28	1.64	32.36	2.13	3.55	0.23		
11/27/95-5a	168	0.87	30.27	1.57	29.35	2.08	3.36	0.24	3.38	0.03
11/27/95-5b	168	1.06	37.44	1.55	36.52	2.06	3.40	0.19		
11/27/95-16a	166	0.84	23.42	0.05	22.50	1.36	2.68	0.16	2.68	0.29
11/27/95-16bd										
11/27/95-42a	163	0.80	29.44	2.32	28.52	2.69	3.64	0.34	3.56	0.12
11/27/95-42b	163	1.00	34.97	2.09	34.05	2.49	3.47	0.25		
12/04/95-5a	168	1.02	32.94	0.92	32.02	1.64	3.12	0.16	3.09	0.05
12/04/95-5b	168	1.06	33.41	0.22	32.49	1.37	3.05	0.13		
12/04/95-16a	171	0.84	23.27	0.19	22.35	1.37	2.62	0.16	2.69	0.10
12/04/95-16b	171	0.70	20.62	0.62	19.70	1.49	2.76	0.21		
12/04/95-42a	172	0.94	31.38	0.27	30.46	1.38	3.15	0.14	3.16	0.02
12/04/95-42b	172	0.97	32.61	0.21	31.69	1.37	3.17	0.14		
12/11/95-5a	170	1.05	46.32	1.54	45.40	2.05	4.23	0.19	4.28	0.07
12/11/95-5b	170	1.01	45.54	2.22	44.62	2.60	4.32	0.25		
12/11/95-16a	166	0.85	39.65	0.59	38.73	1.48	4.58	0.17	4.24	0.47
12/11/95-16b	166	0.72	29.08	1.62	28.16	2.11	3.91	0.29		
12/11/95-42a	167	1.04	44.33	1.67	43.41	2.15	4.16	0.21	3.96	0.29
12/11/95-42b	167	1.07	41.28	1.85	40.36	2.30	3.75	0.21		
02/01/96-5a	173	1.00	57.43	4.05	56.51	4.27	5.41	0.41	5.67	0.37

Table A.1. NO_3 Airborne Concentrations on Zefluor Filters (continued).

Sample	Time (hr)	Flow rate (L/min)	NO3 mass (μg)	NO3 mass std. dev. (μg)[a]	Net NO3 mass (μg)[b]	Net NO3 mass std. Dev (μg)	NO3 conc. (μg/m^3)	NO3 conc. std. dev. (μg/m^3)	Ave NO3 conc. (μg/m^3)	Ave NO3 conc. std. dev. (μg/m^3)C
02/01/96-5b	173	0.89	55.86	3.43	54.94	3.68	5.93	0.40		
02/01/96-16a	172	0.73	43.14	3.72	42.22	3.96	5.58	0.52	5.35	0.33
02/01/96-16b	172	0.85	45.89	3.53	44.96	3.78	5.12	0.43		.
02/01/96-42a	169	0.89	36.69	1.02	35.77	1.69	3.98	0.19	3.86	0.17
02/01/96-42b	169	0.97	37.86	0.16	36.94	1.36	3.74	0.14		
02/08/96-5a	163	0.87	31.48	0.29	30.56	1.39	3.60	0.16	3.48	0.16
02/08/96-5b	163	0.93	31.46	0.03	30.54	1.36	3.37	0.15		
02/08/96-16a	164	0.55	17.31	0.54	16.39	1.46	3.05	0.27	2.97	0.12
02/08/96-16b	164	1.01	29.63	0.11	28.70	1.36	2.88	0.14		
02/08/96-42a	166	0.77	26.04	0.38	25.12	1.41	3.28	0.18	3.38	0.14
02/08/96-42b	166	0.99	35.02	0.35	34.10	1.40	3.47	0.14		
02/15/96-5a	169	0.83	33.93	0.56	33.01	1.47	3.94	0.17	4.14	0.29
02/15196-5b	169	0.86	38.96	0.83	38.04	1.59	4.35	0.18		
02/15/96-16a	168	0.74	28.67	0.14	27.75	1.36	3.74	0.18	3.25	0.69
02/15/96-16b	168	0.86	24.89	1.35	23.97	1.92	2.77	0.22		
02/15/96-42a	167	1.12	35.74	1.39	34.82	1.94	3.09	0.17	3.10	0.01
02/15/96-42b	167	0.85	27.47	0.91	26.55	1.63	3.11	0.19		
02/22/96-5a	167	0.74	15.10	1.00	14.18	1.68	1.91	0.23	2.21	0.43
02/22/96-5b	167	0.81	21.38	1.07	20.46	1.73	2.52	0.21		
02/22/96-16a	168	0.63	12.96	0.18	12.04	1.37	1.89	0.21	2.01	0.17
02/22/96-16b	168	0.77	17.43	1.10	16.51	1.74	2.14	0.23		
02/22/96-42a	169	1.02	22.19	0.51	21.27	1.45	2.05	0.14	2.21	0.23
02/22/96-42b	169	0.70	17.80	0.40	16.88	1.41	2.37	0.20		
05/14/96-5a	192	0.94	9.85	0.33	8.93	1.40	0.82	0.13	0.74	0.12
05/14/96-5b	192	0.82	7.08	0.23	6.16	1.38	0.65	0.15		

Table A.1. NO_3 Airborne Concentrations on Zefluor Filters (continued).

Sample	Time (hr)	Flow rate (L/min)	NO3 mass (µg)	NO3 mass std. dev. (µg)[a]	Net NO3 mass (µg)[b]	Net NO3 mass std. dev. (µg)	NO3 conc. (µg/m^3)	NO3 conc. std. dev. (µg/m^3)	Ave NO3 conc. (µg/m^3)	Ave NO3 conc. std. dev. (µg/m^3)[C]
05/14/96-16a	193	0.84	7.56	0.38	6.64	1.41	0.68	0.14	0.73	0.07
05/14/96-16b	193	0.78	7.96	0.46	7.04	1.43	0.78	0.16		
05/14/96-42a	193	1.09	9.94	0.56	9.02	1.47	0.71	0.12	0.64	0.10
05/14/96-42b	193	0.96	7.19	0.44	6.27	1.43	0.56	0.13		
05/22/96-5a	164	0.77	11.44	0.48	10.52	1.44	1.39	0.19	1.50	0.15
05/22/96-5b	164	0.73	12.52	0.55	11.60	1.46	1.60	0.20		
05/22/96-16a	166	0.44	8.03	0.04	7.11	1.36	1.62	0.31	1.62	0.18
05/22/96-16b[d]										
05/22/96-42a	165	0.60	9.46	0.14	8.54	1.36	1.45	0.23	1.19	0.37
05/22/96-42b	165	0.88	9.02	0.30	8.09	1.39	0.93	0.16		
05/29/96-5a	173	0.48	5.14	0.45	4.22	1.43	0.85	0.29	0.75	0.14
05/29/96-5b	173	0.42	3.75	0.20	2.83	1.37	0.64	0.31		
05/29/96-16a	159	0.87	9.86	0.69	8.94	1.52	1.08	0.18	1.13	0.06
05/29/96-16b	159	0.56	7.19	0.80	6.27	1.58	.17	0.29		
05/29/96-42a	171	1.19	13.73	0.65	12.81	1.50	1.05	0.12	0.99	0.09
05/29/96-42b	171	0.97	10.12	0.50	9.20	1.44	0.93	0.15		
06/05/96-5a	168	0.50	4.87	0.58	3.95	1.47	0.78	0.29	0.78	0.09
06/05/96-5b[d]										
06/05/96-16a[e]	131	0.90	3.41	0.37	2.49	1.41	0.35	0.20	0.35	0.04
06/05/96-16b[d]										
06/05/96-42a	167	0.95	6.18	0.80	5.26	1.58	0.55	0.16	0.51	0.06
06/05/96-42b	167	0.86	4.94	0.34	4.02	1.40	0.47	0.16		
07/24/96-5a	166	0.83	5.49	0.08	4.57	1.36	0.55	0.16	0.69	0.20
07/24/96-5b	166	0.85	7.95	0.24	7.03	1.38	0.83	0.16		

Table A. 1. NO_3 Airborne Concentrations on Zefluor Filters (continued).

Sample	Time (hr)	Flow rate (L/min)	NO_3 mass (µg)	NO_3 mass std. dev. (µg)[a]	Net NO_3 mass (µg)[b]	Net NO_3 mass std. dev. (µg)	NO_3 conc. (µg/m^3)	NO_3 conc. std. dev. (µg/m^3)	Ave NO_3 conc. (µg/m^3)	Ave NO_3 conc. std. dev. (µg/m^3)[C]
07/24/96-16b	166	1.14	8.13	0.86	7.21	1.60	0.63	0.14		
07/24/96-42a	165	1.17	9.56	0.63	8.64	1.50	0.75	0.13	0.75	0.01
07/24/96-42b	165	1.19	9.81	0.07	8.89	1.36	0.76	0.12		
07/31/96-5a	171	1.75	7.82	0.21	6.90	1.37	0.90	0.18	0.88	0.03
07/31/96-5b	171	1.07	10.30	0.71	9.38	1.53	0.85	0.14		
07/31/96-16a	158	1.22	12.22	1.05	11.30	1.72	0.97	0.15	0.98	0.01
07/31/96-16b	158	1.22	12.29	0.82	11.37	1.59	0.98	0.14		
07/31/96-42a	159	1.16	10.47	0.37	9.55	1.41	0.86	0.13	0.83	0.05
7/31/96-42b	159	1.27	10.61	0.60	9.69	1.48	0.80	0.12		
8/07/96-5a	166	0.75	4.78	0.30	3.86	1.39	0.52	0.19	0.55	0.05
08/07/96-5b	166	1.08	7.24	0.23	6.32	1.38	0.59	0.13		
08/07/96-16a	179	1.20	8.22	0.16	7.30	1.36	0.56	0.11	0.57	0.00
08/07/96-16b	179	1.22	8.40	0.04	7.48	1.36	0.57	0.10		
08/07/96-42a	182	1.18	7.38	0.04	6.46	1.36	0.50	0.11	0.50	0.01
08/07/96-42b	182	1.21	7.39	0.03	6.47	1.36	0.49	0.10		
08/14/96-5a	167	0.71	5.14	0.33	4.22	1.40	0.59	0.20	0.66	0.09
08/14/96-5b	167	0.98	8.00	0.17	7.08	1.37	0.72	014		
08114/96-16a	166	1.11	8.47	0.00	7.55	1.36	0.68	0.12	0.65	0.04
08/14/96-16b	166	1.15	8.07	0.02	7.15	1.36	0.63	0.12		
08/14/96-42a	163	1.16	7.22	0.08	6.30	1.36	0.56	0.12	0.58	0.03
08/14/96-42b	163	1.18	7.85	0.17	6.93	1.37	0.60	0.12		

[a] The % standard deviation from IC replication is 4.2%.

[b] The subtracted blank mass is 0.92 ± 1.36 µg.

[c] The average % standard deviation from adjacent replicates was 10.9%

[d] Sample lost due to leak in sampling line.

[e] Sample was only exposed for 131 hours due to a power failure.

Table A.2. SO$_4$ Airborne Concentrations on Zefluor Filters.

Sample	Time (hr)	Flow rate (L/min)	SO$_4$ mass (µg)	SO$_4$ mass std. dev. (µg)[a]	Net SO$_4$ mass (µg)[b]	Net SO$_4$ mass std. dev. (µg)	SO$_4$ conc. (µg/m^3)	SO$_4$ conc. std. dev. (µg/m^3)	Ave SO$_4$ conc. (µg/m^3)	Ave SO$_4$ conc. std. dev. (µg/m^3)C
1/20/95-5a	165	0.83	12.68	0.46	12.25	0.55	1.50	0.07	2.45	1.35
1/20/95-5b	165	1.10	37.32	2.31	36.89	2.33	3.40	0.21		
1/20/95-16a	166	0.33	5.46	0.17	5.03	0.35	1.53	0.11	2.48	1.34
11/20/95-16b	166	0.78	27.10	1.09	26.67	1.13	3.43	0.15		
1/20/95-42a	169	0.99	40.14	0.90	39.71	0.95	3.98	0.09	4.58	0.85
1/20/95-42b	169	0.90	47.66	0.65	47.23	0.72	5.18	0.08		
11/27/95-5a	168	0.87	38.45	0.73	38.02	0.79	4.36	0.09	4.23	0.17
11/27/95-5b	168	1.06	44.55	1.55	44.12	1.58	4.11	0.15		
11/27/95-16a	166	0.84	37.51	2.63	37.08	2.64	4.41	0.31	4.41	0.38
11/27/95-16b[d]										
11 /27/95-42a	163	0.80	33.52	1.35	33.09	1.39	4.23	0.18	4.45	0.32
11/27/95-42b	163	1.00	46.21	0.84	45.78	0.89	4.67	0.09		
12/04/95-5a	168	1.02	27.10	0.50	26.66	0.58	2.60	0.06	2.64	0.06
12/04/95-5b	168	1.06	29.01	0.89	28.58	0.94	2.69	0.09		
12/04/95-16a	171	0.84	23.20	0.56	22.77	0.64	2.66	0.07	2.76	0.14
12/04/95-16b	171	0.70	20.87	0.33	20.44	0.45	2.86	0.06		
12/04/95-42a	172	0.94	30.08	0.96	29.65	1.01	3.07	0.10	3.11	0.06
12/04/95-42b	172	0.97	31.88	0.90	31.45	0.95	3.15	0.09		
12/11/95-5a	170	1.05	45.55	0.55	45.12	0.63	4.21	0.06	4.22	0.02
12/11/95-5b	170	1.01	44.08	1.04	43.65	1.08	4.23	0.10		
12/11/95-16a	166	0.85	36.77	0.30	36.34	0.43	4.29	0.05	3.96	0.47
12/11/95-16b	166	0.72	26.59	1.94	26.16	1.96	3.63	0.27		
12/11/95-42a	167	1.04	44.60	0.35	44.17	0.46	4.23	0.04	4.03	0.29
12/11/95-42b	167	1.07	41.52	0.22	41.08	0.38	3.82	0.04	.	
02/01/96-5a	1.73	1.00	47.73	2.19	47.30	2.21	4.53	0.21	4.66	0.19

Table A.2. SO_4 Airborne Concentrations on Zefluor Filters (continued).

Sample	Time (hr)	Flow rate (L/min)	SO_4 mass (μg)	SO_4 mass std. dev. (μg)[a]	Net SO_4 mass (μg)[b]	Net SO_4 mass std. dev. (μg)	SO_4 conc. (μg/m^3)	SO_4 conc. std. dev. (μg/m^3)	Ave SO_4 conc. (μg/m^3)	Ave SO_4 conc. std. dev. (μg/m3)[C]
02/01/96-5b	173	0.89	44.85	4.18	44.42	4.19	4.80	0.45		
02/01/96-16a	172	0.73	36.97	2.86	36.54	2.88	4.83	0.38	4.64	0.27
02/01/96-16b	172	0.85	39.57	2.49	39.14	2.51	4.45	0.29		
02/01/96-42a	169	0.89	32.30	1.48	31.87	1.52	3.54	0.17	3.35	0.27
02/01/96-42b	169	0.97	31.69	0.22	31.26	0.37	3.16	0.04		
02/08/96-5a	163	0.87	32.02	1.60	31.59	1.63	3.72	0.19	3.54	0.25
02/08/96-5b	163	0.93	30.97	2.11	30.54	2.13	3.37	0.23		
02/08/96-16a	164	0.55	18.71	1.47	18.28	1.50	3.40	0.28	3.13	0.39
02/08/96-16b	164	1.01	28.81	1.78	28.38	1.81	2.85	0.18		
02/08/96-42a	166	0.77	26.54	1.87	26.11	1.89	3.41	0.25	3.46	0.08
02/08/96-42b	166	0.99	34.94	1.78	34.51	1.81	3.52	0.18		
02/15/96-5a	169	0.83	54.98	1.34	54.55	1.37	6.51	0.16	6.61	0.13
02/15/96-5b	169	0.86	59.05	1.66	58.62	1.69	6.70	0.19		
02/15/96-16a	168	0.74	59.20	1.93	58.77	1.95	7.92	0.26	7.13	1.12
02/15/96-16b	168	0.86	55.24	2.28	54.81	2.30	6.33	0.27		
02/15/96-42a	167	1.12	88.02	0.44	87.59	0.53	7.77	0.05	7.79	0.03
02/15/96-42b	167	0.85	67.21	1.89	66.78	1.91	7.82	0.22		
02/22/96-5a	167	0.74	33.77	0.96	33.34	1.00	4.48	0.14	5.09	0.86
02/22/96-5b	167	0.81	46.77	0.81	46.34	0.87	5.70	0.11		
02/22/96-16a	168	0.63	29.63	2.08	29.20	2.11	4.59	0.33	4.94	0.50
02/22/96-16b	168	0.77	41.34	2.50	40.91	2.52	5.30	0.33		
02/22/96-42a	169	1.02	52.54	1.04	52.11	1.09	5.03	0.10	5.33	0.43
02/22/96-42b	169	0.70	40.52	1.80	40.09	1.83	5.64	0.26		
05/14/96-5a	192	0.94	78.79	0.55	78.35	0.63	7.20	0.06	6.69	0.72
05/14/96-5b	192	0.82	58.95	0.73	58.52	0.79	6.18	0.08		

Table A.2. SO$_4$ Airborne Concentrations on Zefluor Filters (continued).

Sample	Time (hr)	Flow rate (L/min)	SO$_4$ mass (µg)	SO$_4$ mass std. dev. (µg)[a]	Net SO$_4$ mass (µg)[b]	Net SO$_4$ mass std. dev. (µg)	SO$_4$ conc. (µg/m^3)	SO$_4$ conc. std. dev. (µg/m^3)	Ave SO$_4$ conc. (µg/m^3)	Ave SO$_4$ conc. std. dev. (µg/m^3)C
05/14/96-16a	193	0.84	69.88	1.70	69.45	173	7.13	0.18	7.47	0.47
05/14/96-16b	193	0.78	71.01	1.35	70.58	1.39	7.80	0.15		
05/14/96-42a	193	1.09	83.66	2.06	83.23	2.09	6.57	0.16	6.35	0.30
05/14/96-42b	193	0.96	68.68	1.43	68.25	1.46	6.14	0.13		
05/22/96-5a	164	0.77	31.62	0.46	31.19	0.55	4.11	0.07	4.17	0.09
05/22/96-5b	164	0.73	31.03	0.51	30.60	0.59	4.23	0.08		
05/22/96-16a	166	0.44	20.18	0.57	19.75	0.65	4.51	0.15	4.51	0.38
05/22/96-16b[d]										
05/22/96-42a	165	0.60	22.07	0.32	21.64	0.44	3.67	0.07	3.13	0.76
05/22/96-42b	165	0.88	23.11	0.00	22.68	0.30	2.59	0.03		
05/29/96-5a	173	0.48	22.69	1.05	22.25	1.09	4.46	0.22	4.36	0.15
05/29/96-5b	173	0.42	19.10	0.66	18.67	0.72	4.25	0.17		
05/29/96-16a	159	0.87	45.42	2.15	44.99	2.17	5.45	0.26	5.78	0.47
05/29/96-16b	159	0.56	33.08	1.07	32.65	1.11	6.11	0.21		
05/29/96-42a	171	1.19	62.73	2.17	62.30	2.20	5.12	0.18	4.98	0.20
05/29/96-42b	171	0.97	48.41	1.31	47.98	1.35	4.85	0.14		
06/05/96-5a	168	0.50	45.25	1.45	44.82	1.48	8.89	0.29	8.89	0.76
06/05/96-5b[d]										
06/05/96-16a[e]	131	0.90	40.31	1.71	39.88	1.74	5.67	0.25	5.67	0.48
06/05/96-16b[d]										
06/05/96-42a	167	0.95	72.54	1.31	72.11	1.34	7.55	0.14	7.36	0.26
06/05/96-42b	167	0.86	62.06	1.90	61.63	1.92	7.18	0.22		
07/24/96-5a	166	0.83	49.80	2.58	49.37	2.60	5.95	0.31	7.32	1.94
07/24/96-5b	166	0.85	74.01	2.24	73.58	2.26	8.69	0.27		
07/24/96-16a	166	1.15	77.31	4.38	76.88	4.39	6.72	0.38	6.64	0.11

Table A.2. SO_4 Airborne Concentrations on Zefluor Filters (continued).

Sample	Time (hr)	Flow rate (L/min)	SO_4 mass (µg)	SO_4 mass std. dev. (µg)[a]	Net SO_4 mass (µg)[b]	Net SO_4 mass std. dev. (µg)	SO_4 conc. (µg/m^3)	SO_4 conc. std. dev. (µg/m^3)	Ave SO_4 conc. (µg/m^3)	Ave SO_4 conc. std. dev. (µg/m^3)[C]
07/24/96-16b	166	1.14	75.28	7.53	74.85	7.54	6.57	0.66		
07/24/96-42a	165	1.17	75.43	3.58	75.00	3.59	6.47	0.31	6.55	0.11
07/24/96-42b	165	1.19	78.43	0.16	78.00	0.34	6.63	0.03		
07/31/96-5a	171	0.75	87.59	1.36	87.16	1.40	11.40	0.18	11.37	0.04
07/31/96-5b	171	1.07	125.03	1.18	124.60	1.22	11.33	0.11		
07/31/96-16a	158	1.22	146.58	3.71	146.15	3.73	12.59	0.32	12.58	0.01
07/31/96-16b	158	1.22	145.76	2.49	145.33	2.51	12.58	0.22		
07/31/96-42a	159	1.16	146.74	5.51	146.31	5.52	13.22	0.50	12.79	0.60
07/31/96-42b	159	1.27	150.59	3.87	150.16	3.88	12.37	0.32		
08/07/96-5a	166	0.75	64.00	1.54	63.57	1.57	8.53	0.21	8.66	0.18
08/07/96-5b	166	1.08	94.78	0.19	94.35	0.36	8.78	0.03		
08/07/96-Wa	179	1.20	103.13	1.67	102.69	1.70	7.94	0.03	7.94	0.00
8/07/96-16b	179	1.22	104.43	1.42	104.00	1.45	7.94	0.11		
8/07/96-42a	182	1.18	104.82	2.12	104.38	2.14	8.09	0.17	8.09	0.00
08/07/96-42b	182	1.21	107.06	0.76	106.63	0.82	8.09	0.06		
08/14/96-5a	167	0.71	85.39	0.98	84.96	1.02	11.93	0.14	12.25	0.45
08/14/96-5b	167	0.98	124.22	2.19	123.79	2.21	12.56	0.22		
08/14/96-16a	166	1.11	137.95	0.16	137.52	0.34	11.84	0.03	12.11	0.39
08/14/96-16b	166	1.15	135.48	0.11	135.05	0.32		0.03		
08/14/96-42a	163	1.16	129.43	1.14	129.00	1.18	11.41	0.10	11.65	0.33
08/14/96-42b	163	1.18	137.85	0.65	137.42	0.71	11.88	0.06		

[a] The % standard deviation from IC replication is 3.1%.

[b] The subtracted blank mass is 0.43 ± 0.30 µg.

[c] The average % standard deviation from adjacent replicates was 8.5%

[d] Sample lost due to leak in sampling line.

[e] Sample was only exposed for 131 hours due to a power failure.

Table A.3. HNO$_3$ Airborne Concentrations on Nylasorb Filters.

Sample	Time (hr)	Flow rate (L/min)	NO$_3$ mass (µg)	NO$_3$ mass std. dev. (µg)[a]	Net NO$_3$ mass (µg)[b]	Net NO$_3$ mass std. dev. (µg)	NO$_3$ conc. (µg/m^3)	NO$_3$ conc. std. dev. (µg/m^3)	Ave NO$_3$ conc. (µg/m^3)	Ave NO$_3$ conc. std. dev. (µg/m^3)[C]
11/20/95-5a	165	0.83	8.93	0.22	8.46	0.53	1.03	0.06	1.12	0.12
11/20/95-5b	165	1.10	13.53	0.25	13.06	0.54	1.20	0.05		
11/20/95-16a	166	0.33	8.06	0.20	7.59	0.52	2.31	0.16	1.95	0.50
11/20/95-16b	166	0.78	12.92	0.25	12.45	0.54	1.60	0.07		
11/20/95-42a	169	0.99	12.48	0.31	12.01	0.57	1.20	0.06	1.35	0.21
11/20/95-42b	169	0.90	14.15	0.08	13.68	0.49	1.50	0.05		
11/27/95-5a	168	0.87	17.29	0.61	16.82	0.77	1.93	0.09	1.90	0.04
11/27/95-5b	168	1.06	20.53	0.31	20.06	0.57	1.87	0.05		
11/27/95-16a	166	0.84	17.64	0.33	17.17	0.58	2.04	0.07	2.04	0.17
11/27/95-16b[d]										
11/27/95-16a	163	0.80	16.53	0.28	16.06	0.56	2.05	0.07	1.88	0.24
11/27/95-42b	163	1.00	17.29	0.23	16.82	0.53	1.72	0.05		
12/04/95-5a	168	1.02	12.91	0.10	12.44	0.49	1.21	0.05	1.15	0.09
12/04/95-5b	168	1.06	12.00	0.76	11.53	0.90	1.08	0.08		
12/04/95-16a	171	0.84	11.73	0.08	11.26	0.49	1.32	0.06	1.34	0.04
12/04/95-16b	71	0.70	10.24	0.23	9.77	0.53	1.37	0.07		
12/04/95-42a	172	0.94	12.00	0.11	11.53	0.49	1.19	0.05	1.13	0.09
12/04/95-42b	172	0.97	11.07	0.43	10.60	0.64	1.06	0.06		
12/11/95-5a	170	1.05	6.57	0.25	6.10	0.54	0.57	0.05	0.58	0.02
12/11/95-5b	170	1.01	6.63	0.25	6.16	0.54	0.60	0.05		
12/11/95-16a	166	0.85	8.53	0.43	8.06	0.64	0.95	0.08	0.98	0.04
12/11/95-16b	166	0.72	7.79	0.37	7.32	0.60	1.02	0.08		
12/11/95-42a	167	1.04	8.09	0.39	7.62	0.62	0.73	0.06	0.72	0.02
12/11/95-42b	167	1.07	8.01	0.39	7.54	0.62	0.70	0.06		
02/01/96-5a	173	1.00	16.11	0.85	15.64	0.97	1.50	0.09	1.61	0.15

Table A.3. HNO_3 Airborne Concentrations on Nylasorb Filters (continued).

Sample	**Time (hr)**	**Flow rate (L/min)**	**NO_3 mass (μg)**	**NO_3 mass std. dev. (μg)[a]**	**Net NO_3 mass (μg)[b]**	**Net NO_3 mass std. dev. (μg)**	**NO_3 conc. (μg/m^3)**	**NO_3 conc. std. dev. (μg/m^3)**	**Ave NO_3 conc. (μg/m^3)**	**Ave NO_3 conc. std. dev. (μg/m^3)[C]**
02/01/96-5b	173	0.89	16.35	1.25	15.88	1.34	1.71	0.14		
02/01/96-16a	172	0.73	13.19	0.48	12.72	0.68	1.68	0.09	1.79	0.15
02/01/96-16b	172	0.85	17.07	0.91	16.60	1.02	1.89	0.12		
02/01/96-42a	169	0.89	9.68	0.81	9.21	0.94	1.02	0.10	1.03	0.01
02/01/96-42b	169	0.97	10.71	0.12	10.24	0.49	1.04	0.05		
02/08/96-5a	163	0.87	11.42	0.69	10.95	0.84	1.29	0.10	1.20	0.12
2/08/96-5b	163	0.93	10.55	0.69	10.08	0.84	1.11	0.09		
02/08/96-16a	164	0.55	7.94	0.21	7.47	0.52	1.39	0.10	1.23	0.23
02/08/96-16b	164	1.01	11.14	0.50	10.67	0.69	1.07	0.07		
02/08/96-42a	166	0.77	9.27	0.56	8.80	0.74	1.15	0.10	0.88	0.37
02/08/96-42b	166	0.99	6.56	5.68	6.09	5.70	0.62	0.58		
02/15/96-5a	169	0.83	23.78	1.39	23.31	1.47	2.78	0.18	2.80	0.03
02/15/96-5b	169	0.86	25.17	1.50	24.70	1.58	2.82	0.18		
02/15/96-16a	168	0.74	29.44	0.41	28.98	0.63	3.90	0.08	3.44	0.65
02/15/96-16b	168	0.86	26.28	1.15	25.82	1.25	2.98	0.14		
02/15/96-42a	167	1.12	37.46	1.67	36.99	1.74	3.28	0.15	3.28	0.00
02/15/96-42b	167	0.85	28.48	0.49	28.01	0.68	3.28	0.08		
02/22/96-5a	167	0.74	8.71	0.51	8.24	0.70	1.11	0.09	1.34	0.32
02/22/96-5b	167	0.81	13.18	0.67	12.71	0.83	1.56	0.10		
02/22/96-16a	168	0.63		0.46	9.34	0.66	1.47	0.10	1.59	0.18
02/22/96-16b	168	0.77	13.75	0.65	13.28	0.81	1.72	0.10		
02/22/96-42a	169	1.02	17.01	0.65	16.54	0.81	1.60	0.08	1.77	0.25
02/22/96-42b	169	0.70	14.32	0.80	13.85	0.93	1.95	0.13		
05/14/96-5a	192	0.94	48.97	0.84	48.50	0.97	4.46	0.09	4.17	0.41
05/14/96-5b	192	0.82	37.24	0.60	36.77	0.77	3.88	0.08		

Table A.3. HNO_3 Airborne Concentrations on Nylasorb Filters (continued).

Sample	Time (hr)	Flow rate (L/min)	NO_3 mass (µg)	NO_3 mass std. dev. (µg)[a]	Net NO_3 mass (µg)[b]	Net NO_3 mass std. dev. (µg)	NO_3 conc. (µg/m^3)	NO_3 conc. std. dev. (µg/m^3)	Ave NO_3 conc. (µg/m^3)	Ave NO_3 conc. std. dev. (µg/m^3)[C]
05/14/96-16a	193	0.84	42.16	0.70	41.69	0.85	4.28	0.09	4.40	0.17
05/14/96-16b	193	0.78	41.36	0.06	40.89	0.48	4.52	0.05		
05/14/96-42a	193	1.09	55.26	0.54	54.79	0.72	4.32	0.06	4.18	0.21
05/14/96-42b	193	0.96	45.27	0.07	44.80	0.49	4.03	0.04		
05/22/96-5a	164	0.77	22.85	0.19	22.38	0.52	2.95	0.07	3.04	0.13
05/22/96-5b	164	0.73	23.07	0.12	22.60	0.49	3.13	0.07		
05/22/96-16a	166	0.44	16.30	0.16	15.83	0.51	3.61	0.12	3.61	0.30
05/22/96-16b[d]										
05/22/96-42a	165	0.60	18.69	0.05	18.22	0.48	3.09	0.08	2.68	0.57
05/22/96-42b	165	0.88	20.40	0.17	19.93	0.51	2.28	0.06		
05/29/96-5a	173	0.48	18.82	0.56	18.35	0.74	3.68	0.15	3.73	0.07
05/29/96-5b	173	0.42	17.07	0.56	16.60	0.74	3.78	0.17	4.35	0.80
05/29/96-16a	159	0.87	31.73	1.29	31.26	1.38	3.79	0.17		
05/29/96-16b	159	0.56	26.76	1.06	26.29	1.17	4.92	0.22		
05/29/96-42a	171	1.19	38.38	1.61	37.91	1.68	3.12	0.14	3.15	0.04
05/29/96-42b	171	0.97	31.92	1.25	31.45	1.34	3.18	0.14		
06/05/96-5a	168	0.50	30.51	0.05	30.04	0.48	5.96	0.10	5.96	0.49
06/05/96-5b[d]										
06/05/96-16a[e]	131	0.90	25.68	0.17	25.21	0.51	3.58	0.07	3.58	0.30
06/05/96-16b[d]										
06/05/96-42a	167	0.95	42.20	0.28	41.73	0.56	4.37	0.06	4.42	0.07
06/05/96-42b	167	0.86	38.83	0.51	38.36	0.70	4.47	0.08		
07/24/96-5a	166	0.83	33.67	1.03	33.20	1.13	4.00	0.14	4.56	0.79
07/24/96-5b	166	0.85	43.82	1.27	43.35	1.36	5.12	0.16		
07/24/96-16a	166	1.15	51.10	2.09	50.63	2.14	4.43	0.19	4.41	0.02

Table A.3. HNO_3 Airborne Concentrations on Nylasorb Filters (continued).

Sample	**Time (hr)**	**Flow rate (L/min)**	**NO_3 mass (μg)**	**NO_3 mass std. dev. (μg)[a]**	**Net NO_3 mass (μg)[b]**	**Net NO_3 mass std. dev. (μg)**	**NO_3 conc. ($\mu g/m^3$)**	**NO_3 conc. std. dev. ($\mu g/m^3$)**	**Ave NO_3 conc. ($\mu g/m^3$)**	**Ave NO_3 conc. std. dev. ($\mu g/m^3$)[C]**
07/24/96-16b	166	1.14	50.58	0.72	50.11	0.87	4.40	0.08		
07/24/96-42a	165	1.17	45.10	1.17	44.63	1.27	3.85	0.11	3.84	0.01
07/24/96-42b	165	1.19	45.54	0.73	45.07	0.87	3.83	0.07		
07/31/96-5a	171	0.75	37.32	4.05	36.85	4.07	4.82	0.53	5.19	0.52
07/31/96-5b	171	1.07	61.54	5.76	61.07	5.78	5.56	0.53		
07/31/96-16a	158	1.22	79.98	2.99	79.51	3.02	6.85	0.26	6.67	0.26
07/31/96-16b	158	1.22	75.39	2.21	74.92	2.26	6.48	0.20		
07/31/96-42a	159	1.16	70.32	6.10	69.85	6.12	6.31	0.55	6.18	0.18
07/31/96-42b	159	1.27	74.02	1.85	73.55	1.91	6.06	0.16		
08/07/96-5a	166	0.75	26.22	1.65	25.75	1.72	3.46	0.23	3.41	0.06 -
08/07/96-5b	166	1.08	36.61	3.18	36.14	3.22	3.37	0.30		
08/07/96-16a	179	1.20	42.21	4.47	41.74	4.50	3.23	0.35	3.22	0.01
08/07/96-16b	179	1.22	42.48	4.62	42.01	4.64	3.21	0.35		
08/07/96-42a	182	1.18	43.12	3.92	42.65	3.95	3.30	0.31	3.29	0.02
08/07/96-42b	182	1.21	43.59	4.86	43.12	4.88	3.27	0.37		
08/14/96-5a	167	0.71	39.37	3.63	38.90	3.66	5.46	0.51	5.51	0.06
08/14/96-5b	167	0.98	55.17	3.75	54.70	3.78	5.55	0.38		
08/14/96-16a	166	1.11	60.31	2.62	59.84	2.66	5.39	0.24	5.49	0.14
08/14/96-16b	166	1.15	64.21	4.02	63.74	4.05	5.59	0.35		
08/14/96-42a	163	1.16	60.66	3.58	60.19	3.61	5.33	0.32	5.29	0.05

[a] The % standard deviation from IC replication is 4.7%.

[b] The subtracted blank mass is 0.47 ± 0.48 µg.

[C] The average % standard deviation from adjacent replicates was 8.3%

[d] Sample lost due to leak in sampling line.

[e] Sample was only exposed for 131 hours due to a power failure.

Table A.4. SO$_4$ Airborne Concentrations on Nylasorb Filters.

Sample	Time (hr)	Flow rate (L/min)	SO$_4$ mass (µg)	SO$_4$ mass std. dev. (µg)[a]	Net SO$_4$ mass (µg)[b]	Net SO$_4$ mass std. dev. (µg)	SO$_4$ conc. (µg/m^3)	SO$_4$ conc. std. dev. (µg/m^3)	Ave SO$_4$ conc. (µg/m^3)	Ave SO$_4$ conc. std. dev. (µg/m^3)[C]
11/20/95-5a	165	0.83	31.67	1.25	31.08	1.36	3.79	0.17	3.55	0.35
11/20/95-5b	165	1.10	36.45	0.45	35.86	0.68	3.30	0.06		
11/20/95-16a	166	0.33	31.96	0.74	31.37	0.90	9.53	0.27	7.63	2.69
11/20/95-16b	166	0.78	45.18	2.98	44.59	3.02	5.73	0.39		
11/20/95-42a	169	0.99	33.22	0.11	32.63	0.53	3.27	0.05	3.58	0.44
1 1/20/95-42b	169	0.90	36.09	0.30	35.50	0.59	3.89	0.07		
11/27/95-5a	168	0.87	35.99	0.27	35.40	0.58	4.06	0.07	3.61	0.63
11/27/95-5b	168	1.06	34.60	0.96	34.01	1.09	3.17	0.10		
11/27/95-16a	166	0.84	38.91	0.28	38.32	0.58	4.56	0.07	4.56	0.61
11/27/95-16b[d]										
11/27/95-42a	163	0.80	39.44	0.66	38.85	0.84	4.96	0.11	4.29	0.95
11/27/95-42b	163	1.00	36.04	0.11	35.45	0.53	3.62	0.05		
12/04/95-5a	168	1.02	40.26	0.20	39.67	0.55	3.87	0.05	3.51	0.51
12/04/95-5b	168	1.06	34.03	0.02	33.44	0.52	3.14	0.05		
12/04/95-16a	171	0.84	37.26	0.35	36.66	0.62	4.29	0.07	5.26	1.37
12/04/95-16b	171	0.70	45.07	1.96	44.48	2.02	6.22	0.28		
12/04/95-42a	172	0.94	42.52	0.63	41.93	0.81	4.34	0.08	4.23	0.14
12/04/95-42b	172	0.97	41.83	0.31	41.24	0.60	4.13	0.06		
12/11/95-5a	170	1.05	32.44	0.83	31.85	0.98	2.97	0.09	3.04	0.11
12/11/95-5b	170	1.01	32.77	1.78	32.18	1.86	3.12	0.18		
12/11/95-16a	166	0.85	39.58	0.02	38.99	0.52	4.61	0.06	5.14	0.76
12/11/95-16b	166	0.72	41.49	0.82	40.90	0.97	5.68	0.13		
12/11/95-42a	167	1.04	40.13	0.35	39.54	0.63	3.79	0.06	3.56	0.33
12/11/95-42b	167	1.07	36.32	1.25	35.73	1.35	3.32	0.13		
02/01/96-5a	173	1.00	36.94	0.33	36.35	0.61	3.48	0.06	3.79	0.44

Table A.4. SO$_4$ Airborne Concentrations on Nylasorb Filters (continued).

Sample	**Time (hr)**	**Flow rate (L/min)**	**SO$_4$ mass (µg)**	**SO$_4$ mass std. dev. (µg)[a]**	**Net SO$_4$ mass (µg)[b]**	**Net SO$_4$ mass std. dev. (µg)**	**SO$_4$ conc. (µg/m^3)**	**SO$_4$ conc. std. dev. (µg/m^3)**	**Ave SO$_4$ conc. (µg/m^3)**	**Ave SO$_4$ conc. std. dev. (µg/m^3)[C]**
02/01/96-5b	173	0.89	38.54	1.40	37.95	1.49	4.10	0.16		
02/01/96-16a	172	0.73	38.63	0.10	38.03	0.53	5.03	0.07	4.62	0.58
02/01/96-16b	172	0.85	37.57	0.26	36.98	0.58	4.21	0.07		
02/01/96-42a	169	0.89	32.79	0.69	32.20	0.86	3.58	0.10	3.62	0.05
02/01/96-42b	169	0.97	36.71	0.93	36.12	1.06	3.65	0.11		
02/08/96-5a	163	0.87	40.87	0.26	40.27	0.58	4.74	0.07	4.63	0.15
02/08/96-5b	163	0.93	41.58	0.35	40.99	0.62	4.53	0.07		
2/08/96-16a	164	0.55	34.73	4.67	34.14	4.70	6.35	0.87	5.53	1.17
2/08/96-16b	164	1.01	47.38	0.18	46.78	0.54	4.70	0.05		
02/08/96-42a	166	0.77	44.24	0.55	43.65	0.75	5.70	0.10	4.29	1.99
02/08/96-42b	166	0.99	28.91	26.1 1	28.32	26.11	2.89	2.66		
02/15/96-5a	169	0.83	38.73	0.74	38.13	0.90	4.55	0.11	4.68	0.18
02/15/96-5b	169	0.86	42.64	1.69	42.05	1.77	4.81	0.20		
02/15/96-1 6a	168	0.74	55.57	2.46	54.98	2.52	7.41	0.34	6.10	1.84
02/15/96-16b	168	0.86	42.11	0.81	41.52	0.96	4.80	0.11		
02/15/96-42a	167	1.12	42.66	1.95	42.07	2.02	3.73	0.18	4.28	0.77
02/15/96-42b	167	0.85	41.79	2.53	41.19	2.58	4.82	0.30		
02/22/96-5a	167	0.74	47.90	1.32	47.31	1.41	6.36	0.19	5.76	0.85
02/22/96-5b	167	0.81	42.54	1.38	41.95	1.47	5.16	0.18		
02/22/96-16a	168	0.63	48.14	1.47	47.55	1.56	7.47	0.24	6.97	0.70
02/22/96-16b	168	0.77	50.58	1.43	49.99	1.52	6.47	0.20		
02/22/96-42a	169	1.02	44.55	1.16	43.96	1.27	4.24	0.12	5.55	1.85
02/22/96-42b	169	0.70	49.39	1.80	48.80	1.87	6.87	0.26		
05/14/96-5a	192	0.94	65.46	2.51	64.87	2.56	5.96	0.24	6.00	0.06
05/14/96-5b	192	0.82	57.82	2.06	57.22	2.12	6.04	0.22		

Table A.4. SO_4 Airborne Concentrations on Nylasorb Filters (continued).

Sample	**Time (hr)**	**Flow rate (L/min)**	**SO_4 mass (μg)**	**SO_4 mass std. dev. (μg)[a]**	**Net SO_4 mass (μg)[b]**	**Net SO_4 mass std. dev. (μg)**	**SO_4 conc. ($\mu g/m^3$)**	**SO_4 conc. std. dev. ($\mu g/m^3$)**	**Ave SO_4 conc. ($\mu g/m^3$)**	**Ave SO_4 conc. std. dev. ($\mu g/m^3$)[C]**
05/14/96-16a	193	0.84	64.02	2.46	63.43	2.51	6.51	0.26	6.63	0.17
05/14/96-16b	193	0.78	61.69	1.61	61.09	1.69	6.75	0.19		
05/14/96-42a	193	1.09	63.48	2.07	62.89	2.13	4.96	0.17	5.16	0.28
5/14/96-42b	193	0.96	60.22	1.69	59.63	1.76	5.36	0.16		
05/22/96-5a	164	0.77	34.35	1.07	33.76	1.19	4.45	0.16	4.83	0.54
05/22/96-5b	164	0.73	38.26	1.19	37.66	1.29	5.21	0.18	7.95	1.07
05/22/96-16a	166	0.44	35.41	1.01	34.82	1.13	7.95	0.26		
05/22/96-16b[e]										
05/22/96-42a	165	0.60	36.16	0.73	35.57	0.90	6.03	0.15	4.52	2.13
05/22/96-42b	165	0.88	26.93	1.02	26.34	1.14	3.01	0.13		
05/29/96-5a	173	0.48	46.68	1.96	46.09	2.03	9.25	0.41	9.75	0.71
05/29/96-5b	173	0.42	45.56	2.49	44.97	2.54	10.25	0.58		
05/29/96-16a	159	0.87	46.36	1.88	45.77	1.95	5.54	0.24	7.36	2.58
05/29/96-16b	159	0.56	49.67		49.08	2.03	9.19	0.38		
05/29/96-42a	171	1.19	41.28	1.58	40.69	1.66	3.35	0.14	3.75	0.57
05/29/96-42b	171	0.97	41.70	1.93	41.11	1.99	4.15	0.20		
06/05/96-5a	168	0.50	59.48	1.39	58.89	1.48	13.03	0.33	13.03	1.75
06/05/96-5b[e]										
06/05/96-16a[l]	131	0.90	58.97	1.92	58.38	1.99	8.29	0.28	8.29	1.12
06/05/96-1 6b[e]										
06/05/96-42a	167	0.95	60.80	2.05	60.21	2.11	6.30	0.22	6.66	0.51
06/05/96-42b	167	0.86	60.92	2.64	60.33	2.69	7.02	0.31		
07/24/96-5a	166	0.83	51.90	2.02	51.31	2.08	6.18	0.25	6.11	0.11
07/24/96-Sb	166	0.85	51.68	3.08	51.08	3.12	6.03	0.37		
07/24/96-16a	166	1.15	55.89	2.44	55.30	2.49	4.83	0.22	4.90	0.09

Table A.4. SO_4 Airborne Concentrations on Nylasorb Filters (continued).

Sample	Time (hr)	Flow rate (L/min)	SO_4 mass (μg)	SO_4 mass std. dev. (μg)[a]	Net SO_4 mass (μg)[b]	Net SO_4 mass std. dev. (μg)	SO_4 conc. (μg/m^3)	SO_4 conc. std. dev. (μg/m^3)	Ave SO_4 conc. (μg/m^3)	Ave SO_4 conc. std. dev. (μg/m^3)[C]
07/24/96-16b	166	1.14	57.15	3.18	56.56	3.22	4.96	0.28		
07/24/96-42a	165	1.17	54.75	1.63	54.16	1.71	4.67	0.15	4.47	0.28
07/24/96-42b	165	1.19	50.89		50.30	1.71	4.28	0.15		
07/31/96-5a	171	0.75	40.16	7.22	39.56	7.24	5.17	0.95	5.05	0.18
07/31/96-5b	171	1.07	54.70	3.86	54.11	3.89	4.92	0.35		
07/31/96-16a	158	1.22	60.61	2.70	60.02	2.75	5.17	0.24	5.15	0.03
07/31/96-16b	158	1.22	59.85	2.88	59.25	2.92	5.13	0.25		
07/31/96-42a	159	1.16	54.92	2.52	54.33	2.57	4.91	0.23	4.78	0.19
07/31/96-42b	159	1.27	56.98	2.60	56.39	2.66	4.64	0.22		
08/07/96-5a	166	0.75	36.54	0.59	35.95	0.78	4.82	0.10	4.16	0.94
08/07/96-5b	166	1.08	38.08	3.41	37.49	3.45	3.49	0.32		
08/07/96-16a	179	1.20	42.33	4.20	41.74	4.23	3.23	0.33	3.09	0.19
08/07/96-16b	179	1.22	39.32	4.03	38.73	4.06	2.96	0.31		
08/07/96-42a	182	1.18	42.37	3.72	41.77	3.76	3.24	0.29	3.16	0.10
08/07/96-42b	182	1.21	41.32	4.17	40.73	4.20	3.09	0.32		
8t14/96-5a	167	0.71	41.16	3.42	40.57	3.46	5.70	0.49	5.20	0.71
08/14/96-5b	167	0.98	46.85	3.94	46.26	3.98	4.69	0.40		
08/14/96-16a	166	1.11	44.41	3.30	43.82	3.34	3.95	0.30	4.23	0.40
08/14/96-16b	166	1.15	52.12	2.17	51.53	2.23	4.52	0.20		
08/14/96-42a	163	1.16	52.86	1.98	52.27	2.05	4.63	0.18	4.28	0.49
08/14/96-42b	163	1.18	46.15	3.67	45.56	3.71	3.94	0.32		

[a] The % standard deviation from IC replication is 4.7%.

[b] The subtracted blank mass is 0.59 ± 0.52 μg.

[c] SO_2 concentrations are based on the sum of SO4 concentrations found on Nylasorb and Whatman filters.

[d] The average % standard deviation from adjacent replicates was 13.5%

[d] Sample lost due to leak in sampling line.

[e] Sample was only exposed for 131 hours due to a power failure.

Table A.5. SO_4 Airborne Concentrations on Whatman Filters.

Sample	Time (hr)	Flow rate (L/min)	SO_4 mass (μg)	SO_4 mass std. dev. (μg)[a]	Net SO_4 mass (μg)[b]	Net SO_4 mass std. dev. (μg)	SO_4 conc. (μg/m^3)	SO_4 conc. std. dev. (μg/m^3)	Ave SO_4 conc. (μg/m^3)	Ave SO_4 conc. std. dev. (μg/m^3)[C]
11/20/95-5a[l]	165	0.83	189.3	11.35	187.9	11.39	22.94	1.39	32.86	14.03
11/20/95-5b[l]	165	1.10	465.8	4.68	464.5	4.79	42.78	0.44		
11/20/95-16a[l]	166	0.33	109.1	1.18	107.7	1.54	32.72	0.47	39.96	10.24
11/20/95-16b[l]	166	0.78	368.6	8.68	367.2	8.73	47.20	1.12		
11/20/95-42a[l]	169	0.99	501.9	4.13	500.5	4.25	50.11	0.43	50.73	0.88
11/20/95-42b[l]	169	0.90	469.9	7.43	468.5	7.50	51.36	0.82		
11/27/95-5a[l]	168	0.87	362.4	8.86	361.0	8.91	41.37	1.02	37.94	4.86
11/27/95-5b[l]	168	1.06	371.5	9.25	370.2	9.30	34.50	0.87		
11/27/95-16a[l]	166	0.84	387.9	15.05	386.5	15.08	46.01	1.80	45.65	0.51
11/27/95-16b[l]										
11/27/95-42a[l]	163	0.80	303.7	10.37	302.4	10.41	38.62	1.33	37.32	1.84
11/27/95-42b[l]	163	1.00	354.3	7.11	353.0	7.18	36.02	0.73		
2/04/95-5a	168	1.02	420.6	7.45	418.2	7.58	40.81	0.74	42.34	2.17
2/04/95-5b[l]	168	1.06	468.0	5.21	466.6	5.31	43.87	0.50		
2/04/95-16a	171	0.84	380.8	5.30	378.4	5.48	44.28	0.64	46.36	2.95
12/04/95-16b[l]	171	0.70	347.6	12.77	346.2	12.81	48.45	1.79		
2/04/95-42a	172	0.94	475.3	3.77	472.9	4.02	48.89	0.42	48.51	0.54
2/04/95-42b[l]	172	0.97	481.8	4.32	480.4	4.43	48.13	0.44		
2/11/95-5a	170	1.05	369.9	2.45	367.5	2.82	34.26	0.26	32.66	2.26
2/11/95-5b	170	1.01	323.0	3.51	320.5	3.78	31.06	0.37		
2/11/95-16a	166	0.85	315.9	4.27	313.5	4.50	37.04	0.53	34.54	3.54
2/11/95-16b	166	0.72	233.1	7.88	230.7	8.00	32.03	1.11		
2/11/95-42a	167	1.04	404.7	1.63	402.3	2.16	38.57	0.21	35.77	3.97
12/11 /95-42b	167	1.07	356.8	2.90	354.4	3.23	32.96	0.30		
02/01/96-5a	173	1.00	404.5	3.10	402.1	3.40	38.52	0.33	44.15	7.97

Table A.5. SO_4 Airborne Concentrations on Whatman Filters (continued).

Sample	**Time (hr)**	**Flow rate (L/min)**	**SO_4 mass (µg)**	**SO_4 mass std. dev. (µg)[a]**	**Net SO_4 mass (µg)[b]**	**Net SO_4 mass std. dev. (µg)**	**SO_4 conc. (µg/m^3)**	**SO_4 conc. std. dev. (µg/m^3)**	**Ave SO_4 conc. (µg/m^3)**	**Ave SO_4 conc. std. dev. (µg/m^3)[C]**
02/01/96-5b	173	0.89	463.5	7.03	461.1	7.17	49.79	0.77		
02/01/96-16a	172	0.73	361.5	6.46	359.1	6.61	47.47	0.87	45.21	3.19
02/01/96-16b	172	0.85	379.8	5.56	377.4	5.74	42.96	0.65		
02/01/96-42a	169	0.89	301.0	7.44	298.6	7.58	33.19	0.84	32.14	1.49
02/01/96-42b	169	0.97	309.7	5.86	307.3	6.02	31.09	0.61		
02/08/96-5a	163	0.87	173.6	1.48	171.2	2.05	20.15	0.24	19.30	1.21
02/08/96-5b	163	0.93	169.5	1.78	167.1	2.27	18.44	0.25		
02/08/96-16a	164	0.55	85.8	1.08	83.4	1.77	15.52	0.33	15.55	0.05
02/08/96-16b	164	1.01	157.5	1.19	155.0	1.84	15.58	0.19		
02/08/96-42a	166	0.77	131.3	1.56	128.9	2.10	16.82	0.27	17.25	0.61
02/08/96-42b	166	0.99	175.9	8.06	173.5	8.19	17.68	0.83		
02/15/96-5a	169	0.83	495.4	6.05	493.0	6.21	58.83	0.74	61.01	3.08
02/15/96-5b	169	0.86	555.2	8.15	552.8	8.27	63.18	0.94		
02/15/96-16a	168	0.74	715.4	11.60	713.0	11.69	96.05	1.57	84.49	16.35
02/15/96-16b	168	0.86	633.4	12.26	631.0	12.34	72.92	1.43		
02/15/96-42a	167	1.12	1175.1	18.09	1172.7	18.14	104.06	1.61	102.38	2.37
02/15/96-42b	167	0.85	862.9	16.74	860.5	16.80	100.70	1.97		
02/22/96-5a	167	0.74	205.1	1.64	203.7	1.92	27.40	0.26	32.67	7.45
02/22/96-5b	167	0.81	309.8	3.56	308.4	3.70	37.93	0.46		
02/22/96-16a	168	0.63	230.1	1.75	228.7	2.01	35.92	0.32	39.57	5.16
02/22/96-16b	168	0.77	335.3	3.54	333.9	3.68	43.22	0.48		
02/22/96-42a	169	1.02	433.9	5.07	432.5	5.17	41.74	0.50	42.75	1.43
02/22/96-42b	169	0.70	312.4	3.95	311.0	4.07	43.76	0.57		
05/14/96-5a	192	0.94	384.2	7.31	381.8	7.45	35.08	0.68	33.09	2.82
05/14/96-5b	192	0.82	297.0	9.55	294.6	9.65	31.10	1.02		

Table A.5. SO_4 Airborne Concentrations on Whatman Filters (continued).

Sample	**Time (hr)**	**Flow rate (L/min)**	**SO_4 mass (µg)**	**SO_4 mass std. dev. (µg)[a]**	**Net SO_4 mass (µg)[b]**	**Net SO_4 mass std. dev. (µg)**	**SO_4 conc. (µg/m^3)**	**SO_4 conc. std. dev. (µg/m^3)**	**Ave SO_4 conc. (µg/m^3)**	**Ave SO_4 conc. std. dev. (µg/m^3)[C]**
05/14/96-16a	193	0.84	356.7	11.21	354.3	11.30	36.38	1.16	37.91	2.16
05/14/96-16b	193	0.78	359.2	7.84	356.8	7.96	39.44	0.88		
05/14/96-42a	193	1.09	402.8	6.80	400.3	6.94	31.59	0.55	29.72	2.65
05/14/96-42b	193	0.96	312.0	13.28	309.6	13.35	27.85	1.20		
05/22/96-5a	164	0.77	148.6	1.01	146.2	1.73	19.26	0.23	19.04	0.31
05/22/96-Sb	164	0.73	138.4	1.72	136.0	2.22	18.82	0.31		
05/22/96-1 6a	166	0.44	84.7	0.38	82.3	1.46	18.78	0.33	18.78	1.78
5/22/96-16b[g]										
05/22/96-42a	165	0.60	67.2	0.85	64.7	1.65	10.98	0.28	9.76	1.72
5/22/96-42b	165	0.88	77.1	0.78	74.7	1.61	8.54	0.18		
05/29/96-5a	173	0.48	44.2	34.56	41.8	34.59	8.38	6.94	9.89	2.12
5/29/96-Sb	173	0.42	52.4	3.05	50.0	3.36	11.39	0.77		
05/29/96-16a	159	0.87	171.6	2.83	169.1	3.16	20.62	0.39	21.54	1.31
05/29/96-16b	159	0.56	122.5	6.34	120.1	6.50	22.47	1.22		
5/29/96-42a	171	1.19	329.3	15.11	326.9	15.18	26.88	1.25	25.53	1.92
05/29/96-42b	171	0.97	241.8	13.64	239.4	13.71	24.18	1.39		
06/05/96-5a	168	0.50	143.3	1.99	140.9	2.43	27.95	0.48	27.95	2.64
06/05/96-5b[g]										
06/05/96-16a[h]	131	0.90	159.2	2.69	156.8	3.03	22.28	0.43	22.28	2.11
06/05/96-1 6b[g]										
06/05/96-42a	167	0.95	209.9	123.72	207.5	123.73	21.72	12.95	24.22	3.53
06/05/96-42b	167	0.86	231.8	5.38	229.4	5.56	26.71	0.65		
07/24/96-5a	166	0.83	122.7	3.58	120.2	3.85	14.49	0.46	17.84	4.74
07/24/96-Sb	166	0.85	181.9	10.08	179.5	10.18	21.20	1.20		
07/24/96-16a	166	1.15	215.6	24.21	213.2	24.25	18.64	2.12	15.22	4.84

Table A.5. SO_4 Airborne Concentrations on Whatman Filters (continued).

Sample	Time (hr)	Flow rate (L/min)	SO_4 mass (μg)	SO_4 mass std. dev. (μg)[a]	Net SO_4 mass (μg)[b]	Net SO_4 mass std. dev. (μg)	SO_4 conc. (μg/m^3)	SO_4 conc. std. dev. (μg/m^3)	Ave SO_4 conc. (μg/m^3)	Ave SO_4 conc. std. dev. (μg/m^3)[C]
07/24/96-16b	166	1.14	136.9	13.75	134.5	13.82	11.80	1.21		
07/24/96-42a	165	1.17	237.5	14.45	235.1	14.52	20.29	1.25	19.42	1.23
07/24/96-42b	165	1.19	220.6	5.87	218.1	6.03	18.54	0.51		
07/31/96-5a	171	0.75	152.9	3.93	150.5	4.17	19.68	0.55	20.92	1.76
07/31/96-Sb	171	1.07	246.1	1.47	243.7	2.03	22.17	0.19		
07/31/96-16a	158	1.22	339.1	14.76	336.7	14.83	29.00	1.28	29.20	0.29
07/31/96-16b	158	1.22	342.2	12.16	339.8	12.25	29.40	1.06		
07/31/96-42a	159	1.16	413.4	15.76	411.0	15.83	37.13	1.43	34.35	3.93
07/31/96-42b	159	1.27	385.7	15.90	383.3	15.96	31.57	1.31		
08/07/96-5a	166	0.75	190.8	5.76	188.4	5.93	25.28	0.80	26.02	1.05
08/07/96-5b	166	1.08	289.9	8.79	287.5	8.91	26.76	0.83		
08/07/96-16a	179	1.20	366.0	0.63	363.6	1.54	28.10	0.12	27.41	0.98
08/07/96-16b	179	1.22	352.2	11.16	349.7	11.25	26.71	0.86		
08/07/96-42a	182	1.18	283.5	3.30	281.0	3.59	21.77	0.28	21.34	0.61
08/07/96-42b	182	1.21	278.0	1.10	275.6	1.79	20.91	0.14		
08/14/96-5a	167	0.71	177.6	12.79	175.2	12.87	24.60	1.81	24.47	0.18
08/14/96-5b	167	0.98	242.2	9.10	239.8	9.21	24.34	0.94		
08/14/96-16a	166	1.11	297.2	13.16	294.8	13.23	26.55	1.19	26.42	0.19
08/14/96-16b	166	1.15	302.4	13.03	300.0	13.11	26.29	1.15		
08/14/96-42a	163	1.16	314.9	7.49	312.5	7.62	27.65	0.67	27.77	0.17
08/14/96-42b	163	1.18	324.9	10.87	322.5	10.96	27.88	0.95		

[a] SO_4 mass is based on the sum of SO_4 ón both sets of back-to back Whatman filters except where noted.
[b] The % standard deviations from IC replication are 1.8% for the first set of filters and 10.1% for backup filters.
[c] The subtracted blank masses are 1.39 ± 1.00 pg for the first set of filters and 1.03 ± 1.00 μg for backup filters.
[d] SO_2 concentrations are based on the sum of SO_4 concentrations found on Nylasorb and Whatman filters.
[e] The average % standard deviation from adjacent replicates is 9.5%.
[f] The SO_4 mass is based on one set of Whatman filters only. See footnote [a].
[g] Sample lost due to leak in sampling line.
[h] Sample was only exposed for 131 hours due to a power failure.

Table A.6. Elemental Carbon Airborne Concentrations on Quartz Filters.

Sample	Time (hr)	Flow rate (L/min)	Carbon mass (μg)	Carbon mass std. dev. (μg)[a]	Net Carbon mass (μg)[b]	Net Carbon mass std. dev. (μg)	Carbon conc. (μg/m^3)	Carbon conc. std. dev. (μg/m^3)	Ave Carbon conc. (μg/m^3)	Ave Carbon conc. std. dev. (μg/m^3)[C]
11/20/95-5a	165	3.3	127.5	12.37	127.1	12.39	3.96	0.39	3.94	0.03
11/20/95-Sb	165	3.3	128.1	12.43	127.7	12.45	3.92	0.38		
11/20/95-16a	166	3.1	123.1	11.95	122.7	11.96	4.03	0.39	4.32	0.41
11/20/95-16b	166	3.2	147.6	14.33	147.2	14.34	4.61	0.45		
11 /20/95-42a	169	3.3	113.9	11.05	113.5	11.07	3.46	0.34	3.27	0.27
11/20/95-42b[d]	169	2.8	86.0	5.44	85.6	5.48	3.08	0.20		
11/27/95-5a[d]	168	3.0	80.3	6.01	79.9	6.04	2.62	0.20	2.61	0.01
11/27/95-5b	168	2.7	71.8	6.97	71.4	6.99	2.60	0.25		
11/27/95-15a	166	3.0	84.9	8.24	84.5	8.26	2.86	0.28	2.83	0.05
11/27/95-16b	166	3.0	83.0	8.06	82.6	8.08	2.79	0.27		
11/27/95-42a	163	2.6	61.9	6.01	61.5	6.04	2.42	0.24	2.39	0.04
11/27/95-42b	163	2.7	62.1	6.03	61.7	6.06	2.36	0.23		
12/04/95-5a	168	2.5	57.8	5.61	57.4	5.64	2.28	0.22	2.30	0.02
12/04/95-Sb	168	2.9	67.7	6.57	67.3	6.60	2.31	0.23		
12/04/95-16a[d]	171	3.1	50.1	1.70	49.7	1.80	1.59	0.06	1.91	0.44
12/04/95-16b[d]	171	3.0	68.4	5.23	68.0	5.27	2.22	0.17		
12/04/95-42a	172	2.8	55.0	5.34	54.6	5.37	1.90	0.19	1.87	0.03
12/04/95-42b	172	2.8	53.7	5.21	53.3	5.25	1.85	0.18		
12/11/95-5a	170	2.7	40.3	3.91	39.9	3.96	1.45	0.14	1.67	0.30
12/11/95-5b	170	2.9	55.8	5.42	55.4	5.45	1.88	0.18		
12/11/95-16a	166	2.6	42.3	4.11	41.9	4.15	1.62	0.16	1.92	0.42
12/11/95-16b	166	3.0	66.4	6.44	66.0	6.47	2.21	0.22		
12/11 /95-42a[d]	167	2.8	72.1	7.85	71.7	7.87	2.55	0.28	2.37	0.26
12/11/95-42b	167	2.8	61.7	5.99	61.3	6.02	2.18	0.21		
02/01/96-5a	173	2.8	53.1	5.15	52.7	5.19	1.85	0.18	1.90	0.08

Table A.6. Elemental Carbon Airborne Concentrations on Quartz Filters (continued).

Sample	Time (hr)	Flow rate (L/min)	Carbon mass (µg)	Carbon mass std. dev. (µg)[a]	Net Carbon mass (µg)[b]	Net Carbon mass std. dev. (µg)	Carbon conc. (µg/m^3)	Carbon conc. std. dev. (µg/m^3)	Ave Carbon conc. (µg/m^3)	Ave Carbon conc. std. dev. (µg/m^3)[C]
02/01/96-5bd	173	2.8	57.9	6.93	57.5	6.96	1.96	0.24		
02/01/96-16a	172	2.7	51.6	5.01	51.2	5.04	1.84	0.18	1.92	0.11
02/0i/96-16b	172	2.7	55.5	5.39	55.1	5.42	2.00	0.20		
02/01/96-42a	169	2.8	25.3	2.46	24.9	2.53	0.89	0.09	0.94	0.06
02/01/96-42b	169	2.6	26.5	2.57	26.1	2.64	0.98	0.10		
/08/96-5a	163	2.8	40.3	3.91	39.9	3.96	1.45	0.14	1.39	0.09
/08/96-5b	163	3.0	39.4	3.82	39.0	3.87	1.33	0.13		
02/08/96-16a	164	3.0	40.0	3.88	39.6	3.93	1.33	0.13	1.44	0.16
02/08/96-16b[d]	164	2.8	43.0	6.08	42.6	6.11	1.56	0.22		
02/08/96-42a	166	2.9	45.6	4.43	45.2	4.47	1.55	0.15	1.46	0.12
02/08/96-42b[d]	166	3.0	41.2	5.30	40.8	5.34	1.38	0.18		
02/15/96-5a	169	2.7	72.0	6.99	71.6	7.01	2.61	0.26	2.61	0.00
02/15/96-5b	169	2.8	73.3	7.11	72.9	7.14	2.61	0.26		
02/15/96-16a	168	2.8	81.5	7.91	81.1	7.93	2.84	0.28	2.79	0.07
02/15/96-16b	168	2.7	75.1	7.29	74.7	7.31	2.74	0.27		
02/15/96-42a	167	2.6	78.1	7.58	77.7	7.60	2.95	0.29	2.73	0.31
02/15/96-42b	167	2.8	70.8	6.87	70.4	6.90	2.51	0.25		
02/22/96-5a[d]	167	2.8	100.3	1.34	99.9	1.47	3.57	0.05	3.49	0.12
02/22/96-5b	167	2.9	99.0	9.61	98.6	9.63	3.41	0.33		
02/22/96-16a[d]	168	2.8	82.2	3.82	81.8	3.87	2.91	0.14	3.26	0.50
02/22/96-16b	168	2.9	105.7	10.26	105.3	10.28	3.61	0.35		
02/22/96-42a	169	3.0	78.6	7.63	78.2	7.65	2.58	0.25	2.71	0.18
02/22/96-42b	169	3.0	86.5	8.40	86.1	8.42	2.84	0.28		

[a] The % standard deviation from Desert Research Institute replication is 9.7%.

[b] The subtracted blank mass is 0.4 ± 0.6 µg.

[c] The average % standard deviation from adjacent replicates was 7.5%

[c] Replicate chemical analysis performed on this sample.

Table A.7. SO_2 Deposition Fluxes to Whatman Filters.

Sample	Time (hr)	SO_4 mass (μg) [a]	SO_4 mass std. dev. (μg)[b]	Net SO_4 mass (μg)	Net SO_4 mass std. dev. (μg)	SO_2 flux (ng/cm^2/day)	SO_2 flux std dev. (ng/cm^2/day)	ave SO_2 flux (ng/cm^2/day)	ave SO_2 flux Std dev. (ng/cm^2/day)[c]
11/20/95-5a-1	332	2890	39.7	2887	39.7	1616	14.9	1672	43.3
11 /20/95-5a-2	332	3050	22.4	3048	22.4	1706	8.4		
11/20/95-5a-3	332	3050	44.5	3048	44.5	1706	16.7		
11/20/95-5a-4	332	2966	59.0	2963	59.1	1659	22.2		
11/20/95-Sb-i	332	2832	31.7	2830	31.7	1584	11.9	1606	75.7
11/20/95-5b-2	332	3032	22.1	3029	22.1	1696	8.3		
11 /20/95-Sb-3	332	2709	37.7	2707	37.7	1515	14.1		
11/20/95-5b-4	332	2909	41.0	2907	41.1	1627	15.4		
11/20/95-5c-i	332	2903	28.5	2901	28.5	1624	10.7	1667	46.1
11/20/95-5c-2	332	3092	1.8	3090	2.5	1730	0.9		
11/20/95-5c-3	332	2938	38.2	2936	38.2	1643	14.3		
1120/95-5c-4	332	2992	12.3	2989	12.4	1673	4.6		
11/20/95-5d-1	332	2340	215.9	2338	215.9	1309	81.0	1376	54.9
11/20/95-Sd-2	332	2534	11.4	2531	11.5	1417	4.3		
11/20/95-Sd-3	332	2548	30.0	2546	30.1	1425	11.3		
11/20/95-5d-4	332	2423	11.6	2421	11.7	1355	4.4		
1/20/95-5e-1	332	2473	15.0	2471	15.1	1383	5.7	1387	6.8
11/20/95-5e-2	332	2490	41.8	2487	41.9	1392	15.7		
11/20/95-Se-3	332	2491	25.6	2489	25.6	1393	9.6		
11/20/95-5e-4	332	2467	12.1	2464	12.2	1379	4.6		
11/20/9S-5f-1	332	3S81	11.0	3578	11.1	2003	4.2	2004	45.3
11/20/95-5f-2	332	3488	2.3	3485	2.9	1951	1.1		
11/20/9S-5f-3	332	3685	17.4	3683	17.5	2062	6.6		
11/20/95-5f-4	332	3576	0.9	3574	1.9	2000	0.7		

Table A.7. SO$_2$ Deposition Fluxes to Whatman Filters.

Sample	Time (hr)	SO$_4$ mass (µg) [a]	SO$_4$ mass std. dev. (µg)[b]	Net SO$_4$ mass (µg)	Net SO$_4$ mass std. dev. (µg)	SO$_2$ flux (ng/cm^2/day)	SO$_2$ flux std dev. (ng/cm^2/day)	ave SO$_2$ flux (ng/cm^2/day)	ave SO$_2$ flux Std dev. (ng/cm^2/day)[c]
11/20/95-16a-1	332	5636	117.6	5633	117.6	3153	44.1	2902	183.6
11/20/95-16a-2	332	5229	251.3	5226	251.3	2925	94.3		
11/20/95-16a-3	332	4960	164.4	4958	164.4	2775	61.7		
11/20/95-16a-4	332	4925	39.7	4923	39.7	2756	14.9		
11/20/95-16b-1	332	3686	1.8	3683	2.5	2062	0.9	2152	68.4
11/20/95-16b-2	332	3817	124.7	3815	124.7	2135	46.8		
11/20/95-1 6b-3	332	3946	15.9	3943	16.0	2207	6.0		
11/20/95-16b-4	332	3937	39.7	3934	39.7	2202	14.9		
11/20/95-16c-1	332	4795	280.0	4792	280.0	2683	105.0	2691	67.6
1 1/20/95-16c-2	332	4837	278.6	4834	278.6	2706	104.5		
11/20/95-16c-3	332	4659	75.4	4656	75.4	2606	28.3		
11/20/95-1 6c-4	332	4951	118.0	4949	118.0	2770	44.3		
12/04/9S-5a-1	338	3341	52.4	3339	52.4	1836	19.3	1846	25.0
12/04/95-5a-2	338	3420	10.5	3417	10.6	1879	3.9		
12/04/95-5a-3	338	3367	29.1	3364	29.1	1850	10.7		
12/04/95-5a-4	338	3313	107.8	3311	107.8	1820	39.7		
12/04/95-5b-1	338	3105	33.4	3103	33.4	1706	12.3	1725	76.8
12/04/95-5b-2	338	3294	87.8	3292	87.9	1810	32.4		
12/04/95-5b-3	338	3022	49.1	3019	49.1	1660	18.1		
1 2/04/95-5b-4[d]	338								
12/04/95-5c-1	338	3198	21.7	3195	21.8	1757	8.0	1748	79.0
12/04/95-5c-2	338	3312	74.3	3310	74.3	1820	27.4		
12/04/95-Sc-3	338	2978	132.5	2976	132.5	1636	48.8		
12/04/95-5c-4	338	3240	101.5	3237	101.5	1780	37.4		

Table A.7. SO_2 Deposition Fluxes to Whatman Filters (continued).

Sample	**Time (hr)**	**SO_4 mass (µg)** [a]	**SO_4 mass std. dev. (µg)**[b]	**Net SO_4 mass (µg)**	**Net SO_4 mass std. dev. (µg)**	**SO_2 flux (ng/cm^2/day)**	**SO_2 flux std dev. (ng/cm^2/day)**	**ave SO_2 flux (ng/cm^2/day)**	**ave SO_2 flux Std dev. (ng/cm^2/day)**[c]
12/04/95-5d-1	338	3028	11.6	3026	11.8	1664	4.3	1622	100.8
12/04/95-5d-2	338	2991	57.1	2988	57.1	1643	21.0		
12/04/95-5d-3	338	3107	21.8	3104	21.8	1707	8.0		
12/04/95-5d-4	338	2688	49.0	2685	49.0	1477	18.1		
12/04/95-5e-1	338	2894	59.4	2892	59.5	1590	21.9	1579	26.2
12/04/95-5e-2	338	2806	32.8	2803	32.9	1541	12.1		
12/04/95-5e-3	338	2881	14.2	2879	14.3	1583	5.3		
12/04/95-5e-4	338	2915	71.4	2912	71.4	1601	26.3		
12/04/95-5f-1	338	3274	106.4	3271	106.4	1799	39.2	1817	40.7
12/04/95-5f-2	338	3231	114.1	3228	114.1	1775	42.0		
12/04/95-5f-3	338	3317	78.8	3314	78.9	1822	29.1		
12/04/95-5f-4	338	3404	116.2	3402	116.2	1870	42.8		
12/04/95-16a-1	338	4605	231.8	4603	231.8	2531	85.4	2481	86.6
12/04/95-16a-2	338	4379	205.7	4377	205.7	2406	75.8		
12/04/95-16a-3	338	4692	276.6	4689	276.6	2578	101.9		
12/04/95-16a-4	338	4386	234.6	4384	234.6	2410	86.4		
12/04/95-16b-1	338	3268	168.4	3265	168.4	1795	62.0	1811	72.1
12/04/95-16b-2	338	3124	174.6	3121	174.6	1716	64.3		
12/04/95-16b-3	338	3413	181.1	3410	181.2	1875	66.7		
12/04/95-16b-4	338	3382	170.8	3380	170.8	1858	62.9		
12/04/95-16c-1	338	4253	259.8	4251	259.8	2337	95.7	2335	37.8
12/04/95-16c-2	338	4339	257.0	4337	257.0	2384	94.7		
12/04/95-16c-3	338	4172	274.4	4170	274.4	2293	101.1		
12/04/95-16c-4	338	4236	252.9	4234	252.9	2328	93.2		

Table A.7. SO_2 Deposition Fluxes to Whatman Filters (continued).

Sample	**Time (hr)**	**SO_4 mass (μg)** [a]	**SO_4 mass std. dev. (μg)**[b]	**Net SO_4 mass (μg)**	**Net SO_4 mass std. dev. (μg)**	**SO_2 flux (ng/cm^2/day)**	**SO_2 flux std dev. (ng/cm^2/day)**	**ave SO_2 flux (ng/cm^2/day)**	**ave SO_2 flux Std dev. (ng/cm^2/day)**[c]
02/01/96-5a-1	336	2779	172.2	2776	172.2	1534	63.8	1555	42.6
02/01/96-5a-2	336	2911	153.0	2909	153.0	1608	56.7		
02/01/96-5a-3	336	2842	167.6	2839	167.7	1569	62.1		
02/01/96-5a-4	336	2734	208.0	2732	208.1	1510	77.0		
02/01/96-5b-1	336	2526	187.5	2523	187.5	1394	69.4	1377	35.5
02/01/96-5b-2	336	2412	66.2	2409	66.2	1332	24.5		
02/01/96-5b-3	336	2561	139.8	2558	139.8	1414	51.8		
02/01/96-5b-4	336	2480	66.9	2478	66.9	1369	24.8		
02/01/96-5c-1	336	2258	169.7	2255	169.7	1246	62.8	1259	16.3
02/01/96-5c-2	336	2287	148.4	2284	148.4	1263	55.0		
02/01/96-5c-3	336	2321	150.6	2318	150.6	1281	55.8		
02/01/96-5c-4	336	2259	147.2	2257	147.2	1247	54.5		
02/01/96-5d-1	336	2348	226.8	2345	226.8	1296	84.0	1322	25.5
02/01/96-5d-2	336	2415	145.8	2413	145.8	1334	54.0		
02/01/96-5d-3	336	2448	28.2	2445	28.2	1352	10.5		
02/01/96-5d-4	336	2364	110.6	2362	110.6	1305	40.9		
02/01/96-5e-1	336	2425	105.4	2422	105.4	1339	39.0	1330	38.2
02/01/96-5e-2	336	2438	81.5	2436	81.5	1346	30.2		
02/01/96-5e-3	336	2310	51.0	2307	51.0	1275	18.9		
02/01/96-5e-4	336	2467	84.2	2464	84.3	1362	31.2		
02/01/96-51-1	336	3785	297.7	3782	297.7	2090	110.3	2012	92.0
02/01/96-51-2	336	3485	285.2	3482	285.2	1925	105.6		
02/01/96-51-3	336	3513	8.0	3510	8.2	1940	3.0		
02/01/96-5f-4	336	3788	264.3	3786	264.3	2092	97.9		

Table A.7. SO$_2$ Deposition Fluxes to Whatman Filters (continued).

Sample	Time (hr)	SO$_4$ mass (µg) [a]	SO$_4$ mass std. dev. (µg)[b]	Net SO$_4$ mass (µg)	Net SO$_4$ mass std. dev. (µg)	SO$_2$ flux (ng/cm^2/day)	SO$_2$ flux std dev. (ng/cm^2/day)	ave SO$_2$ flux (ng/cm^2/day)	ave SO$_2$ flux Std dev. (ng/cm^2/day)[c]
02/01/96-16a-1	336	3632	165.9	3629	165.9	2006	61.4	1960	251.7
02/01/96-16a-2	336	2971	66.6	2969	66.6	1641	24.7		
02/01/96-16a-3	336	4078	101.7	4076	101.7	2253	37.7		
02/01/96-16a-4	336	3514	282.4	3512	282.4	1941	104.6		
02/01/96-16b-1	336	2524	22.7	2521	22.8	1393	8.4	1556	192.2
02/01/96-16b-2	336	2539	102.4	2537	102.4	1402	37.9		
02/01/96-16b-3	336	3236	226.6	3233	226.6	1787	83.9		
02/01/96-16b-4	336	2973	216.1	2970	216.1	1641	80.0		
02/01/96-16c-1	336	3421	239.0	3418	239.0	1889	88.5	1786	104.9
02/01/96-16c-2	336	3061	131.9	3058	131.9	1690	48.9		
02/01/96-16c-3	336	3373	271.3	3371	271.3	1863	100.5		
02/01/96-16c-4	336	3079	149.2	3077	149.2	1701	55.2		
02/15/96-5a-1	336	3898	207.2	3895	207.2	2153	76.7	2187	95.6
02/1 5/96-5a-2	336	4211	290.3	4209	290.3	2326	107.5		
02/15/96-5a-3	336	3909	195.1	3907	195.1	2159	72.2		
02/15/96-5a-4	336	3818	118.9	3815	118.9	2109	44.0		
02/15/96-5b-1	336	3069	103.2	3066	103.2	1695	38.2	1741	163.9
02/15/96-5b-2	336	3218	109.6	3216	109.6	1777	40.6		
02/15/96-5b-3	336	2806	117.7	2803	117.7	1549	43.6		
02/15/96-5b-4	336	3516	30.7	3514	30.8	1942	11.4		
02/15/96-5c-1	336	3181	232.0	3179	232.0	1757	85.9	1749	107.9
02/15/96-5c-2	336	3220	214.0	3217	214.0	1778	79.2		
02/15/96-5c-3	336	3369	230.7	3367	230.7	1861	85.4		
02/15/96-5c-4	336	2902	31.3	2899	31.3	1602	11.6		

Table A.7. SO_2 Deposition Fluxes to Whatman Filters (continued).

Sample	**Time (hr)**	**SO_4 mass (μg) [a]**	**SO_4 mass std. dev. (μg)[b]**	**Net SO_4 mass (μg)**	**Net SO_4 mass std. dev. (μg)**	**SO_2 flux (ng/cm^2/day)**	**SO_2 flux std dev. (ng/cm^2/day)**	**ave SO_2 flux (ng/cm^2/day)**	**ave SO_2 flux Std dev. (ng/cm^2/day)[c]**
02/15/96-5d-1[d]	336								
02/15/96.5d-2[d]	336								
02/15/96-5d-3[d]	336								
02/15/96-5d-4[d]	336								
02/15/96-5e-1	336	3435	260.6	3432	260.6	1897	96.5	1833	82.2
02/15/96-5e-2	336	3410	128.2	3407	128.2	1883	47.5		
02/15/96-5e-3	336	3108	188.3	3105	188.3	1716	69.7		
02/15/96-5e-4	336	3325	229.5	3323	229.5	1836	85.0		
02/15/96-5f-1	336	3424	207.0	3422	207.0	1891	76.6	2060	281.2
02/15/96-5f-2	336	3221	120.1	3218	120.1	1779	44.5		
02/15/96-5f-3	336	3926	268.1	3923	268.1	2168	99.3		
02/15/96-5f-4	336	4351	326.9	4349	326.9	2403	121.1		
02/15/96-16a-1	336	5817	329.2	5815	329.2	3216	122.0	2977	202.0
02/15/96-16a-2	336	5306	254.5	5304	254.5	2934	94.3		
02/15/96-16a-3	336	5477	306.4	5475	306.5	3028	113.6		
02/15/96-16a-4	336	4939	222.5	4937	222.5	2730	82.4		
02/15/96-16b-1	336	3485	40.4	3482	40.5	1926	15.0	2003	284.5
02/15/96-16b-2	336	3285	52.8	3282	52.9	1815	19.6		
02/15/96-16b-3	336	3341	63.1	3339	63.2	1847	23.4		
02/15/96-16b-4	336	4385	18.4	4383	18.5	2424	6.8		
02/15/96-16c-1	336	4836	64.5	4833	64.6	2673	23.9	2890	211.4
02/15/96-1 6c-2	336	5379	60.9	5376	61.0	2974	22.6		
02/1 5/96-16c-3	336	5007	59.8	5004	59.8	2768	22.2		
02/15/96-16c-4	336	5689	16.2	5687	16.3	3145	6.0		

Table A.7. SO_2 Deposition Fluxes to Whatman Filters (continued).

Sample	Time (hr)	SO_4 mass (μg) [a]	SO_4 mass std. dev. (μg)[b]	Net SO_4 mass (μg)	Net SO_4 mass std. dev. (μg)	SO_2 flux (ng/cm^2/day)	SO_2 flux std dev. (ng/cm^2/day)	ave SO_2 flux (ng/cm^2/day)	ave SO_2 flux Std dev. (ng/cm^2/day) [c]
05/14/96-5a-1	356	2528	65.7	2525	65.7	1317	23.0	1319	38.7
05/14/96-5a-2	356	2613	95.6	2610	95.6	1362	33.4		
05/14/96-5a-3	356	2549	93.9	2546	93.9	1328	32.8		
05/14/96-5a-4	356	2433	71.4	2431	71.5	1268	25.0		
05/14/96-5b-1	356	2682	71.4	2679	71.4	1397	24.9	1381	28.2
05/14/96-5b-2	356	2634	55.0	2632	55.0	1373	19.2		
0S/14/96-5b-3	356	2701	74.8	2698	74.8	1408	26.1		
05/i 4/96-5b-4	356	2580	26.5	2577	26.5	1344	9.3		
05/14/96-5c-1	356	2645	31.9	2643	31.9	1378	11.1	1392	69.5
05/14/96-5c-2	356	2864	90.7	2862	90.8	1493	31.7		
05/14/96-5c-3	356	2564	57.4	2562	57.5	1336	20.1		
05/14/96-5c-4	356	2609	60.1	2607	60.1	1360	21.0		
05/14/96-5d-1	356	2482	37.5	2479	37.5	293	13.1	1266	35.9
05/14/96-5d-2	356	2483	58.0	2481	58.0	294	20.3		
05/14/96-5d-3	356	2415	104.3	2412	104.4	1258	36.5		
05/i4/96-5d-4	356	2338	89.0	2336	89.0	1218	31.1		
05/14/96-5e-1	356	2523	65.7	2520	65.7	1315	23.0	1349	25.7
05/14/96-5e-2	356	2638	91.6	2636	91.6	1375	32.0		
05/14/96-5e-3	356	2609	74.8	2606	74.8	1360	26.1		
05/14/96-5e-4	356	2583	110.4	2581	110.4	1346	38.6		
05/14/96-51-1	356	3164	105.7	3161	105.7	1649	37.0	1524	117.0
05/14/96-51-2	356	2705	93.3	2703	93.3	1410	32.6		
05/14/96-51-3	356	2763	213.8	2760	213.8	1440	74.7		
05/14/96-51-4	356	3064	97.8	3062	97.8	1597	34.2		

Table A.7. SO_2 Deposition Fluxes to Whatman Filters (continued).

Sample	**Time (hr)**	**SO_4 mass (μg) [a]**	**SO_4 mass std. dev. (μg)[b]**	**Net SO_4 mass (μg)**	**Net SO_4 mass std. dev. (μg)**	**SO_2 flux (ng/cm^2/day)**	**SO_2 flux std dev. (ng/cm^2/day)**	**ave SO_2 flux (ng/cm^2/day)**	**ave SO_2 flux Std dev. (ng/cm^2/day)[c]**
05/14/96-16a-1	358	4287	49.9	4285	50.0	2224	17.4	2378	200.4
05/14/96-16a-2	358	4686	27.9	4684	27.9	2431	9.7		
05/14/96-16a-3	358	5088	76.7	5085	76.7	2640	26.7		
05/14/96-16a-4	358	4276	3.7	4274	4.1	2219	1.4		
05/14/96-16b-1	358	2792	2.3	2790	2.8	1448	1.0	1352	116.2
05/14/96-16b-2	358	2691	22.0	2689	22.1	1396	7.7		
05/14/96-16b-3	358	2664	20.0	2662	20.1	1382	7.0		
05/14/96-16b-4	358	2282	3.0	2279	3.4	1183	1.2		
05/14/96-16c-1	358	2062	20.6	2060	20.7	1069	7.2	961	101.6
05/14/96-16c-2	358	1912	28.4	1910	28.5	991	9.9		
05/14/96-16c-3	358	1593	24.3	1591	24.3	826	8.5		
05/14/96-16c-4	358	1848	38.3	1845	38.3	958	13.3		
05/29/96-5a-1	341	2536	182.6	2534	182.6	1381	66.7	1438	81.9
05/29/96-5a-2	341	2498	216.7	2495	216.7	1360	79.1		
05/29/96-5a-3	341	2817	57.9	2815	57.9	1534	21.2		
05/29/96-5a-4	341	2714	13.4	2711	13.5	1478	4.9		
Ô5/29/96-5b-1	341	2324	64.1	2322	64.1	1265	23.4	1277	40.1
05/29/96-5b-2	341	2406	60.5	2404	60.5	1310	22.1		
05/29/96-5b-3	341	2252	127.9	2250	127.9	1226	46.7		
05/29/96-5b-4	341	2403	64.6	2401	64.6	1308	23.6		
05/29/96-5c-i	341	2609	35.1	2607	35.1	1421	12.8	1439	63.5
05/29/96-5c-2	341	2800	33.5	2798	33.5	1525	12.2		
05/29/96-5c-3	341	2521	49.9	2519	50.0	1373	18.2		
05/29/96-5c-4	341	2639	67.1	2637	67.1	1437	24.5		

Table A.7. SO_2 Deposition Fluxes to Whatman Filters (continued).

Sample	**Time (hr)**	**SO_4 mass (µg) [a]**	**SO_4 mass std. dev. (µg)[b]**	**Net SO_4 mass (µg)**	**Net SO_4 mass std. dev. (µg)**	**SO_2 flux (ng/cm^2/day)**	**SO_2 flux std dev. (ng/cm^2/day)**	**ave SO_2 flux (ng/cm^2/day)**	**ave SO_2 flux Std dev. (ng/cm^2/day)[c]**
05/29/96-Sd-1	341	2118	81.4	2115	81.4	1153	29.7	1131	38.6
05/29/96-5d-2	341	2146	84.5	2143	84.5	1168	30.9		
05/29/96-5d-3	341	2059	80.5	2057	80.5	1121	29.4		
05/29/96-5d-4	341	1985	96.9	1983	97.0	1081	35.4		
05/29/96-5e-1	341	1914	65.1	1911	65.1	1042	23.8	1135	67.5
05/29/96-5e-2	341	2081	92.6	2078	92.6	1133	33.8		
05/29/96-5e-3	341	2156	86.1	2154	86.1	1174	31.4		
05/29/96-5e-4	341	2193	89.8	2190	89.9	1194	32.8		
05/29/96-5f-1	341	2745	169.9	2742	169.9	1494	62.0	1503	10.7
05/29/96-5f-2	341	2754	145.1	2751	145.1	1499	53.0		
05/29/96-5f-3	341	2752	140.7	2749	140.7	1498	51.4		
05/29/96-5f-4	341	2789	109.9	2786	109.9	1518	40.1		
05/29/96-16a-1	340	4413	104.0	4411	104.0	2411	38.1	2327	99.6
05/29/96-16a-2	340	4072	159.2	4069	159.2	2224	58.3		
05/29/96-16a-3	340	4418	54.9	4416	54.9	2414	20.1		
05/29/96-16a-4	340	4135	156.3	4132	156.3	2259	57.2		
05/29/96-16b-1	340	2950	172.3	2948	172.3	1611	63.1	1685	92.9
05/29/96-16b-2	340	2942	166.4	2940	166.4	1607	60.9		
05/29/96-16b-3	340	3162	185.7	3160	185.7	1727	68.0		
05/29/96-16b-4	340	3290	186.7	3287	186.7	1797	68.4		
05/29/96-16c-1	340	4231	161.3	4229	161.3	2311	59.1	2318	49.6
05/29/96-16c-2	340	4254	129.2	4251	129.2	2324	47.3		
05/29/96-16c-3	340	4133	167.8	4131	167.8	2258	61.5		
05/29/96-16c-4	340	4355	169.7	4352	169.7	2379	62.1		

Table A.7. SO$_2$ Deposition Fluxes to Whatman Filters (continued).

Sample	Time (hr)	SO$_4$ mass (µg) [a]	SO$_4$ mass std. dev. (µg)[b]	Net SO$_4$ mass (µg)	Net SO$_4$ mass std. dev. (µg)	SO$_2$ flux (ng/cm^2/day)	SO$_2$ flux std dev. (ng/cm^2/day)	ave SO$_2$ flux (ng/cm^2/day)	ave SO$_2$ flux Std dev. (ng/cm^2/day)[c]
07/24/96-5a-1	336	1929	36.0	1926	36.1	1064	13.4	1037	31.9
07/24/96-5a-2	336	1922	41.2	1919	41.2	1060	15.2		
07/24/96-5a-3	336	1864	38.7	1861	38.7	1028	14.3		
07/24/96-5a-4	336	1805	107.5	1803	107.5	996	39.8		
07/24/96-5b-1	336	1650	51.8	1647	51.8	910	19.2	929	23.8
07/24/96-5b-2	336	1693	6.3	1691	6.5	934	2.4		
07/24/96-5b-3	336	1653	52.1	1651	52.1	912	19.3		
07/24196-5b-4	336	1742	47.4	1740	47.5	961	17.6		
07/24/96-5c-1	336	1739	49.7	1737	49.8	959	18.4	974	42.2
07/24/96-5c-2	336	1875	34.3	1872	34.4	1034	12.7		
07/24/96-5c-3	336	1696	47.0	1693	47.0	935	17.4		
07/24/96-5c-4	336	1757	73.5	1754	73.5	969	27.2		
07/24/96-5d-1	336	1415	76.9	1412	77.0	780	28.5	810	45.5
07/24/96-5d-2	336	1582	53.5	1580	53.5	872	19.8		
07/24/96-5d-3	336	1478	87.3	1476	87.3	815	32.3		
07/24/96-5d-4	336	1402	79.9	1400	79.9	773	29.6		
07/24/96-5e-1	336	1536	35.9	1533	36.0	847	13.3	887	32.5
07/24/96-5e-2	336	1641	75.9	1639	75.9	905	28.1		
07/24/96-5e-3	336	1590	66.1	1587	66.1	877	24.5		
07/24/96-5e-4	336	1669	67.1	1666	67.1	920	24.8		
07/24196-5f-1	336	2042	51.2	2039	51.2	1126	19.0	1097	33.2
07/24/96-5f-2	336	1938	48.8	1935	48.8	1069	18.1		
07/24/96-51-3	336	2038	59.9	2036	59.9	1124	22.2		
07/24/96-51-4	336	1934	32.0	1931	32.1	1067	11.9		

Table A.7. SO_2 Deposition Fluxes to Whatman Filters (continued).

Sample	Time (hr)	SO_4 mass (μg)[a]	SO_4 mass std. dev. (μg)[b]	Net SO_4 mass (μg)	Net SO_4 mass std. dev. (μg)	SO_2 flux (ng/cm^2/day)	SO_2 flux std dev. (ng/cm^2/day)	ave SO_2 flux (ng/cm^2/day)	ave SO_2 flux Std dev. (ng/cm^2/day)[c]
07/24/96-16a-1	336	2558	35.2	2555	35.3	1414	13.1	1412	45.5
07/24/96-16a-2	336	2541	45.3	2538	45.4	1405	16.8		
07/24/96-16a-3	336	2657	45.6	2655	45.6	1469	16.9		
07/24/96-16a-4	336	2457	13.2	2454	13.3	1358	4.9		
07/24/96-16b-1	336	2306	35.3	2303	35.4	1275	13.1	1263	27.4
07/24/96-16b-2	336	2332	10.9	2330	11.0	1289	4.1		
07/24/96-16b-3	336	2216	1.0	2214	2.0	1225	0.7		
07/24/96-16b-4	336	2286	17.1	2283	17.2	1264	6.4		
07/24/96-16c-1	336	1686	33.6	1684	33.6	932	12.5	1034	96.9
07/24/96-16c-2	336	1780	27.4	1778	27.4	984	10.2		
07/24/96-16c-3	336	2086	34.8	2084	34.8	1153	12.9		
07/24/96-16c-4	336	1928	26.2	1925	26.2	1066	9.7		
08/07/96-5a-1	333	1810	10.8	1807	10.9	1007	4.1	984	58.8
08/07/96-5a-2	333	1894	19.0	1891	19.1	1054	7.1		
08/07/96-5a-3	333	1720	35.1	1717	35.1	957	13.1		
08/07/96-5a-4	333	1652	68.0	1649	68.1	919	25.4		
08/07/96-5b-1	333	1613	81.5	1611	81.5	898	30.4	879	48.9
08/07/96-5b-2	333	1671	68.9	1668	69.0	930	25.7		
08/07/96-5b-3	333	1572	118.3	1569	118.3	874	44.2		
08/07/96-5b-4	333	1463	84.3	1461	84.3	814	31.5		
08/07/96-5c-1	333	1667	80.1	1664	80.1	927	29.9	921	57.7
08/07/96-5c-2	333	1781	79.5	1779	79.6	991	29.7		
08/07/96-5c-3	333	1529	89.5	1526	89.5	850	33.4		
08/07/96-5c-4	333	1642	70.8	1640	70.8	914	26.4		

Table A.7. SO_2 Deposition Fluxes to Whatman Filters (continued).

Sample	Time (hr)	SO_4 mass (μg) [a]	SO_4 mass std. dev. (μg)[b]	Net SO_4 mass (μg)	Net SO_4 mass std. dev. (μg)	SO_2 flux (ng/cm^2/day)	SO_2 flux std dev. (ng/cm^2/day)	ave SO_2 flux (ng/cm^2/day)	ave SO_2 flux Std dev. (ng/cm^2/day)[c]
08/07/96-5d-1	333	1488	100.4	1485	100.4	828	37.5	800	25.0
08/07/96-5d-2	333	1463	109.0	1461	109.0	814	40.7		
08/07/96-5d-3	333	1401	109.9	1398	109.9	779	41.0		
08/07/96-5d-4	333	1398	112.1	1396	112.1	778	41.9		
08/07/96-5e-i	333	1433	107.5	1431	107.5	797	40.1	819	25.8
08/07/96-5e-2	333	1459	96.3	1457	96.3	812	35.9		
08/07/96-5e-3	333	1455	106.7	1452	106.7	809	39.8		
08/07/96-5e-4	333	1539	98.5	1536	98.5	856	36.8		
08/07/96-5f-1	333	1828	59.5	1825	59.5	1017	22.2	1061	38.3
08/07/96-5f-2	333	1975	33.0	1973	33.0	1099	12.3		
08/07/96-5f-3	333	1951	44.6	1949	44.7	1086	16.7		
08/07/96-5f-4	333	1871	33.8	1869	33.8	1041	12.6		
08/07/96-16a-1	333	2586	212.7	2584	212.7	1442	79.5	1378	56.8
08/07/96-16a-2	333	2434	107.2	2431	107.3	1357	40.1		
08/07/96-16a-30	333								
08/07/96-16a-4	333	2393	102.6	2391	102.6	1334	38.4		
08/07/96-16b-1	333	1863	62.3	1860	62.3	1038	23.3	1066	36.8
08/07/96-16b-2	333	1864	62.6	1861	62.6	1039	23.4		
08/07/96-16b-3	333	2002	17.0	2000	17.0	1116	6.4		
08/07/96-16b-4	333	1924	36.1	1922	36.2	1072	13.5		
08/07/96-i 6c-1	333	2278	62.0	2276	62.0	1270	23.2	1258	19.0
08/07/96-16c-2	333	2224	80.5	2221	80.6	1240	30.1		
08/07/96-16c-3	333	2230	70.6	2228	70.6	1243	26.4		
08/07/96-16c-4	333	2292	81.6	2289	81.6	1278	30.5		

[a] Average % standard deviation from IC replication is 3.4%.

[b] The subtracted blank mass was 2.53 ± 1.66 μg.

[c] The average % standard deviation from adjacent samples is 4.7%.

[d] Sample was lost during exposure.

Appendix B

Elemental Carbon Airborne Concentrations for the Period 3/18/94 through 6/27/95

Table B.1. Elemental Carbon Airborne Concentrations on quartz Filters For the Period 3/18/94 to 6/27/95.

Sample	Time (hr)	Flow rate (L/min)	Carbon mass (µg)	Carbon mass std. dev. (µg)[a]	Net Carbon mass (µg)[b]	Net Carbon mass std. dev. (µg)	Carbon conc. (µg/m^3)	Carbon conc. std. dev. (µg/m^3)	Ave Carbon conc. (µg/m^3)	Ave Carbon conc. std. dev. (µg/m^3)[C]
03/18/94-5a	163	2.7	103.6	8.7	102.9	8.7	3.88	0.33	4.04	0.22
03/18/94-Sb	163	2.7	111.9	9.3	111.2	9.4	4.20	0.35		
03/25/94-5a	194	2.7	76.5	6.4	75.8	6.4	2.40	0.20	2.30	0.14
03/25/94-5b	194	2.7	70.1	5.9	69.4	5.9	2.20	0.19		
04/02/94-5a[d]	167	2.7	85.1	6.2	84.4	6.3	3.11	0.23	3.09	0.03
04/02/94-5b[d]	167	2.7	84.0	16.9	83.3	16.9	3.07	0.62		
04/09/94-5a	170	2.7	80.4	6.7	79.7	6.8	2.88	0.24	2.92	0.05
04/09/94-Sb	170	2.7	82.2	6.9	81.5	6.9	2.95	0.25		
04/16/94-Sa	168	2.7	87.1	7.3	86.4	7.3	3.16	0.27	2.69	0.67
04/16/94-Sb	168	2.7	61.2	5.1	60.5	5.2	2.22	0.19		
04/23/94-5a	215	2.7	198.4	16.6	197.7	16.6	5.66	0.47	5.85	0.27
04/23/94-5b[d]	215	2.7	211.8	3.5	211.1	3.6	6.04	0.10		
05/02/94-5a	217	2.7		8.4	100.2	8.5	2.84	0.24	2.65	0.27
05/02/94-Sb	217	2.7	87.6	7.3	86.9	7.4	2.46	0.21		
05/11/94-5a	167	2.7	63.2	5.3	62.5	5.3	2.30	0.20	2.23	0.11
05/11/94-Sb	167	2.7	59.1	4.9	58.4	5.0	2.15	0.18		
05/18/94-5a	169	2.7	84.4	7.1	83.7	7.1	3.05	0.26	3.20	0.21
05/18/94-5b	169	2.7	92.6	7.7	91.9	7.8	3.35	0.28		
06/25/94-5a	168	2.7	195.2	16.3	194.5	16.3	7.12	0.60	7.07	0.07
06/25/94-5b	168	2.7	192.5	16.1	191.8	16.1	7.02	0.59		
06/01/94-5a[d]	166	2.7	118.3	14.2	117.6	14.2	4.36	0.53	4.55	0.27
06/01/94-5b	166	2.7	128.6	10.7	127.9	10.8	4.74	0.40		
06/08/94-5a	194	2.7	140.7	11.8	140.0	11.8	4.44	0.37	4.45	0.02
06/08/94-5b[d]	194	2.7	141.7	0.9	141.0	1.2	4.47	0.04		
06/16/94-5a	166	2.7		8.9	105.9	8.9	3.92	0.33	3.90	0.03

Table B.1. Elemental Carbon Airborne Concentrations on quartz Filters For the Period 3/18/94 to 6/27/95 (continued).

Sample	Time (hr)	Flow rate (L/min)	Carbon mass (µg)	Carbon mass std. dev. (µg)[a]	Net Carbon mass (µg)[b]	Net Carbon mass std. dev. (µg)	Carbon conc. (µg/m^3)	Carbon conc. std. dev. (µg/m^3)	Ave Carbon conc. (µg/m^3)	Ave Carbon conc. std. dev. (µg/m^3)[C]
06/16/94-5b	166	2.7	105.3	8.8	104.6	8.8	3.88	0.33	2.19	0.02
06/23/94-5a	170	2.7	60.8	5.1	60.1	5.1	2.18	0.19		
06/23/94-5b	170	2.7	61.4	5.1	60.7	5.2	2.20	0.19		
06/30/94-5a	166	2.8	96.1	8.0	95.4	8.1	3.49	0.30	3.73	0.33
06/30/94-5b	166	2.8	108.7	9.1	108.0	9.1	3.96	0.33		
07/07/94-5a	193	2.8	105.0	8.8	104.3	8.8	3.28	0.28	3.23	0.07
7/07/94-5b	193	2.8	101.7	8.5	101.0	8.5	3.18	0.27		
07/14/94-5a	146	2.8	105.2	8.8	104.5	8.8	4.35	0.37	4.67	0.45
07/14/94-5b	146	2.8	120.5	10.1	119.8	10.1	4.99	0.42		
07/2i/94-5a	168	2.8	81.0	6.8	80.3	6.8	2.90	0.25	3.17	0.38
7/21/94-5b	168	2.8	95.9	8.0	95.2	8.0	3.44	0.29		
7/28/94-5a	189	2.8	119.9	10.0	119.2	10.0	3.83	0.32	4.11	0.40
07/28/94-5b•	189	2.8	137.3	10.3	136.6	10.3	4.39	0.33		
8/05/94-5a	171	2.8	86.0	7.2	85.3	7.2	3.03	0.26	3.06	0.04
08/05/94-5bd	171	2.8	87.7	7.3	87.0	7.4	3.09	0.26		
08/12/94-5a	146	2.8	63.3	5.3	62.6	5.3	2.60	0.22	2.47	0.19
08/12/94-5b	146	2.8	56.7	4.7	56.0	4.8	2.33	0.20		
08/18/94-5a	167	2.8	130.5	10.9	129.8	10.9	4.71	0.40	5.58	1.23
08/18/94-5b	167	2.8	178.6	14.9	177.9	14.9	6.46	0.54		
08/25/94-5a	359	2.8	225.3	18.8	224.6	18.8	3.80	0.32	3.77	0.03
08/25/94-5b[d]	359	2.8	222.6	11.1	221.9	11.1	3.75	0.19		
09/09/94-5a	288	2.8	225.4	18.8	224.7	18.8	4.73	0.40	5.78	1.49
09/09/94-5b	288	2.8	325.4	27.2	324.7	27.2	6.83	0.57		
09/21/94-5a	453	2.8	249.5	20.8	248.8	20.9	3.33	028	3.32	0.02
09/21/94-5b	453	2.8	247.9	20.7	247.2	20.7	3.31	0.28		

Table B.1. Elemental Carbon Airborne Concentrations on quartz Filters
For the Period 3/18/94 to 6/27/95 (continued).

Sample	Time (hr)	Flow rate (L/min)	Carbon mass (μg)	Carbon mass std. dev. (μg)[a]	Net Carbon mass (μg)[b]	Net Carbon mass std. dev. (μg)	Carbon conc. (μg/m^3)	Carbon conc. std. dev. (μg/m^3)	Ave Carbon conc. (μg/m^3)	Ave Carbon conc. std. dev. (μg/m^3)[C]
10/10/94-5a	220	2.8	200.6	16.8	199.9	16.8	5.52	0.46	6.15	0.89
10/10/94-5b	220	2.8	246.4	20.6	245.7	20.6	6.78	0.S7		
10/19/94-5a	216	2.8	195.5	16.3	194.8	16.3	5.48	0.46	5.42	0.08
10/19/94-5b	216	2.8	191.6	16.0	190.9	16.0	5.37	0.45		
10/28/94-5a	575	2.8	635.5	53.1	634.8	53.1	6.70	0.56	7.53	1.18
10/28/94-5b	575	2.8	793.9	66.3	793.2	66.3	1.49	0.70		
11/21/94-5ad	240	2.8	59.6	11.3	58.9	11.3	1.63	0.29	1.56	0.10
11/21/94-5b	240	2.8	65.2	5.4	64.5	5.5	1.63	0.14		
12/01/94-5a	431	2.8	372.8	31.1	372.1	31.2	5.23	0.44	5.36	0.18
12/01/94-5b	431	2.8	390.7	32.6	390.0	32.7	5.48	0.46		
12/1 9/94-5a	601	2.8	342.4	28.6	341.7	28.6	3.44	0.29	3.60	0.22
12/19/94-5b	601	2.8	373.0	31.2	372.3	31.2	3.75	0.31		
01/13/95-5a	168	2.8	86.7	7.2	86.0	7.3	3.10	0.26	2.93	0.24
01/13/95-5b	168	2.8	77.2	6.5	76.5	6.5	2.76	0.23		
01/20/95-5a	243	2.8	51.9	4.3	51.2	4.4	1.28	0.11	1.38	0.14
01/20/95-5b	243	2.8	59.9	5.0	59.2	5.1	1.48	0.13		
01/30/95-5ad	189	2.8	46.0	5.4	45.3	5.5	1.45	0.18	1.67	0.31
01/30/95-5b	189	2.8	59.5	5.0	58.8	5.0	1.89	0.16		
02/07/95-5a	170	2.8	42.6	3.6	41.9	3.6	1.50	0.13	1.62	0.17
02/07/95-5b	170	2.8	49.3	4.1	48.6	4.2	1.74	0.15		
02/14/95-5a	168	2.8	106.8	8.9	106.1	9.0	3.84	0.32	5.13	1.82
02/14/95-5b	168	2.8	178.5	14.9	177.8	14.9	6.42	0.54		
02/21/95-5a	169	2.8	81.5	6.8	80.8	6.8	2.90	0.25	3.31	0.58
02/21/95-5b	169	2.8	104.2	8.7	103.5	8.7	3.72	0.31		
02/28/95-5a	169	2.8	75.0	6.3	74.3	6.3	2.67	0.23	2.62	0.07

Table B.1. Elemental Carbon Airborne Concentrations on quartz Filters For the Period 3/18/94 to 6/27/95 (continued).

Sample	**Time (hr)**	**Flow rate (L/min)**	**Carbon mass (μg)**	**Carbon mass std. dev. (μg)[a]**	**Net Carbon mass (μg)[b]**	**Net Carbon mass std. dev. (μg)**	**Carbon conc. ($\mu g/m^3$)**	**Carbon conc. std. dev. ($\mu g/m^3$)**	**Ave Carbon conc. ($\mu g/m^3$)**	**Ave Carbon conc. std. dev. ($\mu g/m^3$)[C]**
02/28/95-5b[d]	169	2.8	72.1	5.4	71.4	5.4	2.57	0.19		
03/07/95-5a	168	2.8	130.4	10.9	129.7	10.9	4.69	0.40	5.69	1.40
03/07/95-5b	168	2.8	185.3	15.5	184.6	15.5	6.68	0.56		
03/14/95-5a	168	2.8	101.9	8.5	101.2	8.5	3.66	0.31	3.73	0.10
03/14/95-5b	168	2.8	106.2	8.9	105.5	8.9	3.80	0.32		
03/21/9S-5a	168	2.8	63.4	5.3	62.7	5.3	2.26	0.19	2.15	0.16
03/21/95-5b	168	2.8	57.1	4.8	56.4	4.8	2.04	0.17		
03/28/95-5a	168	2.8	42.5	3.6	41.8	3.6	1.51	0.13	1.36	0.21
03/28/95-5b	168	2.8	34.2	2.9	33.5	2.9	1.21	0.11		
04/04/95-5a	168	2.8	54.9	4.6	54.2	4.6	1.96	0.17	2.21	0.36
04/04/95-5b[d]	168	2.8	69.0	4.2	68.3	4.3	2.47	0.16		
04/11/95-5a	193	2.8	83.8	7.0	83.1	7.0	2.61	0.22	2.51	0.10
04/11/95-5b	193	2.8	77.8	6.5	77.1	6.5	2.43	0.21		
04/11/95-5c	193	2.8	79.5	6.6	78.8	6.7	2.48	0.21		
04/19/95-5a	312	2.8	127.2	10.6	126.5	10.7	2.46	0.21	2.51	0.07
04/19/95-5c	312	2.8	132.0	11.0	131.3	11.1	2.55	0.21		
05/02/95-5a	192	2.8	107.2	9.0	106.5	9.0	3.37	0.28	3.21	0.22
05/02/95-5c	192	2.8	97.2	8.1	96.5	8.2	3.06	0.26		
05/10/95-5a	169	2.8	120.7	10.1	120.0	10.1	4.32	0.36	4.19	0.17
05/10/95-5b	169	2.8	111.8	9.3	111.1	9.4	4.00	0.34		
05/10/95-5c	169	2.8	118.7	9.9	118.0	9.9	4.25	0.36		
05/17/95-5a[d]	169	2.8	70.6	4.2	69.9	4.2	2.51	0.15	2.26	0.35
05/17/95-5b	169	2.8	67.8	5.7	67.1	5.7	2.41	0.21		
05/17/95-5c	169	2.8	52.7	4.4	52.0	4.5	1.87	0.16		
05/24/95-5a	384	2.8	193.2	16.1	192.5	16.2	3.04	0.25	2.85	0.26

Table B.1. Elemental Carbon Airborne Concentrations on quartz Filters For the Period 3/18/94 to 6/27/95 (continued).

Sample	Time (hr)	Flow rate (L/min)	Carbon mass (μg)	Carbon mass std. dev. (μg)[a]	Net Carbon mass (μg)[b]	Net Carbon mass std. dev. (μg)	Carbon conc. (μg/m^3)	Carbon conc. std. dev. (μg/m^3)	Ave Carbon conc. (μg/m^3)	Ave Carbon conc. std. dev. (μg/m^3)[C]
05/24/95-5c	384	2.8	170.1	14.2	169.4	14.2	2.67	0.22		
06/09/95-5a	167	2.8	127.3	10.6	126.6	10.7	4.59	0.39	4.82	0.24
06/09/95-5b	167	2.8	140.3	11.7	139.6	11.7	5.06	0.43		
06/09/95-5c	167	2.8	133.3	11.1	132.6	11.2	4.81	0.40		
06/16/95[e]										
06/27/95-5a	213	2.8	105.4	8.8	104.7	8.8	2.98	0.25	3.03	0.08
06/27/95-5b	213	2.8	106.5	8.9	105.8	8.9	3.01	0.25		
06/27/95-5cd	213	2.8	110.5	4.5	109.8	4.5	3.12	0.13		

[a] The % standard deviation from Desert Research Institute replication is 8.4%.

[b] The subtracted blank mass is 0.7 ± 0.7 μg.

[c] The average % standard deviation from adjacent replicates was 8.7%.

[d] Replicate chemical analysis performed on this sample.

[e] Sample was lost due to a power outage at the Cathedral.

Appendix C

Measurements of Carbon Particle Washoff at the Cathedral of Learning

Greg Mumpower

Introduction

The Cathedral of Learning at the University of Pittsburgh is one of many limestone structures that have become soiled by the deposition of black carbon. The soiling has been aided by the presence of SO_2 which reacts with CaCO3 to form gypsum. The gypsum creates a porous surface which traps the carbon particles more effectively than the original limestone. Because of the location of the Cathedral of Learning in an urban setting in Pittsburgh, it has been exposed to many sources of pollution including factories, domestic sources, local traffic, and steel mills since its erection in the 1920’s and 1930’s.

Background

The initial examination of washoff processes at the Cathedral of Learning was conducted by Frank Molfetta during the 1994-1 995 academic year. The major focus of his project was to determine whether it is feasible to initiate a long-term study of washoff of applied carbon spots by rain on the walls of the Cathedral. Initially, four different substances were applied to the exterior on five different types of surface preparation. A Kodak gray scale was used to measure the decrease in intensity over several months. It was determined that one of the four substances, namely activated carbon, was effective in estimating relative washoff rates on the exterior of the Cathedral of Learning. These initial experiments were used as the foundation for the next set of experiments which are described here.

Objectives

The purpose of this experiment is to determine if the soiling patterns on the Cathedral of Learning can in part be explained by rain washoff rates of carbon particles on the surface. By examining different heights, sides, and soiled and unsoiled areas, it may be possible to reach conclusions about the importance of rain in the overall process of pollutant deposition and washoff on the building.

There are four basic hypotheses that are being tested in this experiment:

1. The washoff rate is different for black (soiled) areas and white (unsoiled) areas. To test this hypothesis, spots were painted on areas that have white and black areas adjacent to one another.

2. Washoff at higher levels of the Cathedral occurs at a faster rate than at lower levels. To test this, spots were painted on the 5th floor, the 16th floor, and the 38th floor.

3. The washoff rate varies for different stone finishes on the Cathedral. This hypothesis was tested by painting spots on the five different stone finishes (ultra smooth, smooth, vertical machine cut, horizontal machine cut, and rough) that were used in the construction of the Cathedral.

4. Different sides of the Cathedral have different washoff rates. This was tested by painting spots on three sides of the 5th floor and two sides of the 16th floor.

Experimental Procedure

The soiled areas on the Cathedral are largely black because of soot carbon particles from motor vehicles and stationary sources deposited on the building. To reproduce the deposition of this soot carbon from pollutant sources, activated carbon was obtained from Columbian Chemicals Company and Miles Inc. Two types of carbon were available: Raven H20 Powder and Carbon Black FR Lake J-1088 from the two companies, respectively. Both types were analyzed with a coulter counter to make sure that the majority of particles had diameters smaller than 10 microns. Small particles were desired to simulate soot carbon emitted from pollution sources. Both types of carbon paint satisfied this constraint and thus were deemed suitable for further testing.

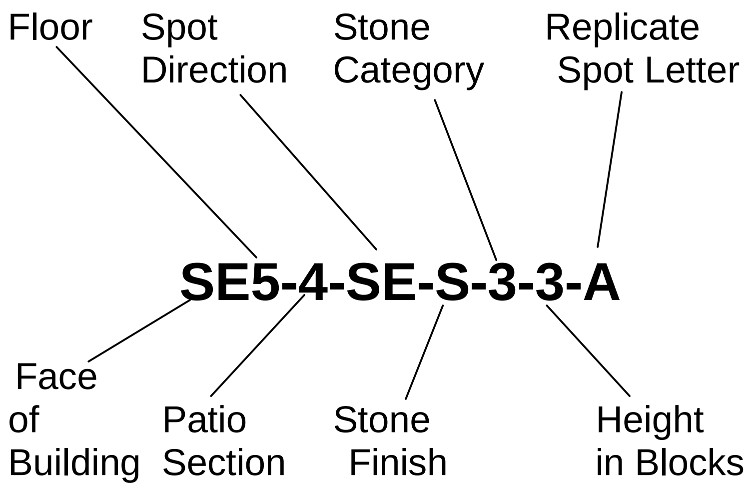
Both types of carbon paint were suspended in de-ionized water in different concentrations. Each sample was then painted on a test slab of limestone. After the paint dried each sample was examined to determine if the paint was dark enough. Then water was poured over the spots to determine if the carbon particles would wash off at a reasonable rate. After many tests, the Carbon Black FR Lake J-1088 brand paint was selected.

The next step was to determine which areas of the Cathedral would be selected as test areas. There are four different sites on the building that are available to conduct experiments: fifth floor patio (that extends to three sides of the building), sixteenth floor Forbes Avenue side, sixteenth floor Fifth Avenue side, and the thirty-eighth floor Forbes Avenue side. On the fifth and sixteenth floors, two types of adjacent black/white areas exist. The first type is on the same face of a stone where both black and white areas are in the same plane. The second type is on a corner stone that is black on one face and white on the other face. Both black and white areas can be further categorized according to stone finish: ultra smooth, smooth, vertical machine cut, horizontal machine cut, and rough. Locations that contained more than one stone finish, and either type of adjacent black/white areas, were selected as test locations. On the thirty-eighth floor, because there is no soiling, four areas were selected randomly. In order to avoid splashing of rain, stones that were very close to the floors of the patios were not used.

A total of 180 replicate pairs of spots were painted on the Cathedral. Table 1 shows the locations of all pairs of spots.

Before the carbon was applied to the surface of the Cathedral, the stone was prepared. In all areas there were two types of stone preparation. One type involved leaving the stone untouched. The other type of preparation started by using a wire brush to clean the surface of the stone. Then a nylon brush and some water were used to remove any particles that were loosened with the wire brush. The stones were left to dry for twenty-four hours before the carbon was applied. Stones subjected to this preparation are termed “sanded”. The sanding process decreased the natural black intensity of the stone in some areas.

After the paint was selected and the spot locations were determined, a numbering system that identified each spot was developed. The system contains the following information: building side and floor; patio section; compass direction the spot is facing, also termed “spot direction”; stone finish [ultra smooth(U), smooth(S), horizontal machine cuts(H), vertical machine cuts(V), rough(R)]; stone category [sanded black(1), black(2), sanded white(3), white(4)]; height in blocks; replicate spot letter.



The carbon was then painted in 1 inch diameter circles. After the paint was allowed to dry, an initial reading was taken by visual comparison of the blackness intensity using a Kodak gray scale. At two to three week intervals, the spots were checked to record the decrease in intensity as rain progressively washed off some of the carbon.

Results

The replicate spots agreed to within one intensity unit in all but eleven pairs. In those eleven pairs, only three had a difference greater than 1 ½ intensity units. One hundred sixty one pairs agreed to within ½ intensity unit.

Stone Category: Soiled and Unsoiled Areas (graphs 1-7)
Every testing area had both soiled (black) and unsoiled (white) areas adjacent to each other. The unsoiled areas washed off faster than the soiled areas. This suggests that the local soiling patterns can be explained in part by the difference in washoff rates between the black and white areas.

Stone Category: Surface Preparation (graphs 1-7)
The testing areas all had stone surfaces with two different types of preparation. The areas that were wire brushed and water washed, referred to as sanded, washed off faster than the areas that had no surface preparation. This result suggests that the small surface texture is important in influencing washoff rates. Given the results about stone finish, this result suggests that the small surface texture is more important than the overall stone texture.

Elevation (graphs 8-11)
The carbon was applied at three different elevations on the Cathedral: the 5th floor, the 16th floors, and the 38th floor. The 38th floor had much faster washoff rates than the 5th and 16th floors. This is most likely due to the extreme weather conditions at the higher floors of the Cathedral. Such as higher wind speeds, greater exposure to cloud droplets, and greater exposure to rain. The 5th floor and the 16th floor had very similar washoff rates.

Stone Finish (graphs 12-13)
There are fiver different stone finishes that were used on the limestone at the Cathedral of Learning. The first four finishes (i.e. smooth, vertical machine cut, horizontal machine cut, and rough) make up the majority of the stones. The ultra smooth stone finish was only used in the detail work such as the window frames. The first four stone finishes were tested all over the building and there was no significant difference in the washoff rates on any of the stone finishes. The ultra smooth was only tested on the fifth floor and it had a much slower washoff rate. This result, however, does not imply that soiling on the ultra smooth stone finish washes off faster because the ultra smooth testing areas

were not similar to the testing areas of the other four stone finish.

Building Side (graphs 14-15)

Test areas were available on three sides of the 5th floor, two sides of the 16th floor, and one side of the 38th floor. The southeast side of the 5th floor washed off faster than the southwest and northwest sides of the 5th floor. The southwest side and northwest side of the 5th floor washed off at approximately the same rate. On the 16th floor the results were similar to the 5th floor with the southeast side washing off faster than the northwest side. This finding is in contrast to observations showing that the southwest and northwest sides of the building are overall less soiled than the other two sides: one might expect greater washoff rates on these less soiled sides. However, only locations with adjacent black and white areas were used in this project, thus biasing the sample. The locations studied on the southwest and northwest sides were among the few areas that had appreciable soiling on these sides. Thus the results cannot be used to draw conclusions about washoff on the rest of the southwest and northwest walls. Note that graphs 14 and 15 include only white areas; the original data show similar trends for black areas on different sides of the building.

Spot Direction (graphs 16-22)

The direction that the testing area faced was often different from the overall direction that the building wall faced due to corners, facades, and other protrusions of the wall. In some cases on the 38th floor, spots were on a section of wall at a 45 degree angle to the main direction of the side of the building. These east-facing and south-facing spots were only located on the 38th floor, and so the results cannot be compared to data for the other compass directions where spots were on the 5th and 16th floors. The following is a list of the other directions in order of increasing washoff rate: northwest, southwest, southeast, and northeast. These results are similar to those obtained for spots on different sides of the building. This suggests that factors responsible for the washoff rate differences on the four sides of the building are similar to those responsible for the differences in washoff rates of spots facing various directions, even when those directions are not the same as the predominant direction that the wall faced. Note that graphs 16-22 include only white areas; the original data show similar trends for black areas for different spot directions.

Summary and Conclusions

The Cathedral of Learning at the University of Pittsburgh is one of many limestone structures that have been exposed to sources of pollution including factories, domestic sources, local traffic, and steel mills. The continual exposure has caused discoloration of the building due in part deposition of black carbon. This project has examined rain washoff rates of black carbon spots painted on the Cathedral in an attempt to explain the soiling patterns.

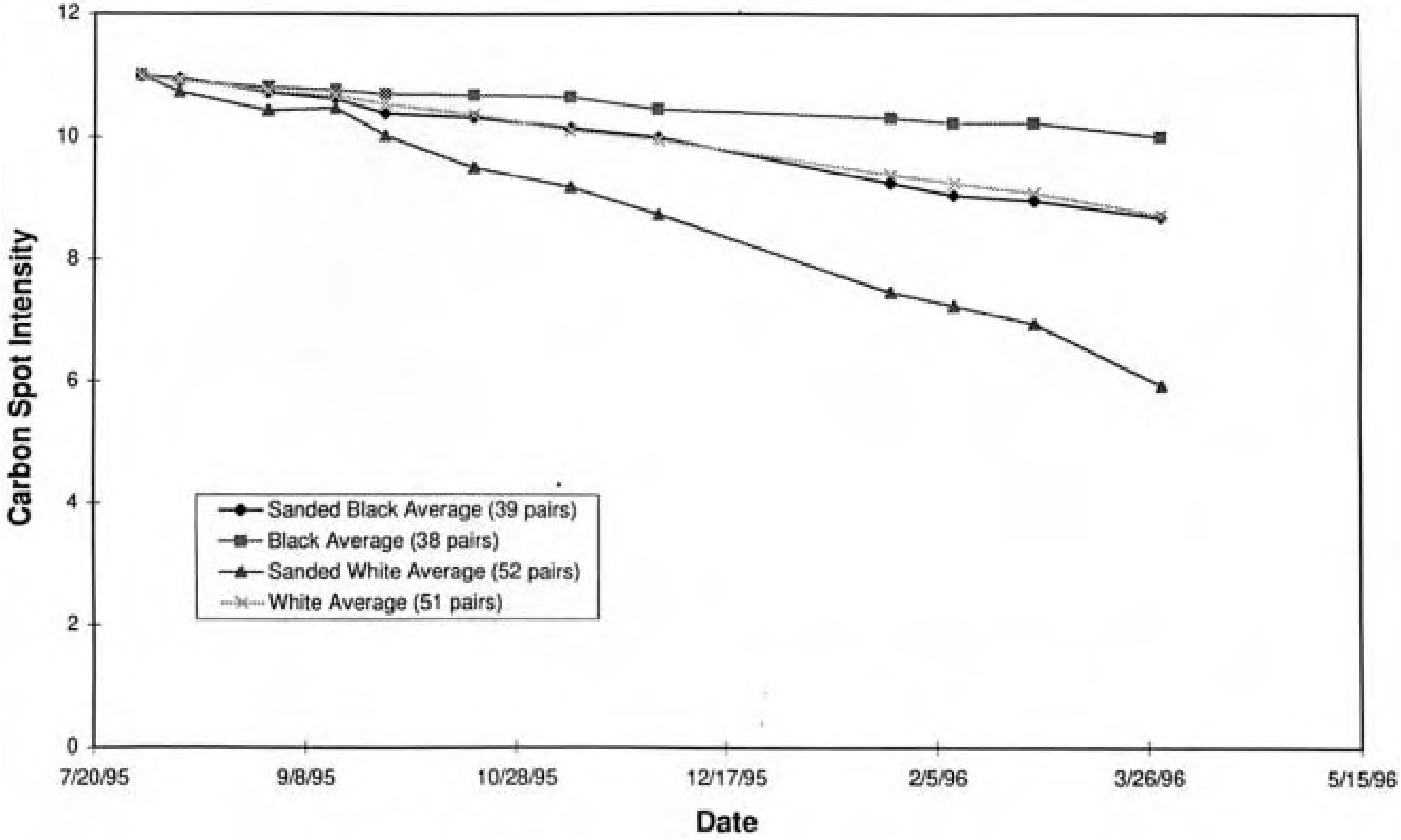
The decrease of intensity of the carbon spots could be due to two different types of washoff. These include the impact of raindrops directly on the spot as well as the effect of rain water dripping down along the walls. The second type of washoff is limited by the distance over which water drips down the building walls since the water is absorbed into the limestone fairly quickly.

Four basic results have come out of this examination of washoff rates. First, the carbon spots on the unsoiled areas wash off faster than those on the soiled areas when the areas are adjacent to one another. This is consistent with the hypothesis that the soiling patterns on the Cathedral are in part due to different exposures to rain. Second, the upper levels of the Cathedral have a higher washoff rate than the lower levels. This is consistent with the overall observations that the upper levels of the Cathedral are unsoiled. Third, the stone finish does not appear to influence washoff rates, but the small surface texture altered by brushing and sanding the stone does affect washoff rates. Fourth, the washoff rates on the southwest and northwest sides of the Cathedral are slower than on the other two sides. Although the southwest and northwest sides are overall less soiled and might be expected to have faster washoff rates, the areas where spots are painted on these sides had appreciable soiling. Thus the results cannot be used to draw conclusions about washoff on the entire southwest and northwest walls.

Table 1. Locations of replicate pairs of spots painted on the Cathedral. The values indicate the number of pairs of spots.

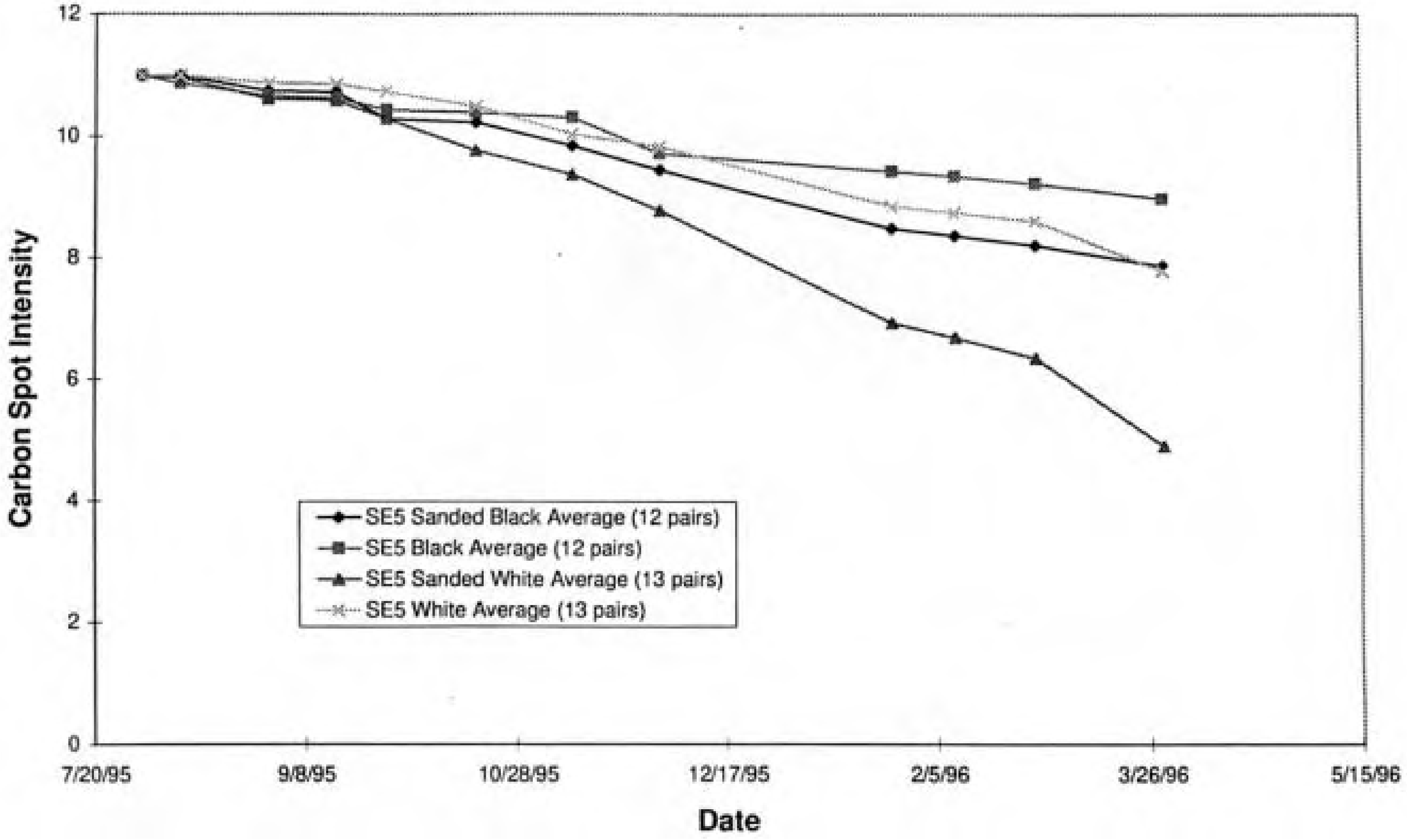
SPOT LOCATIONS					.
		SANDED BLACK	BLACK	SANDED WHITE	WHITE
SE5FLOOR		12	12	13	13
	SEFACE	9	9	7	7
	NEFACE	2	2	5	5
	SWFACE	1	1	1	1
SW5FLOOR		7	7	9	9
	NWFACE	0	0	2	2
	SWFACE	7	7	7	7
NW5FLOOR		9	8	11	10
	NWFACE	2	1	4	3
	SWFACE	6	6	7	7
	SEFACE	1	1		
SE16FLOOR		9	9	9	9
	SEFACE	9	9	7	7
	SWFACE	0	0	1	1
	NEFACE	0	0	1	1
NW16FLOOR		2	2	6	6
	NWFACE	2	2	6	6
SE38FLOOR		0	0	4	4
	NEFACE	0	0	1	1
	EFACE	0	0	1	1
	SFACE	0	0	1	1
	SWFACE	0	0	1	1

Carbon Spot Intensity versus Time for Soiled and Unsoiled Areas, Sanded and Unsanded, on the 5th, 16th and 38th Floors



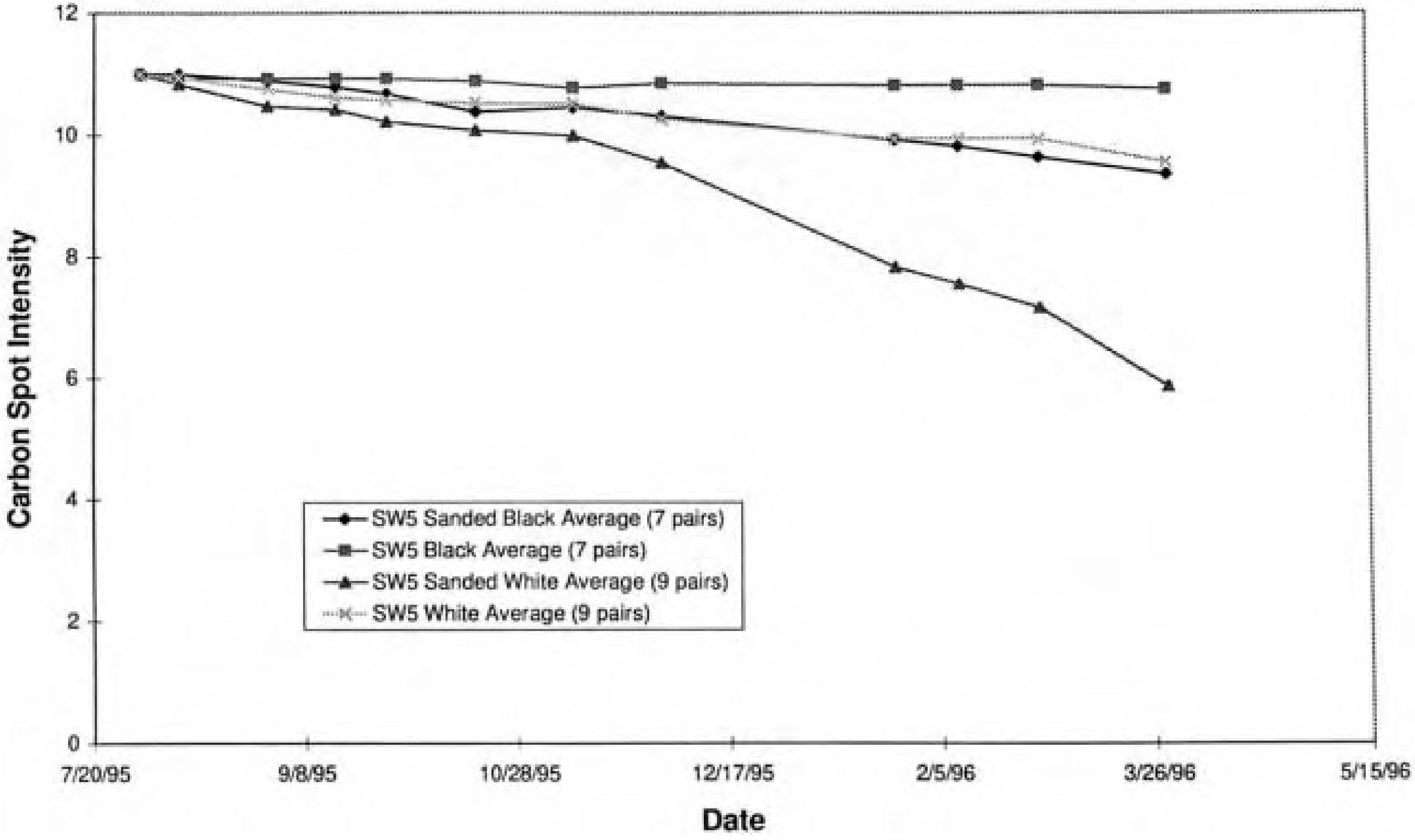
Graph 1

Carbon Spot Intensity versus Time for Soiled and Unsoiled Areas, Sanded and Unsanded, on the Southeast 5th Floor



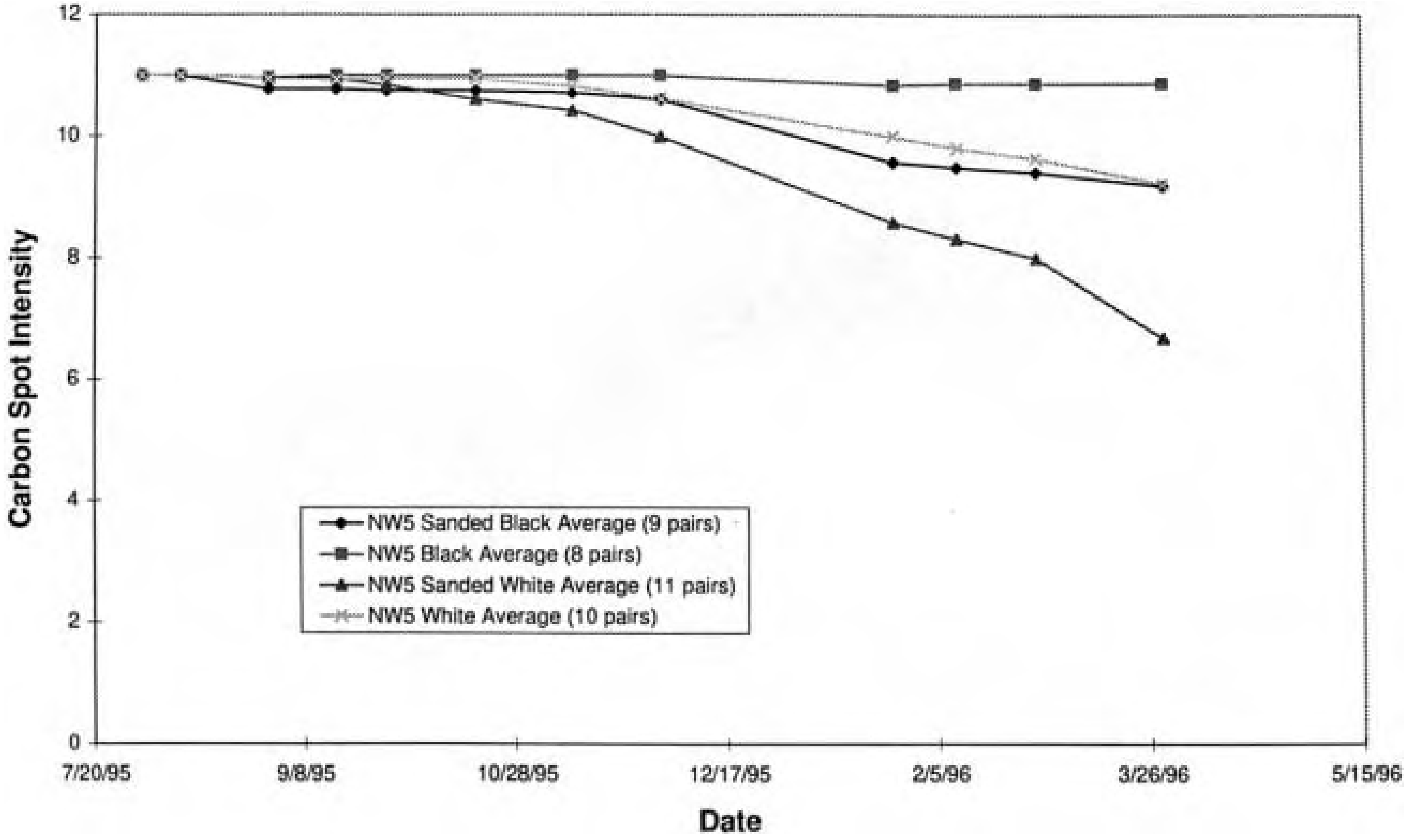
Graph 2

Carbon Spot Intensity versus Time for Soiled and Unsoiled Areas, Sanded and Unsanded, on the Southwest 5th Floor



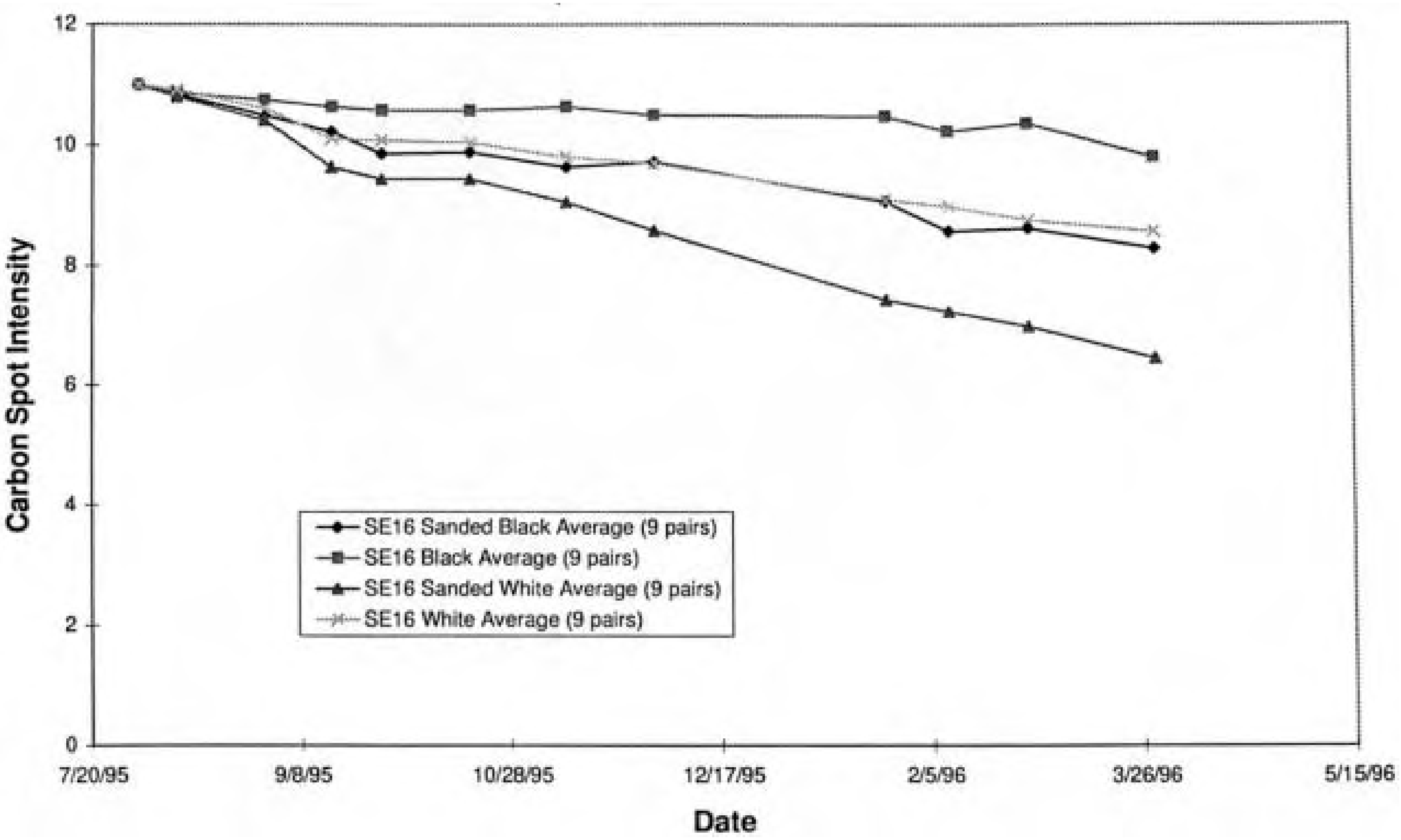
Graph 3

Carbon Spot Intensity versus Time for Soiled and Unsoiled Areas, Sanded and Unsanded, on the Northwest 5th Floor



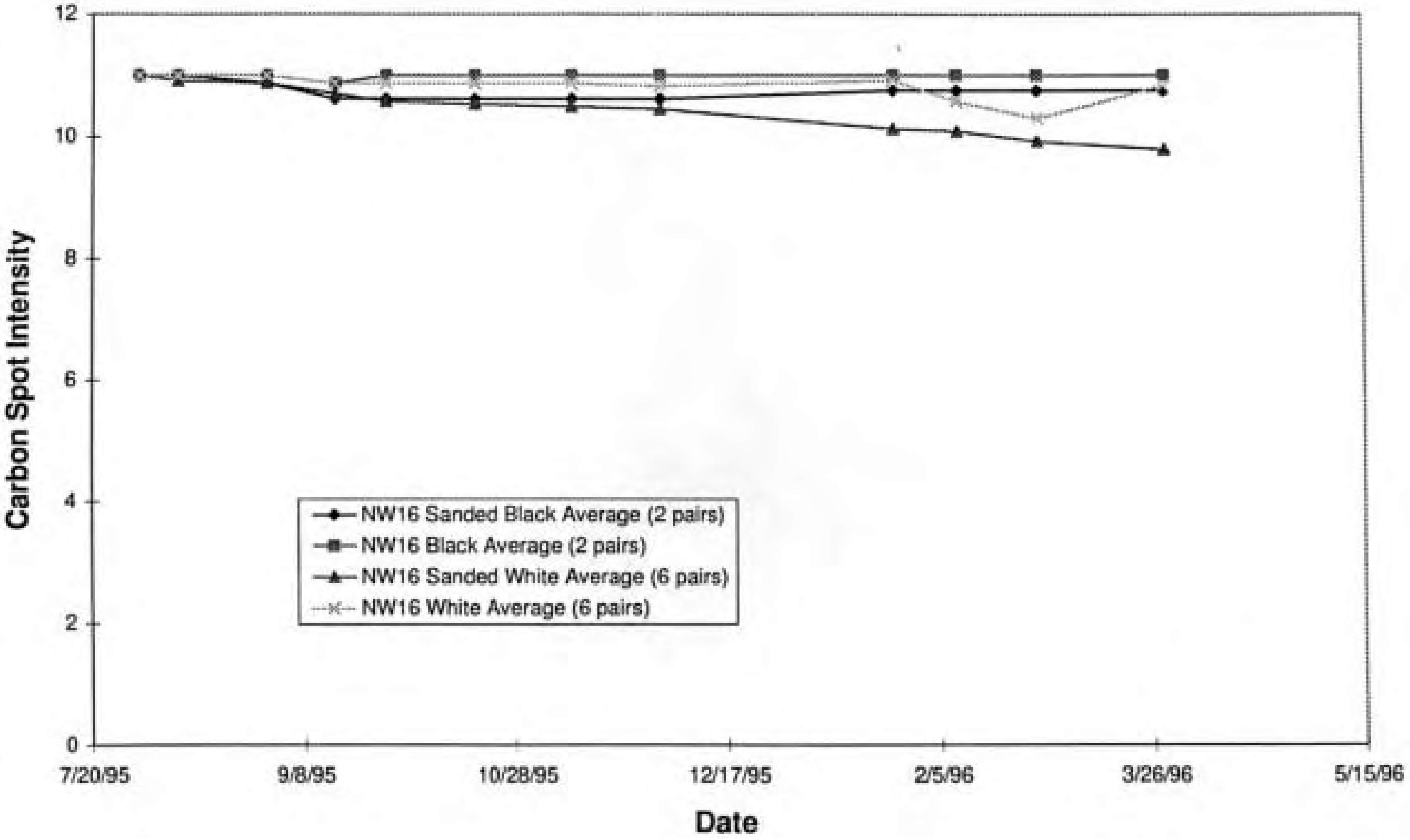
Graph 4

Carbon Spot Intensity versus Time for Soiled and Unsoiled Areas, Sanded and Unsanded, on the Southeast 16th Floor



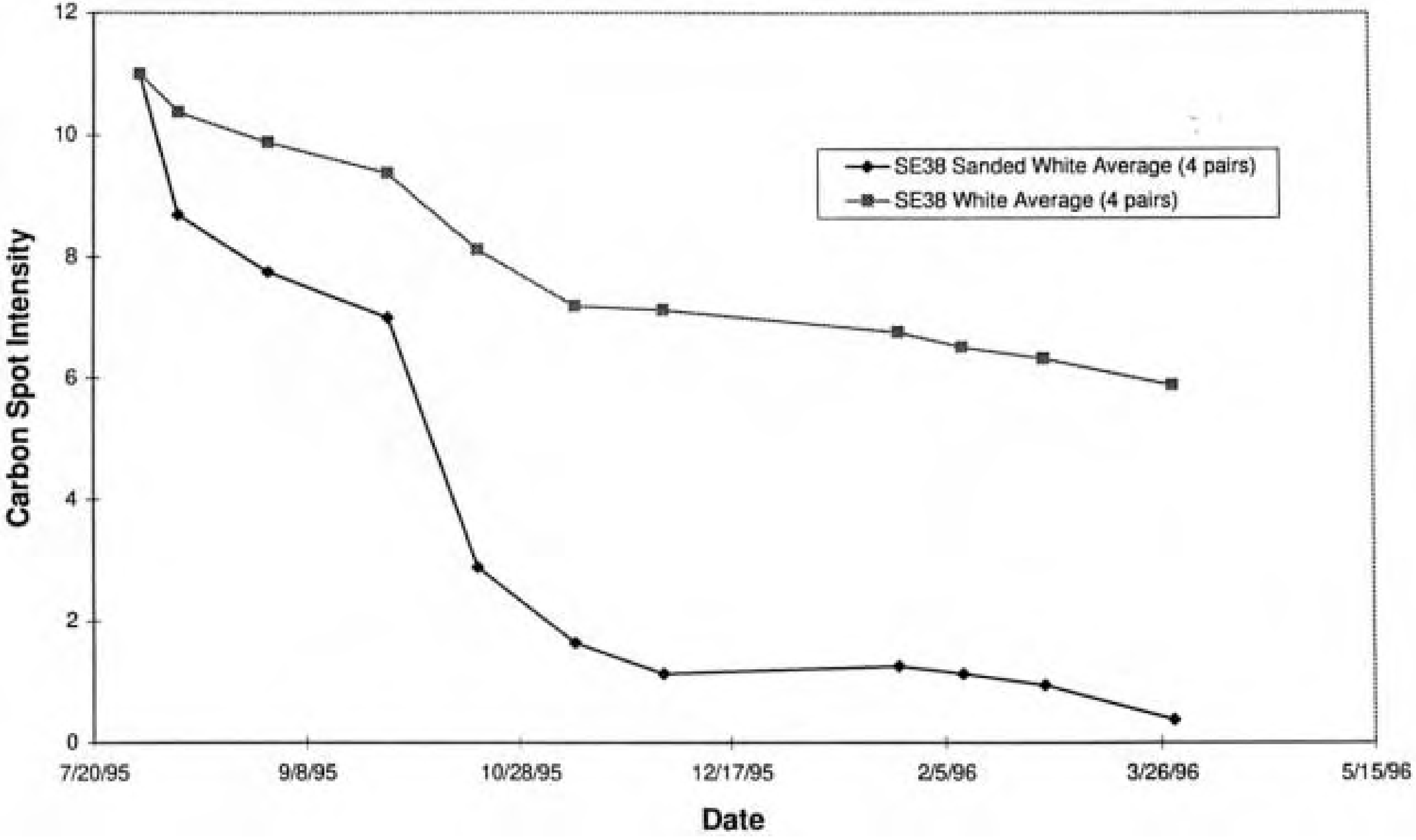
Graph 5

Carbon Spot Intensity versus Time for Soiled and Unsoiled Areas, Sanded and Unsanded, on the Northwest 16th Floor



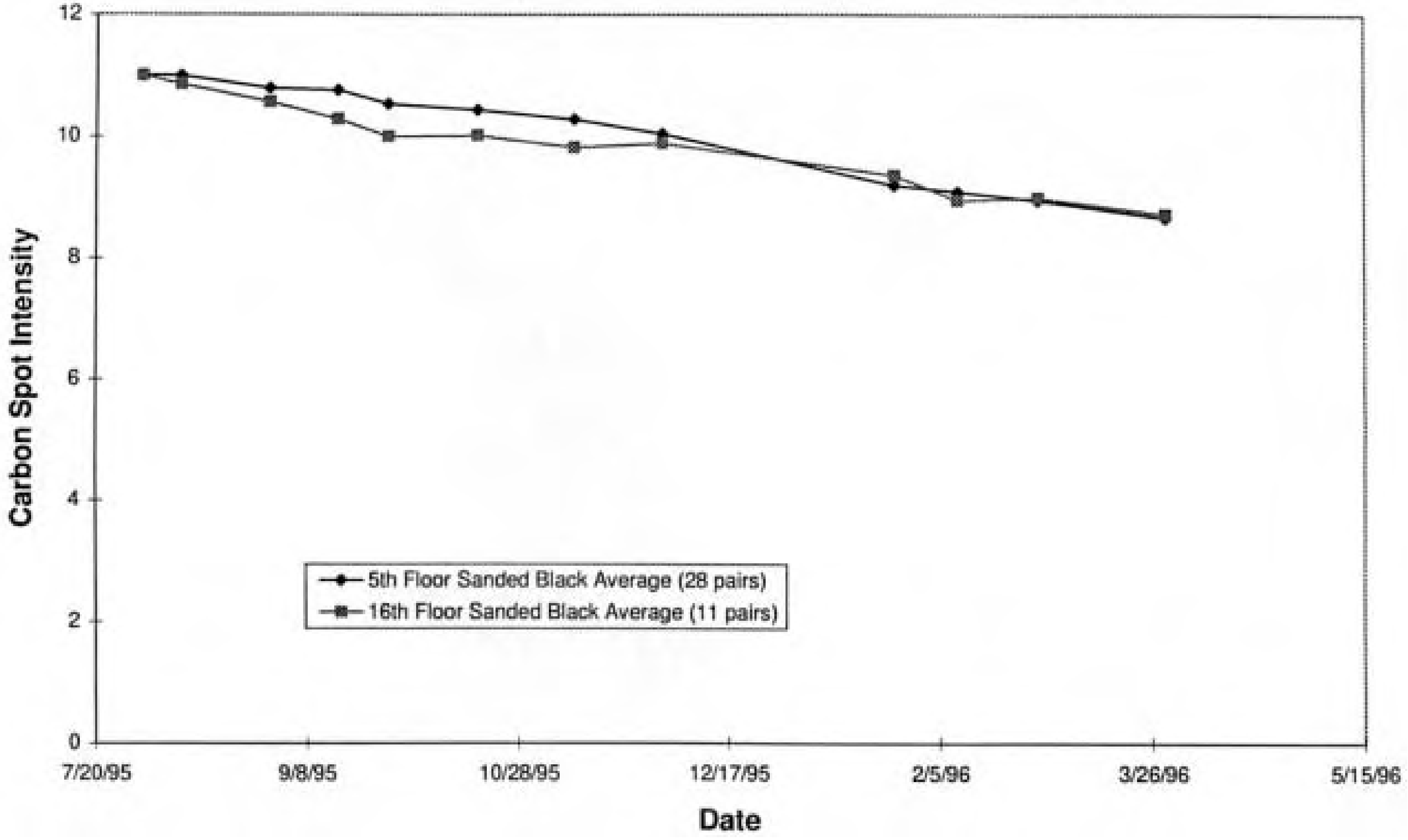
Graph 6

Carbon Spot Intensity versus Time for Sanded and Unsanded Areas on the Southeast 38th Floor



Graph 7

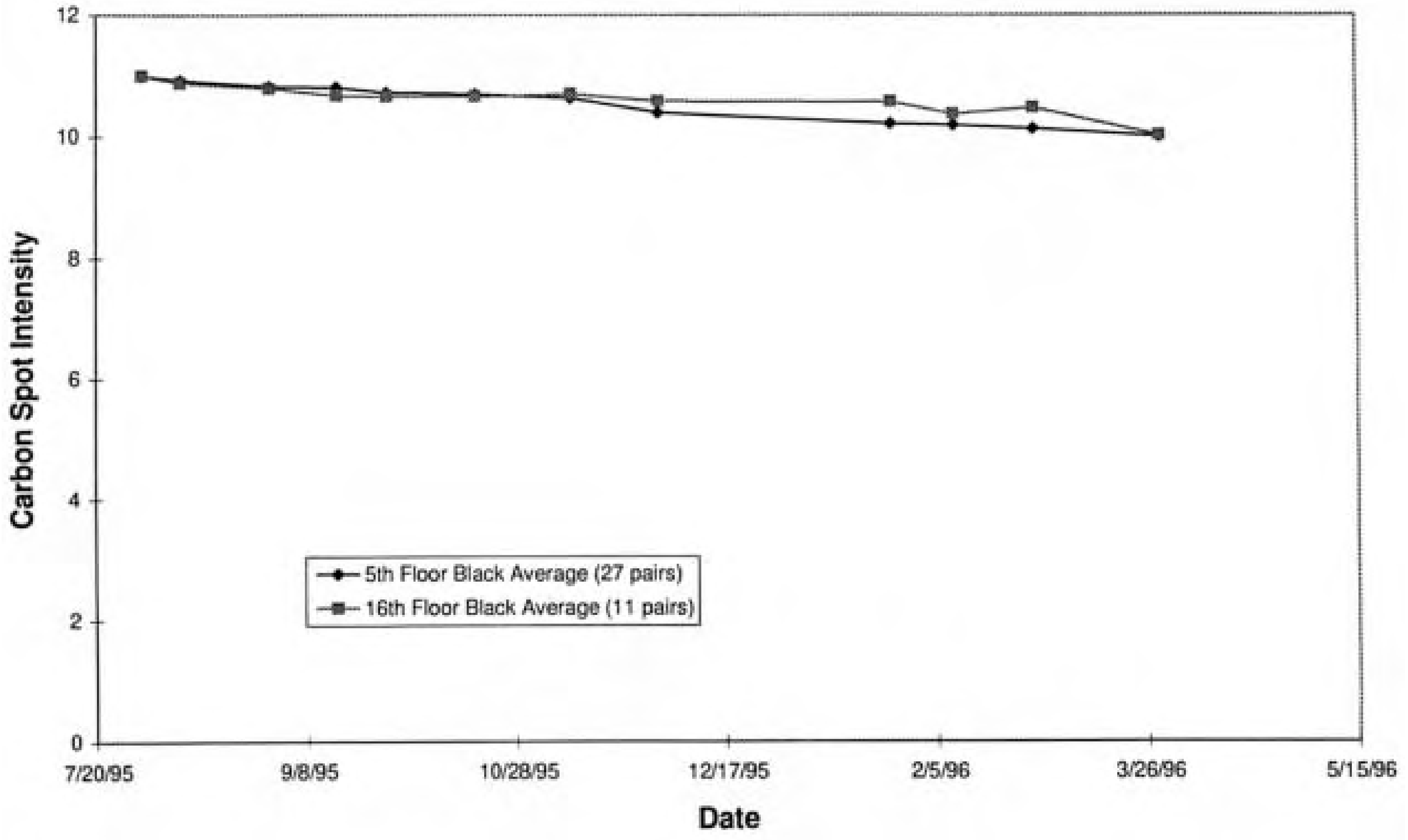
Carbon Spot Intensity versus Time for Sanded Black Areas at Different Elevations (5th and 16th Floors)



Graph 8

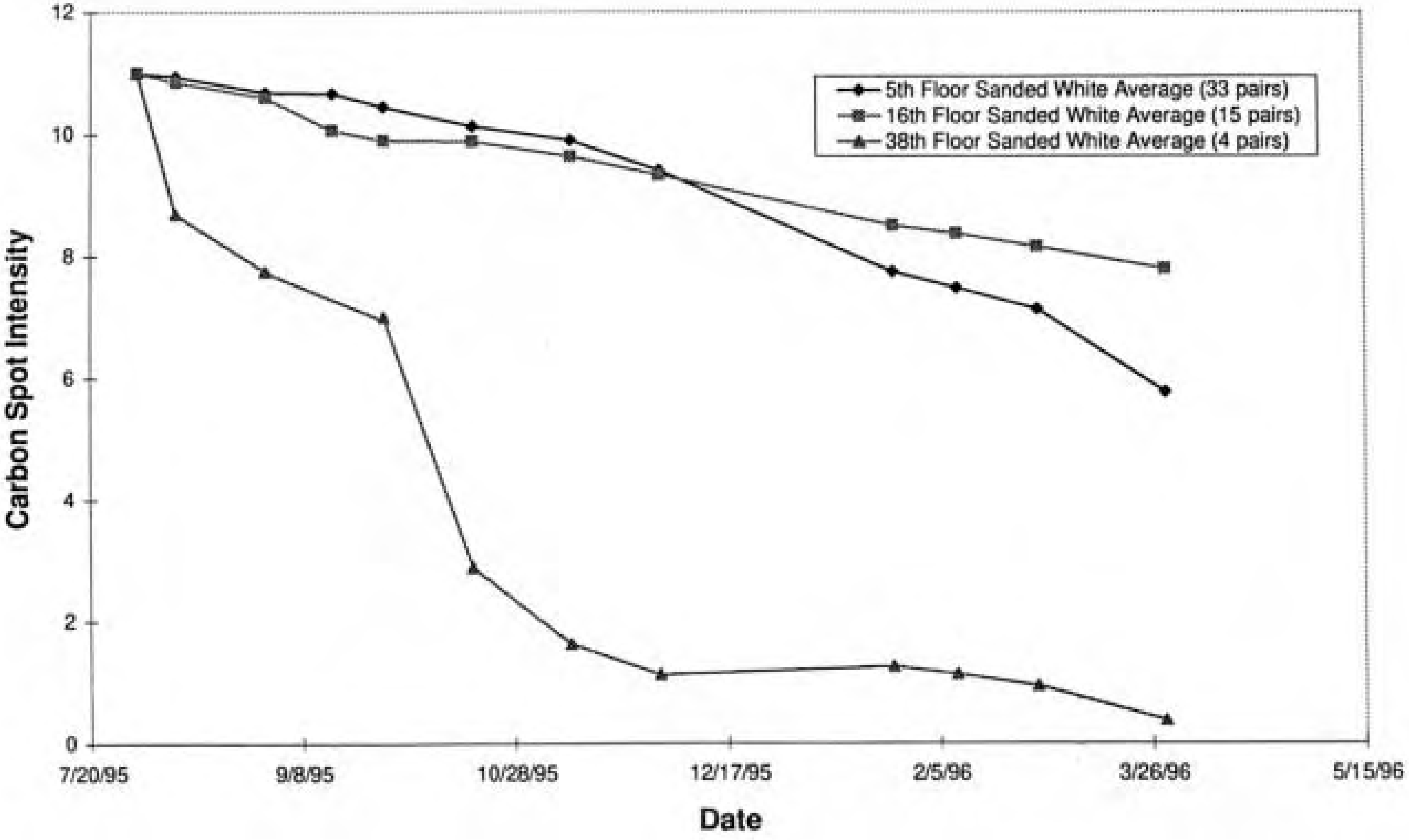
L.

Carbon Spot Intensity versus Time for Black Areas at Different Elevations (5th and 16th Floors)



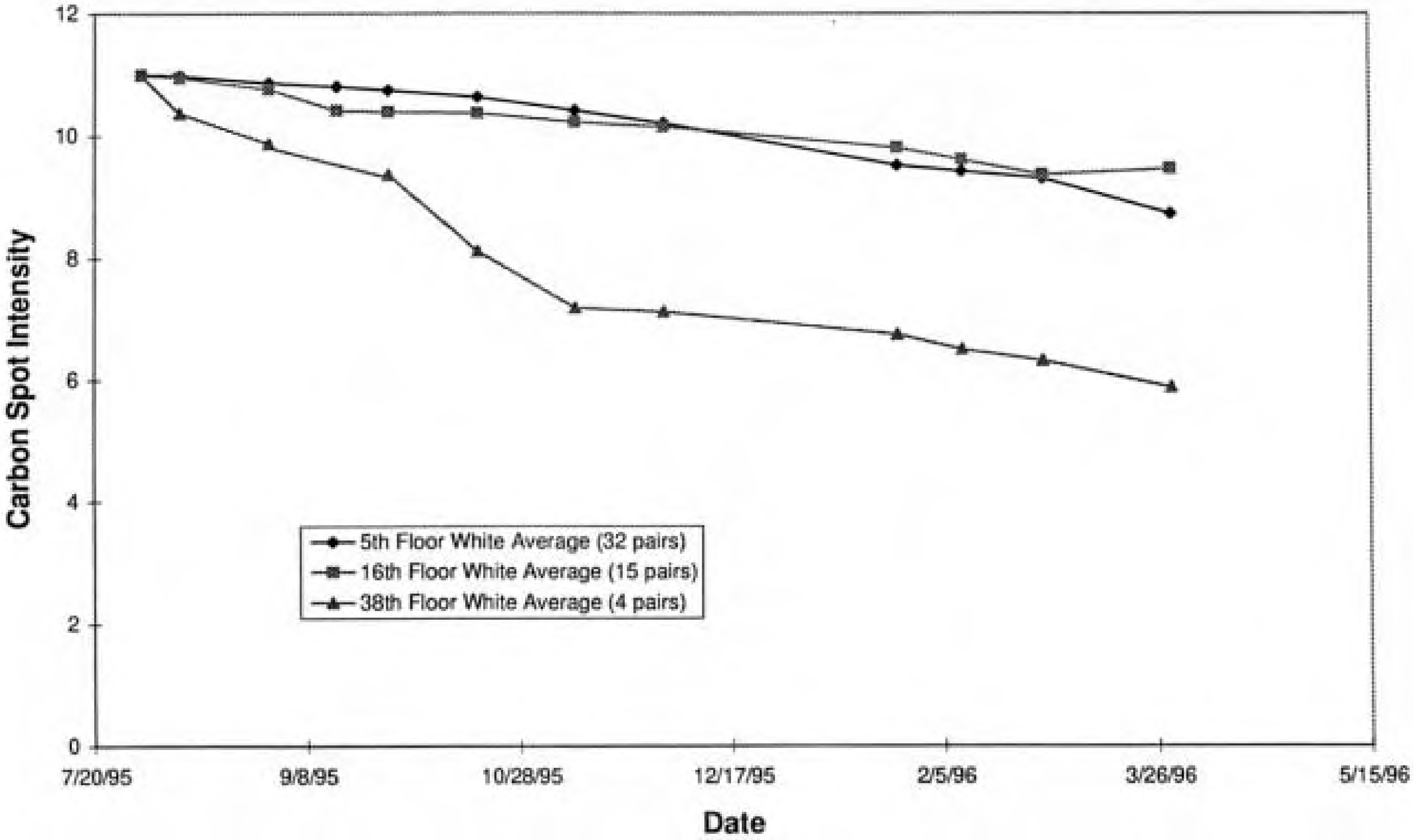
Graph 9

Carbon Spot Intensity versus Time for Sanded White Areas at Different Elevations (5th, 16th, and 38th Floors)



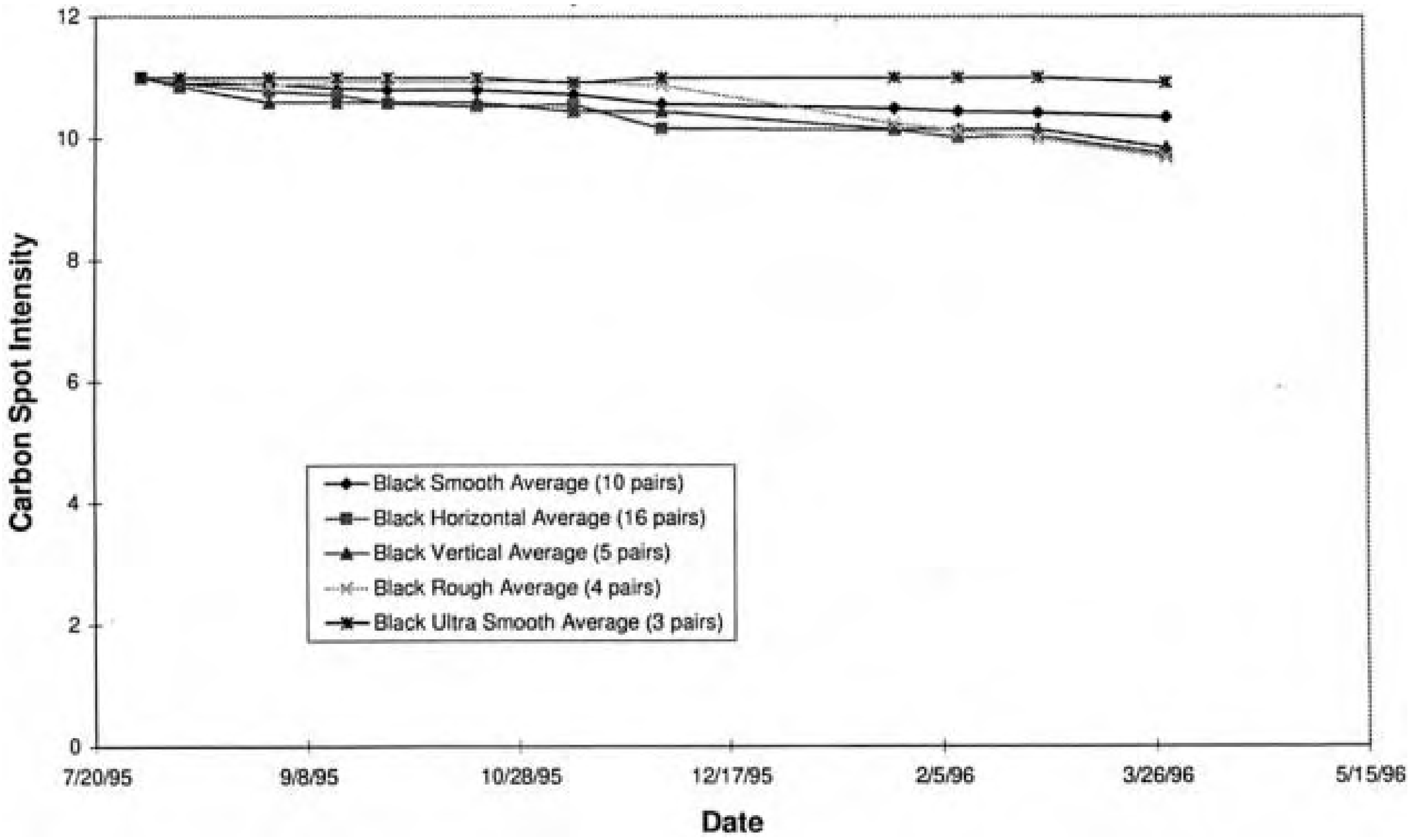
Graph 10

Carbon Spot Intensity versus Time for White Areas at Different Elevations (5th, 16th, and 38th Floors)



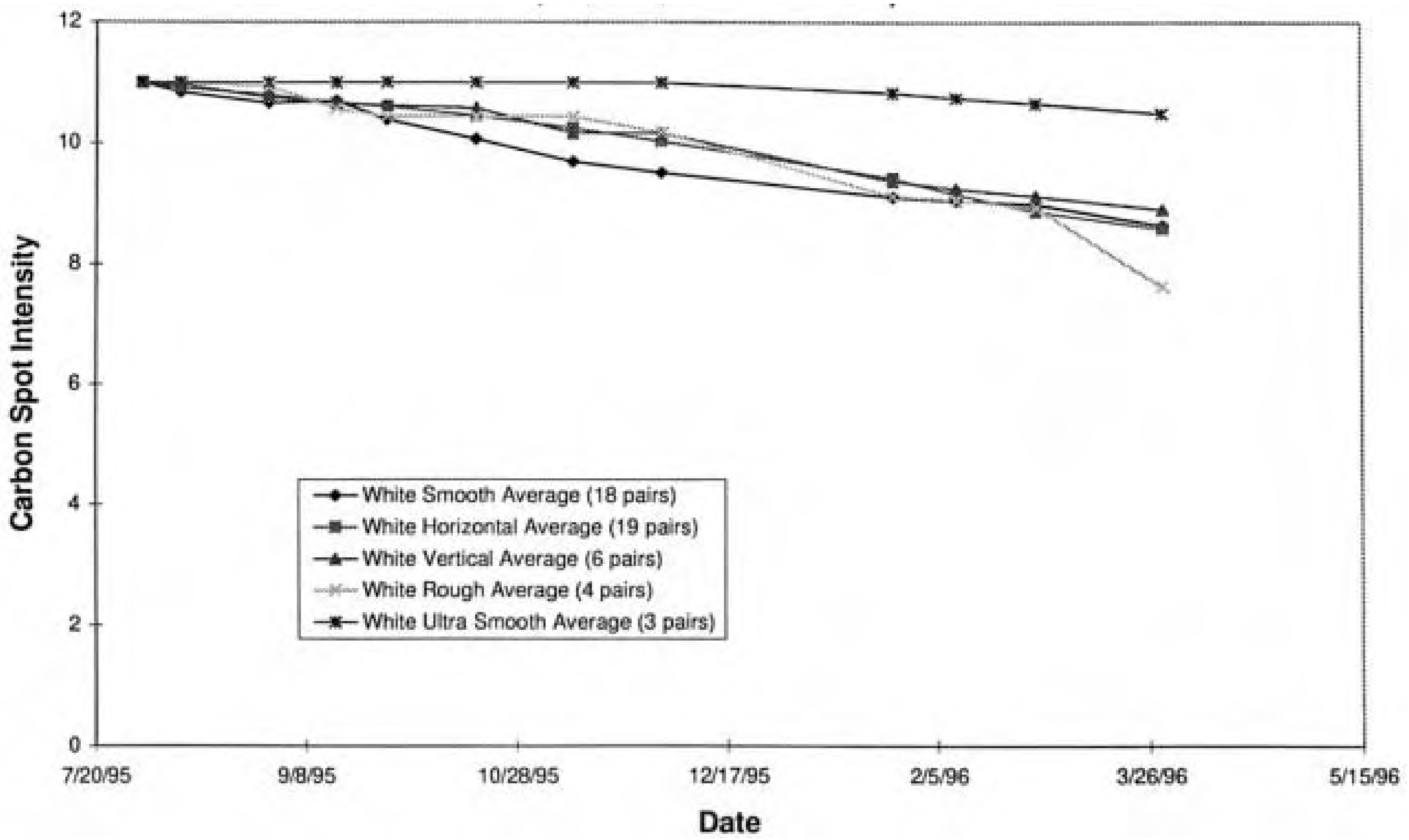
Graph 11

Carbon Spot Intensity versus Time on Black Areas for Different Stone Finishes (5th and 16th Floors)



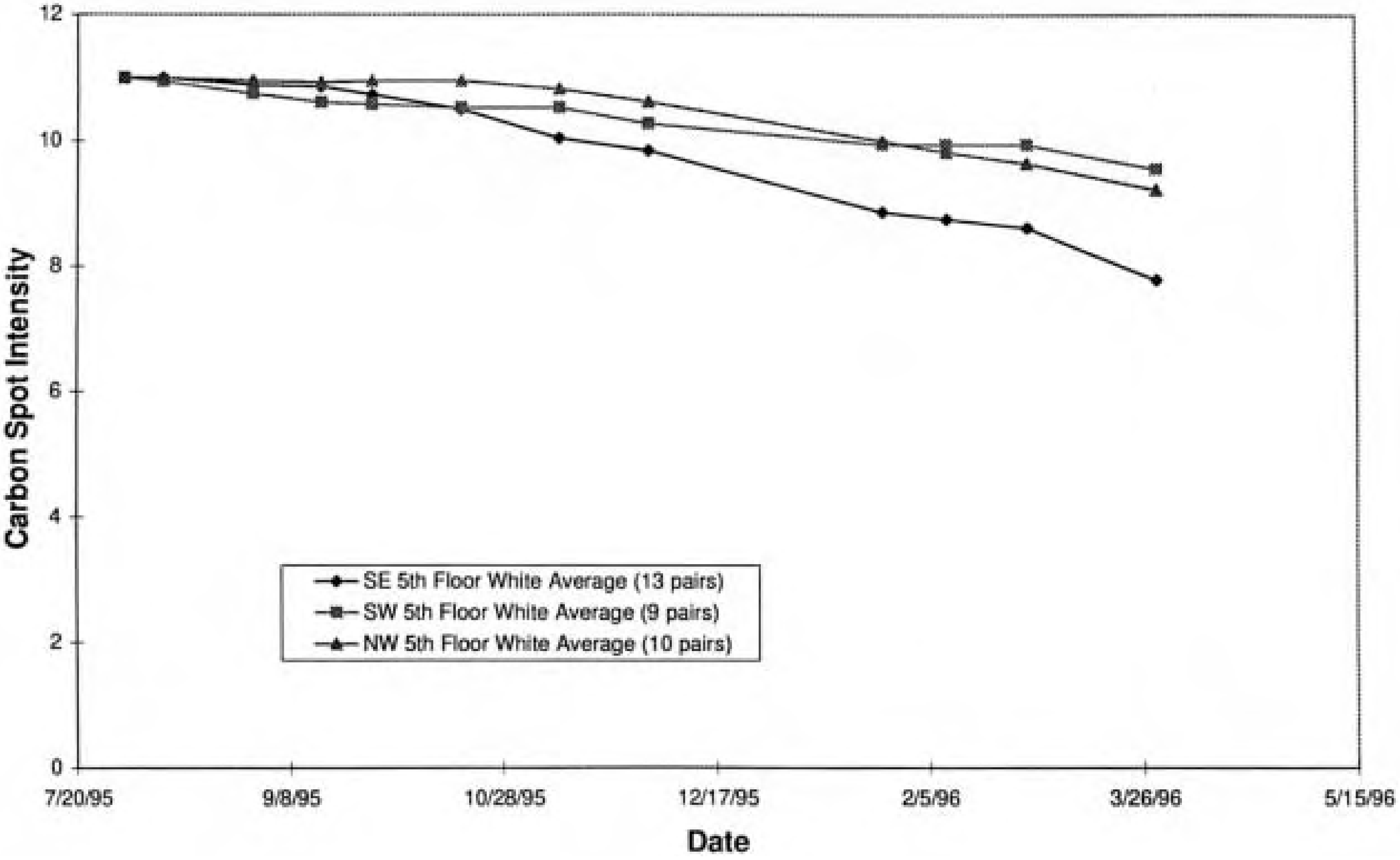
Graph 12

Carbon Spot Intensity versus Time on White Areas for Different Stone Finishes (5th, 16th, and 38th Floors)



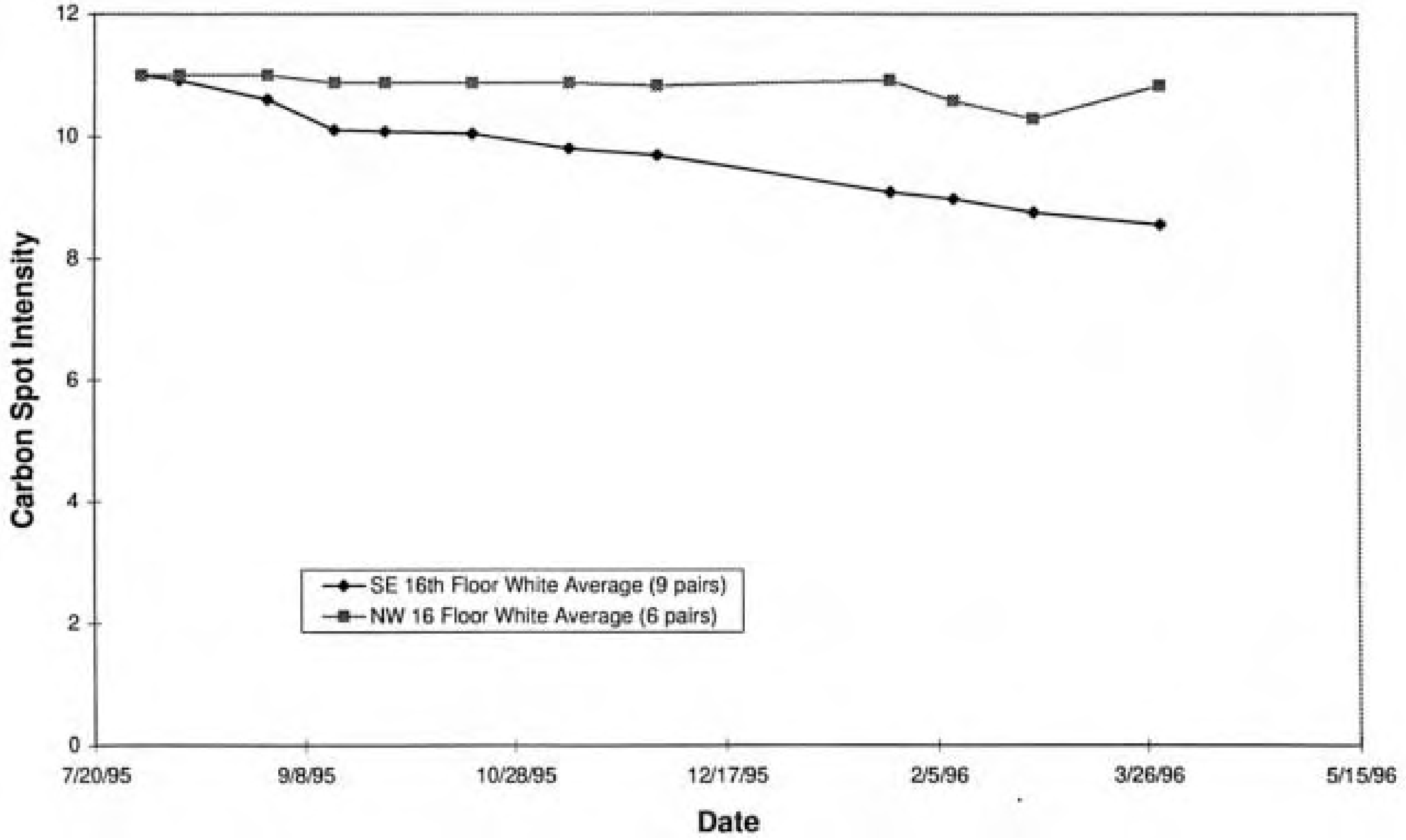
Graph 13

Carbon Spot Intensity versus Time on White Areas on the Three Sides of the 5th Floor



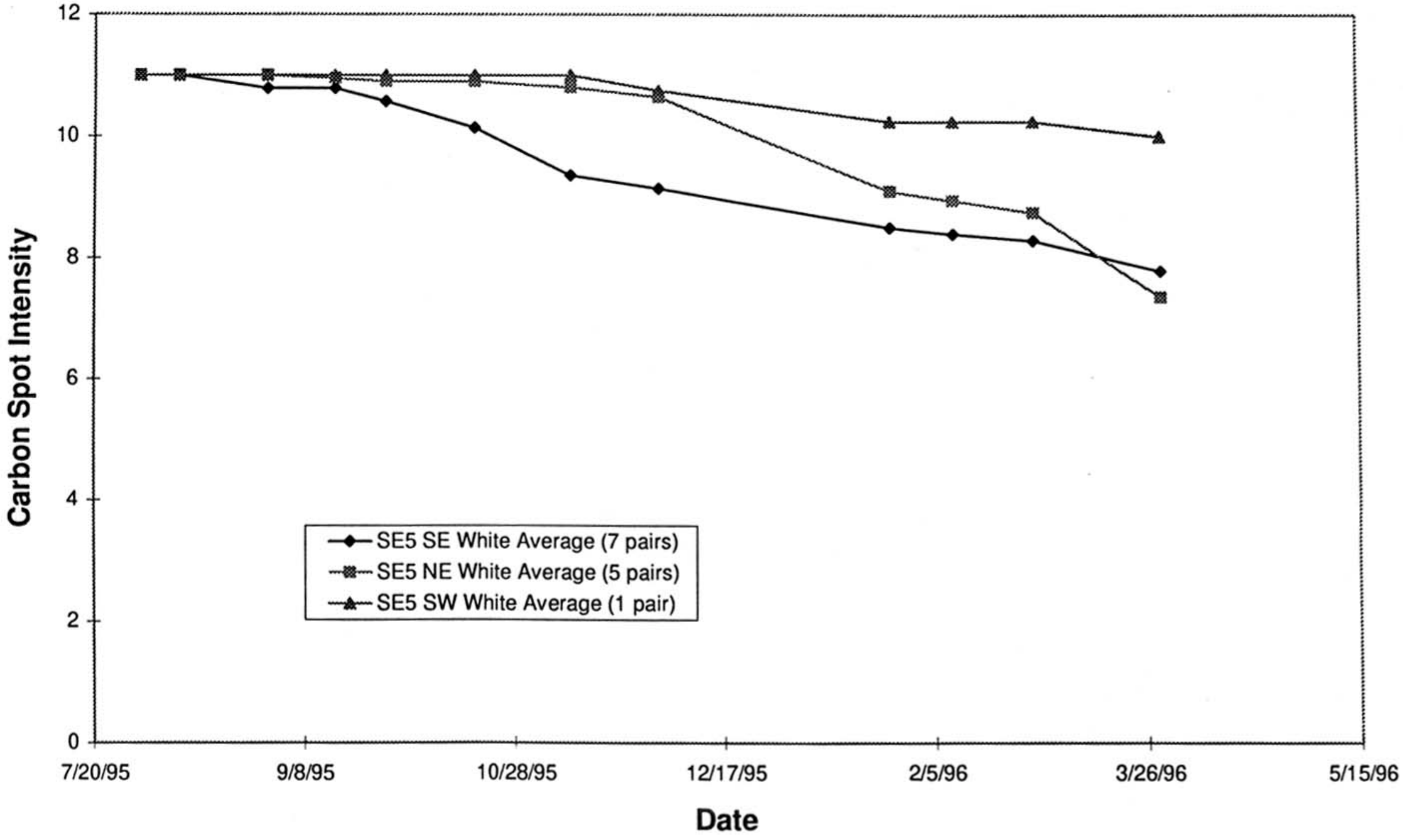
Graph 14

Carbon Spot Intensity versus Time on White Areas on the Two Sides of the 16th Floor



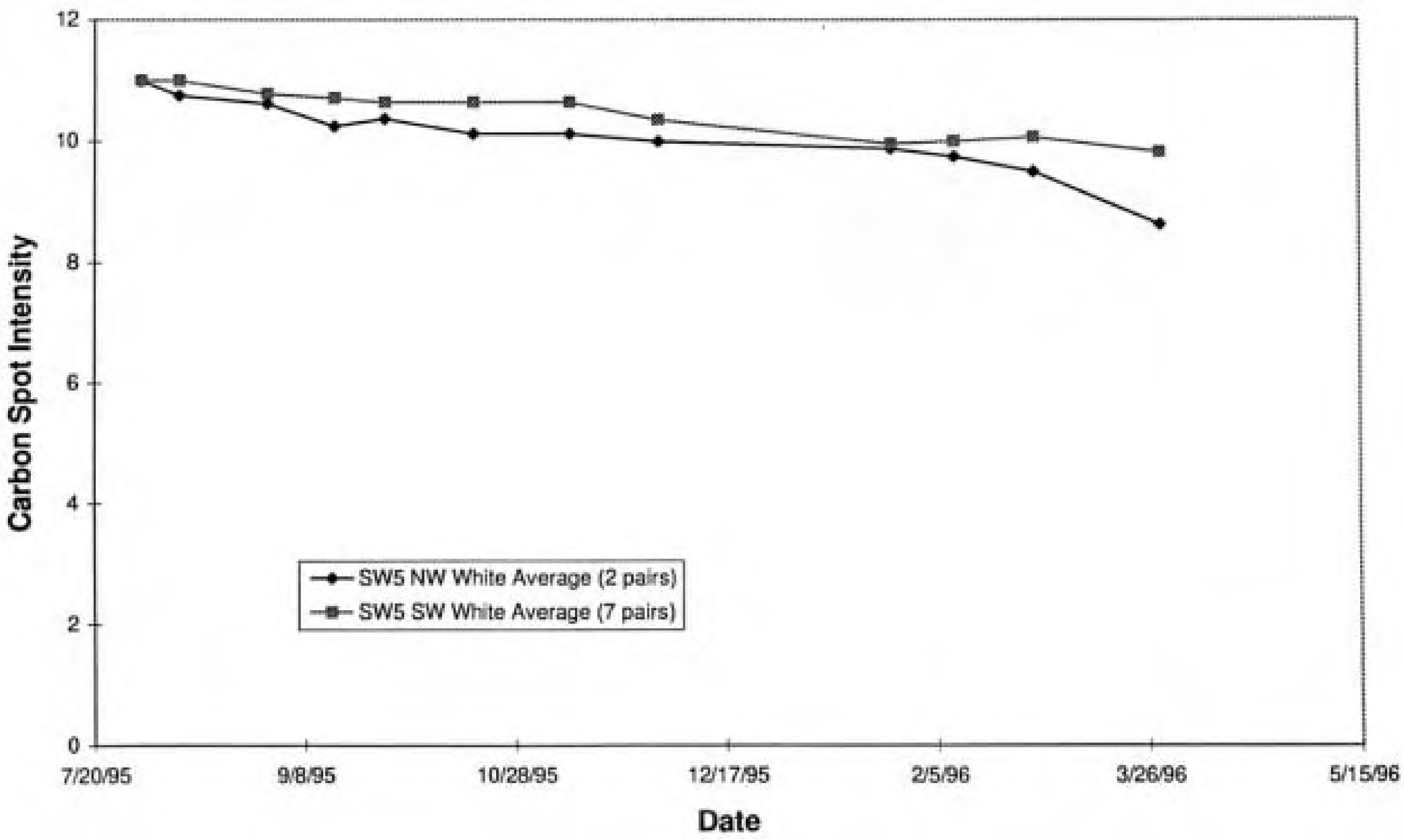
Graph 15

Carbon Spot Intensity versus Time on White Areas as a Function of Spot Direction on the Southeast 5th Floor



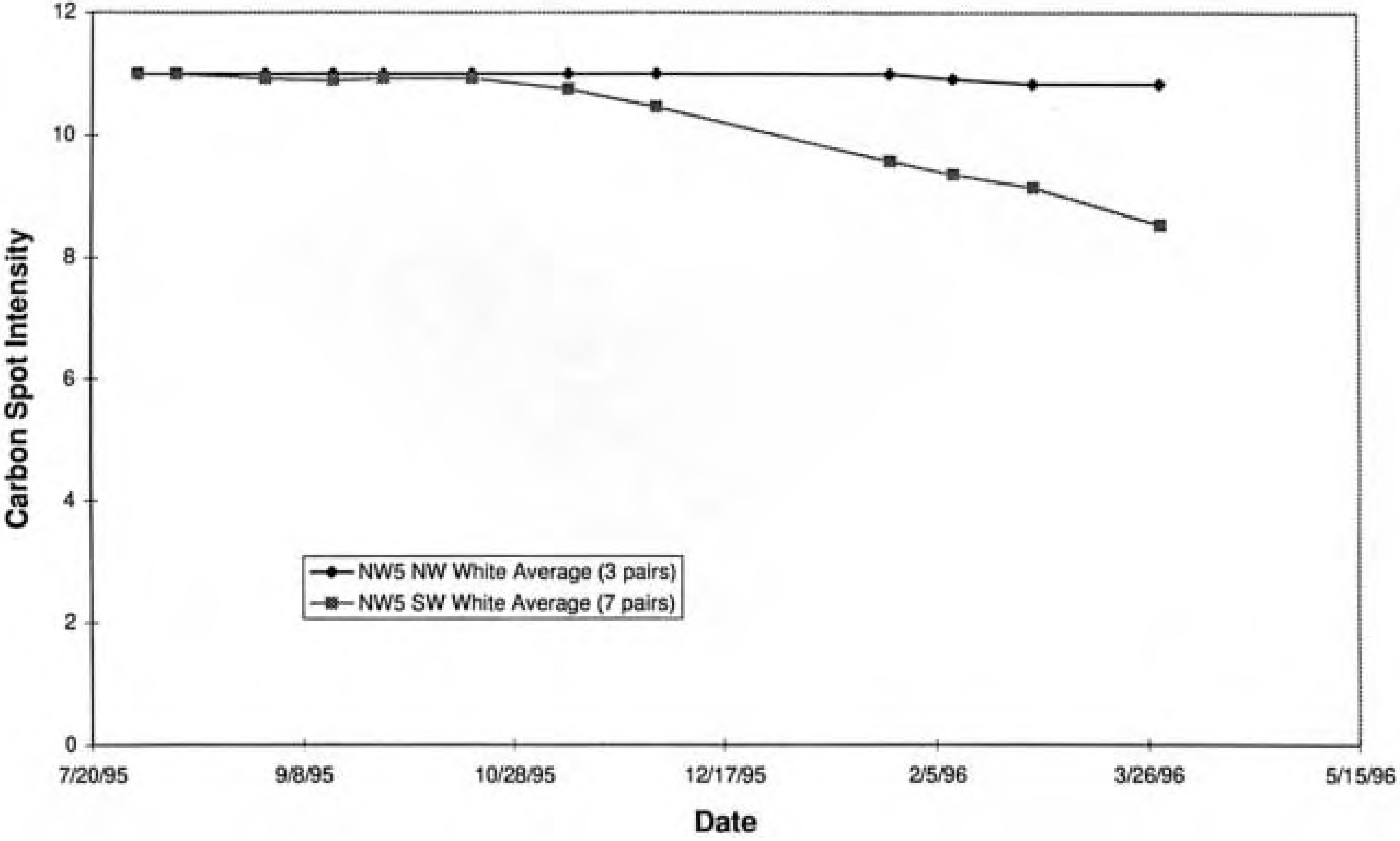
Graph 16

Carbon Spot Intensity versus Time on White Areas as a Function of Spot Direction on the Southwest 5th Floor



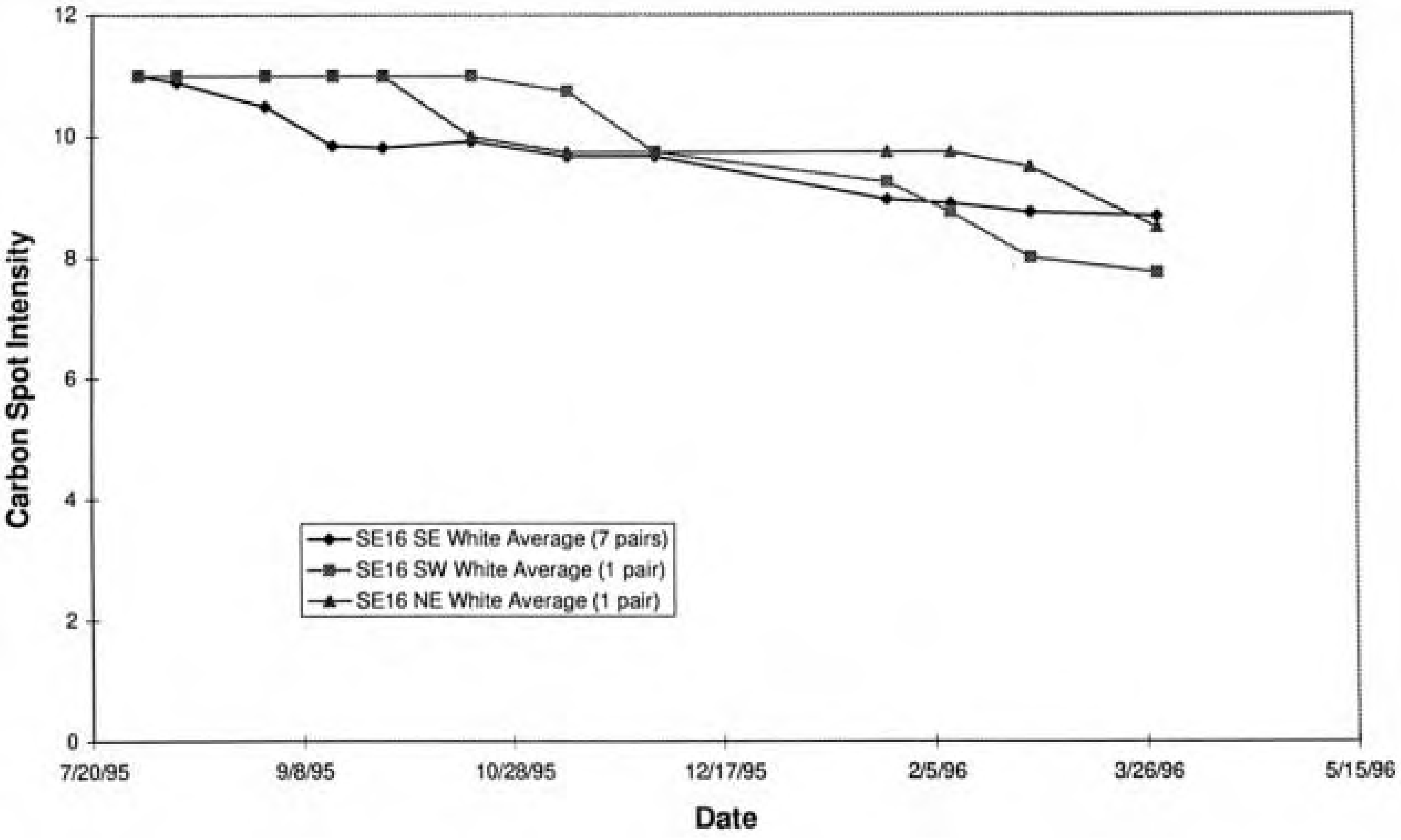
Graph 17

Carbon Spot Intensity versus Time on White Areas as a Function of Spot Direction on the Northwest 5th Floor



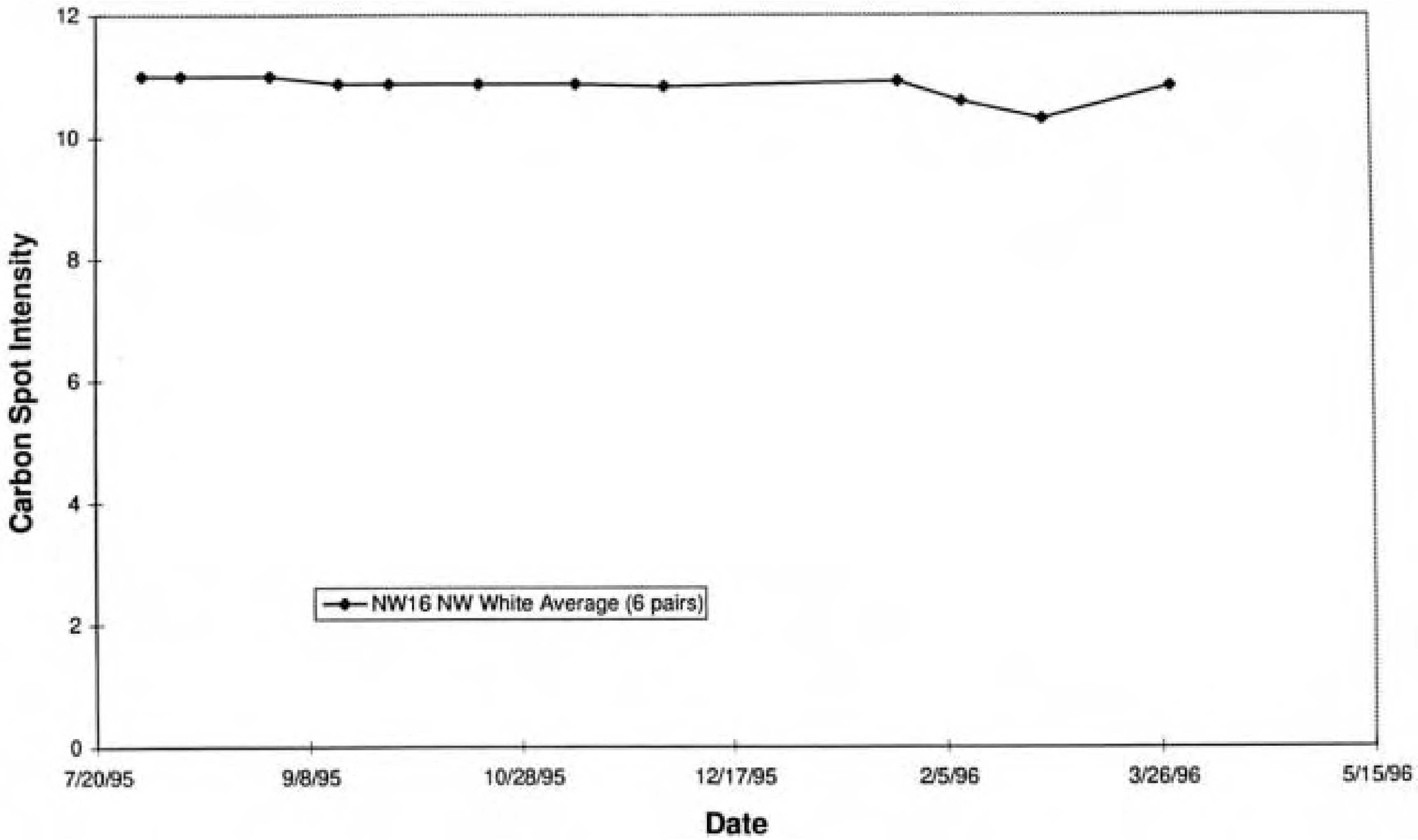
Graph 18

Carbon Spot Intensity versus Time on White Areas as a Function of Spot Direction on the Southeast 16th Floor



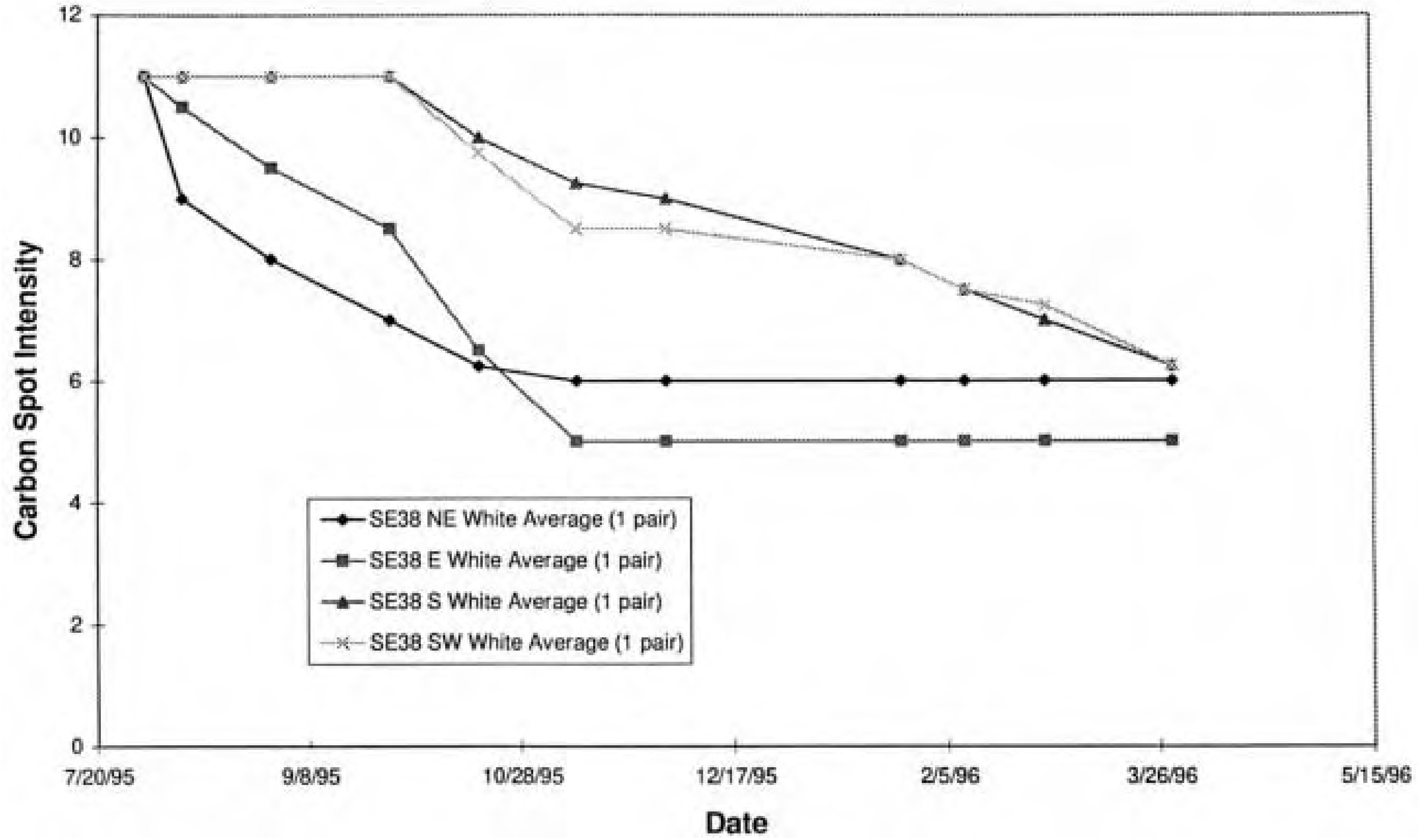
Graph 19

Carbon Spot Intensity versus Time on White Areas as a Function of Spot Direction on the Northwest 16th Floor



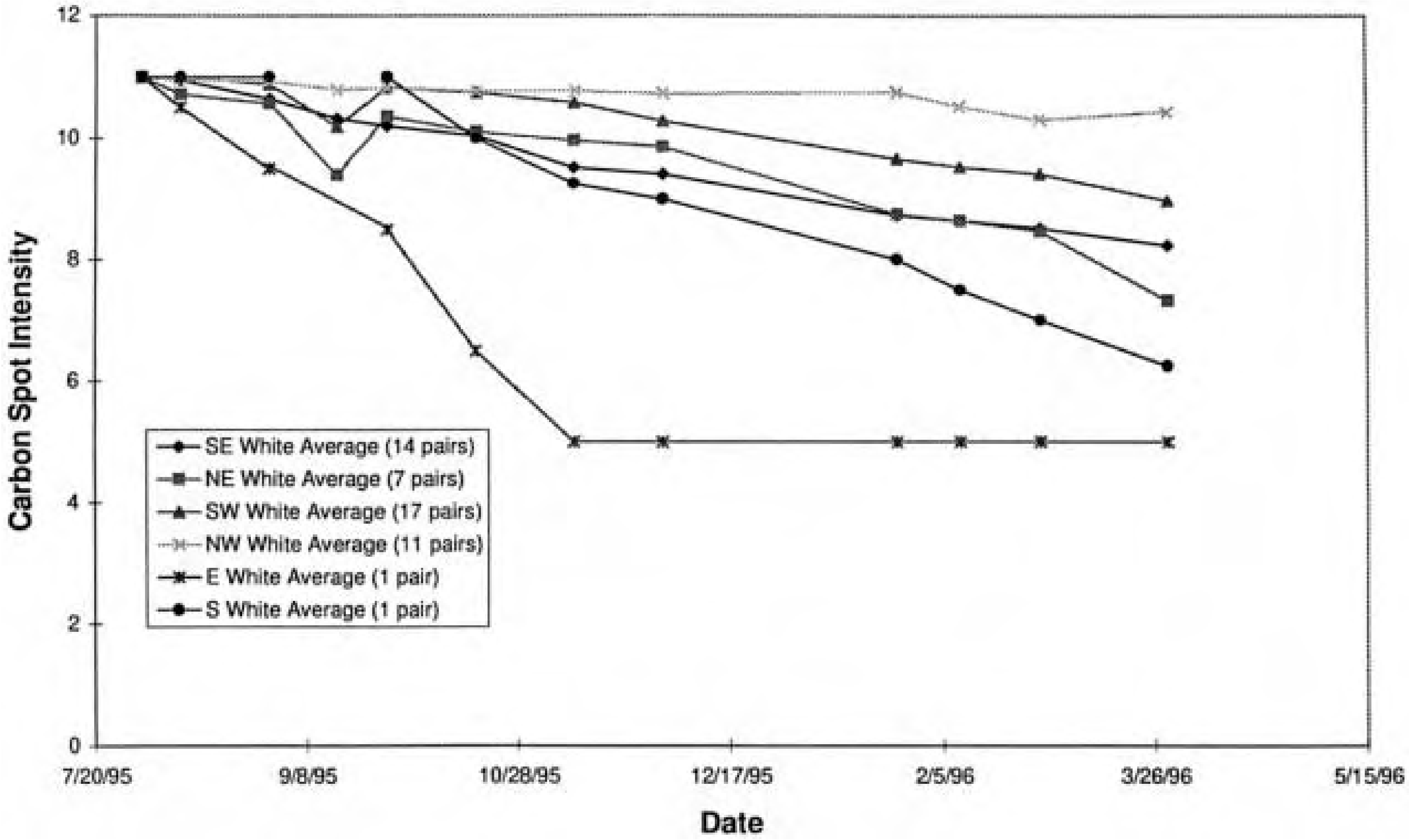
Graph 20

Carbon Spot Intensity versus Time on White Areas as a Function of Spot Direction on the Southeast 38th Floor



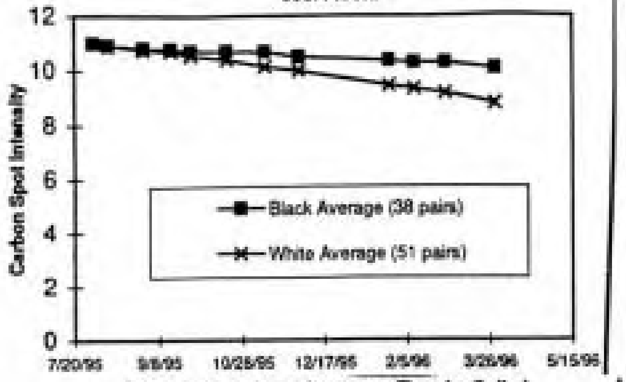
Graph 21

Carbon Spot Intensity versus Time on White Areas as a Function of Spot Direction on the 5th, 16th, and 38th Floors

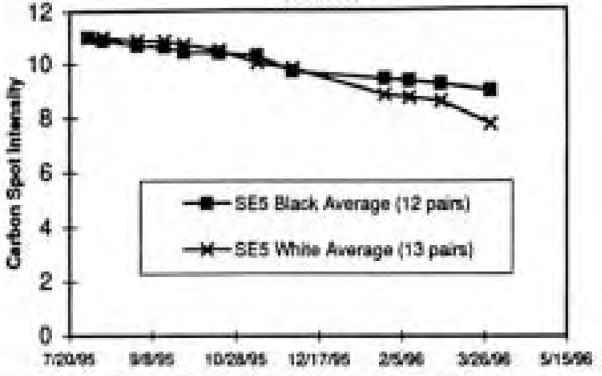


Graph 22

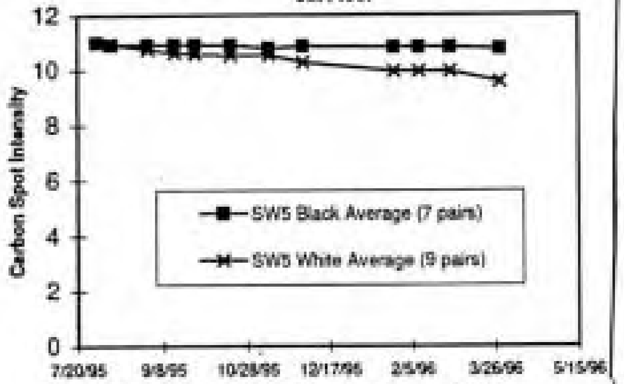
Carbon Spot Intensity versus Time for Soiled and Unsoiled Areas on the 5th, 16th, and 38th Floors



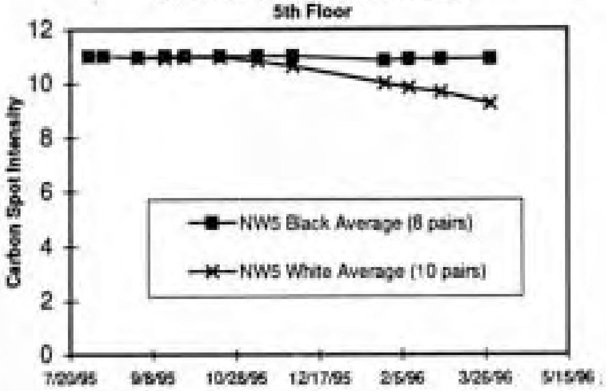
Carbon Spot Intensity versus Time for Soiled and Unsoiled Areas on the Southeast 5th Floor



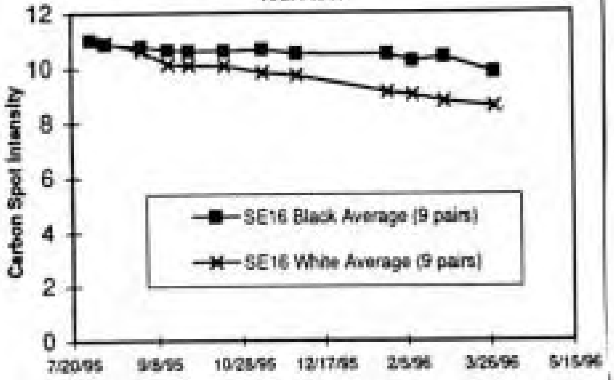
Carbon Spot Intensity versus Time for Soiled and Unsoiled Areas on the Southwest 5th Floor



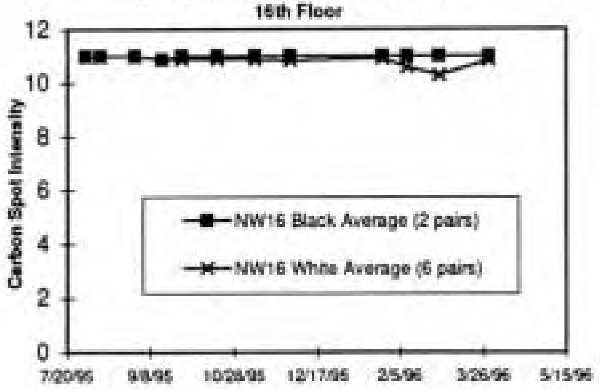
Carbon Spot Intensity versus Time for Soiled and Unsoiled Areas on the Northwest 5th Floor



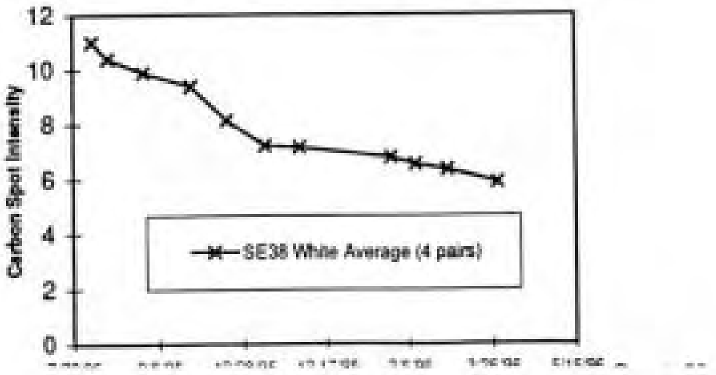
Carbon Spot Intensity versus Time for Soiled and Unsoiled Areas on the Southeast 16th Floor



Carbon Spot Intensity versus Time for Soiled and Unsoiled Areas on the Northwest 16th Floor



Carbon Spot Intensity versus Time for Unsanded Areas on the Southeast 38th Floor



Appendix D

A Protocol for Measurement of Vertical Wind Speeds at Five Locations at the Cathedral of Learning

Sorachai Sean Jutahkiti

INTRODUCTION

To study the wind patterns at the Cathedral of Learning, we use anemometers to measure windspecd and direction. For this project, we obtain data from five points at the building. The anemometers measure the vertical component of the windspeed. Three points were chosen on the fifth floor, facing Forbes Avenue, Fifth Avenue and Bigelow Boulevard, respectively. The remaining two points are on the sixteenth floor facing Forbes and Fifth Avenues, respectively. These points were chosen because they were accessible and representative of each face of the building.

To maximize the usefulness of the data collected, it would be ideal and convenient to log data from all five points simultaneously. Poles were used to hang the anemometers from the wall, and wires connected them to the same data logger. This will be discussed in detail in the "Equipment and Setup" section.

Preliminary work was done by Anthony Paul, who designed the poles for the sixteenth and fifth floor. He built a pole for the fifth floor and both poles for the sixteenth floor. He also chose the five sampling points at the Cathedral.

EQUIPMENT AND SETUP

Wiring

Wires connect the five anemometers to the data logger. Wires from the Fifth Avenue and Bigelow Boulevard sides are connected to a bundle of wires which lead to the data logger. Wires from the Forbes Avenue side connect to a separate bundle. The wires are color coded for easy reference. Each anemometer has two wires, so there are ten wires connected to the data logger.

	Bigelow (5th)	**Fifth (5th)**	**Fifth (15th)**	**Forbes (5th)**	**Forbes (15th)**
Wire Colors	yellow/blue	brown! green	red/white	brown! green	red/white
Data Logger Input Channel	**2**	3	4	5	6
Storage Location	**1**	**2**	**3**	**4**	5

Since the anemometers have to be stored after every data collection session, the wire and anemometer connections are made with quick connect adapters. The current quick connects being used are flimsy; finding sturdier quick connect adapters would be advisable.

Anemometers

Each anemometer used is a Gill Propeller made by R.M. Young Company. Air flow from any direction may be measured, although the propeller responds only to the component of the air flow that is parallel to the axis of its rotation. The rotation of the propeller creates a DC voltage difference that is linearly proportional to air velocity. This signal could be positive or negative, depending on the direction of the wind.

Data Logger/Storage Module

The data logger is the 21X Micrologger made by Campbell Scientific. It has been programmed to read the voltage difference created by the anemometer and convert it to windspced in meters per second. The data are stored in a storage module. To avoid logging in junk data, the data logger has been programmed to store data in the storage module only when the operator allows data input to begin (see step 3 in the next section on procedure for collecting data).

A printout of the program is in Table I. This program will erase if power to the data logger is cut. However, copies of the program are stored in the storage module and the hard drive of the laptop computer. The program can easily be downloaded into the data logger. The program was written in an application called “Edlog” available on the laptop. All applications and files for the data logger and storage module can be found in the “campbell” directory in the “C” drive. The program was saved as “sean.dld”. To download this file to the storage module, “Smcom” is used. “Smcom” is the software interface between the storage module and the laptop. From the storage module, the program can be downloaded to the data logger by typing this key sequence on the data logger: *D7IA2IA.

For each channel on the data logger, there are three inputs. The ones labeled H and L are used. To obtain a positive value for an upward wind component and negative value for a downward wind component, the black wire from the anemometer is connected to L and white to 1-1. The table below summarizes how this is done.

	connects to	**connects to**
Data Logger	**H**	**L**
Anemometer	white	black
wiring scheme I	red	white
wiring scheme 2	brown	green
wiring scheme 3	yellow	blue

Poles

There arc two types of poles, one for the fifth floor and one for the sixteenth floor. The drawings can be seen in Figures 1 and 2. The poles are made of wood and are sturdy, but they arc also quite heavy.

A swivel arm extends from the poles, so the distance from the anemometer to the wall can vary. Distances corresponding to different angles of the swivel arm can be marked on the poles. It should be noted that the poles do not always hang flat against the wall.

PROCEDURE FOR COLLECTING DATA

At the Cathedral:

I. Attach anemometers to poles and connect wires to anemometers.

2. Hang poles off the wall.

3. Type the key sequence :*6ADI. This sets flag one to high. If you're already in the *6 mode, just hit the "D" key and set flag one using the "1" key. When flag one is high, data are logged into the storage module.

4. Collect 10 minutes of data.

5. Set flag one to low in order to end data collection.

6. Collect the anemometers and store them on the fifth floor.

Down loading data:

1. Connect the storage module to the laptop.

2. Go to the "campbell" directory in the "C" drive of the laptop.

3. Type "smcom" to open the application.

4. Choose Corn I.

5. Type "N" since the storage module is not any of the ones stated.

6. When the application is open, type "U" to collect all uncollected data.

7. Type "C" for the file format to be comma delineated ASCII arrays.

8. Each file is named by the month and day. For example, "apr02" is for April 2nd.

9. The file can be opened in Excel and converted to an Excel file. The data can also be plotted in Excel.

Obtaining weather information:

The humidity, windspccd, wind direction and cloud cover on the day of data collection should be noted. This information can be obtained form the Internet. It is possible to get this information by typing “weather -r pit” at the UNIX prompt, but the same information can be obtained from the world wide web.

DATA ANALYSIS

Initially, data were only collected for the fifth floor, because of the problems in setting up the equipment for the sixteenth floor. From the graphs, we can see that the windspeeds are random and change abruptly. We can also see that the average windspeed is positive, indicating it is moving upward along the building.

The average windspecd for the Bigelow side on the days sampled is 0.585m1s. This number is low, because the wind on this side tends to fluctuate a lot between positive and negative.

On the fifth floor, the average windspccd for the Fifth Avenue side on the days sampled is 1.139m/s. This indicates that the wind is usually moving in the upward direction. When the windspced on the Bigelow side is a positive value, winds on the Fifth Avenue side are smaller positive or negative values. When the windspeed on the Bigelow side is a negative value, winds on the Fifth Avenue side are larger positive values. The plot of the average windspccd on the Bigelow side versus the average windspeed on the Fifth Avenue side is in Graph 1. The correlation coefficient obtained using Excel is -0.832. Each point represents data collected on one date over a period ranging from 7 minutes to 1 hour.

When these same data were plotted as individual instantaneous values (obtained each execution interval of 2 seconds or 5 seconds), no correlation was observed. This suggests that precise simultaneous windspccds on these two sides of the Cathedral are not correlated, although average windspccds over longer periods such as 7 minutes to 1 hour are indeed correlated.

On the fifth floor, the average windspecd for the Forbes Avenue side on the days sampled is I .268rn1s.

The plots of the data are in Graphs 2, 3 and 4. A more complete set of data is in Table 2 and on file with the Cathedral Project records.

CONCLUSIONS

- The poles, wiring and anemometer arc set up for immediate use.

- Thc data logger is programmed to log data.

- The collection of data from five locations is successful.

- A negative correlation has been observed between the wind on the Bigelow Boulevard and the Fifth Avenue side.

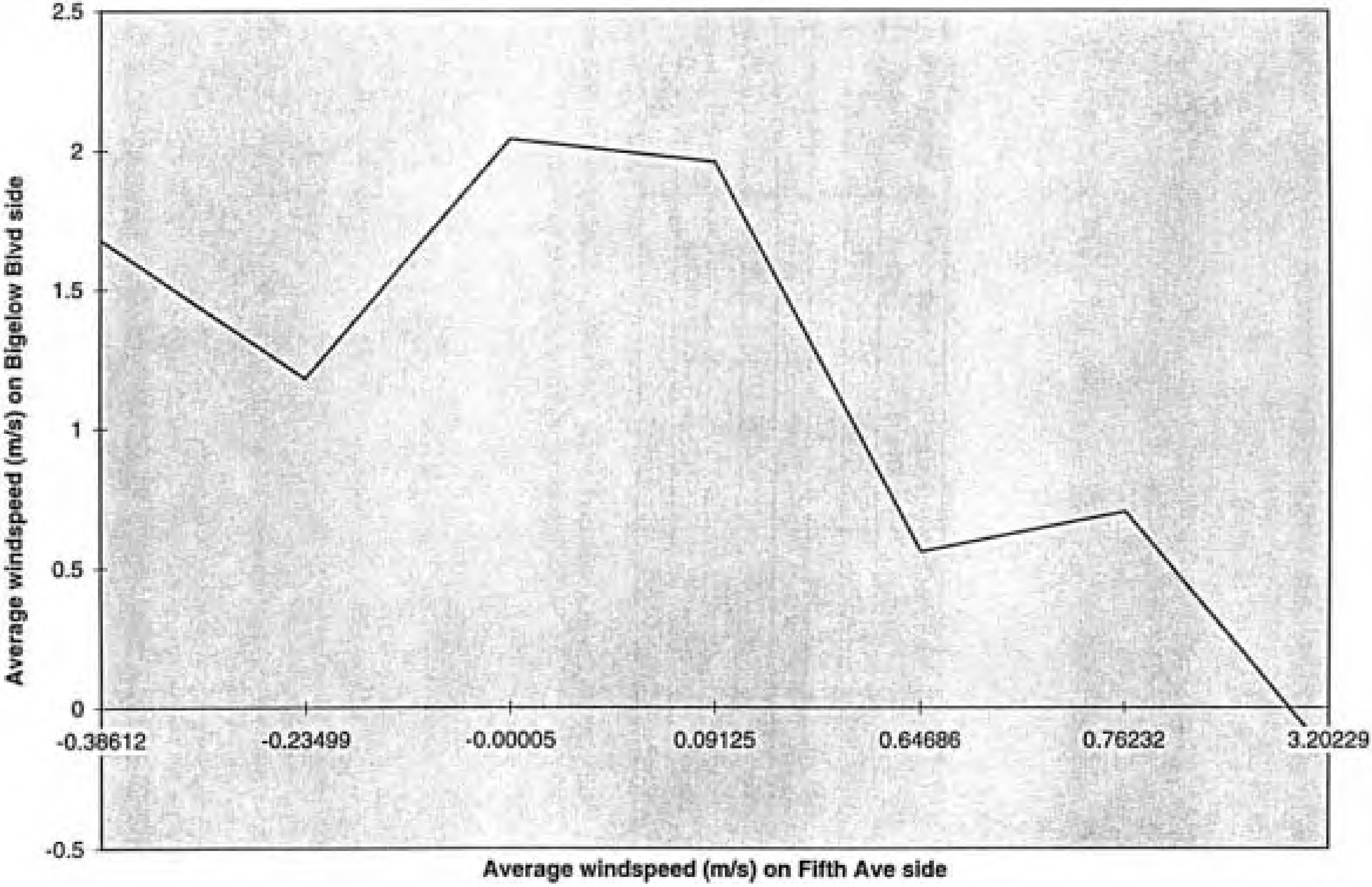
Table 1: Program for data logger

```
} ;2 1X
;SEAN.DLD

MODE 1
SCAN RATE 5

I :P9 I
1:11
2:30

2:P86
1:10

3:P95

4:P2
1:5
2:4
3:2
4:1
5:0.0 176
6:0.0000

5:P70
1:5
2:1

6:P96
1:30

MODE 2
SCAN RATE 0.0000

MODE 3

MODE 4
1:00
2:00

MODE 10
1:28
2:64

MODE 12
1:00
2:0000
••y
```

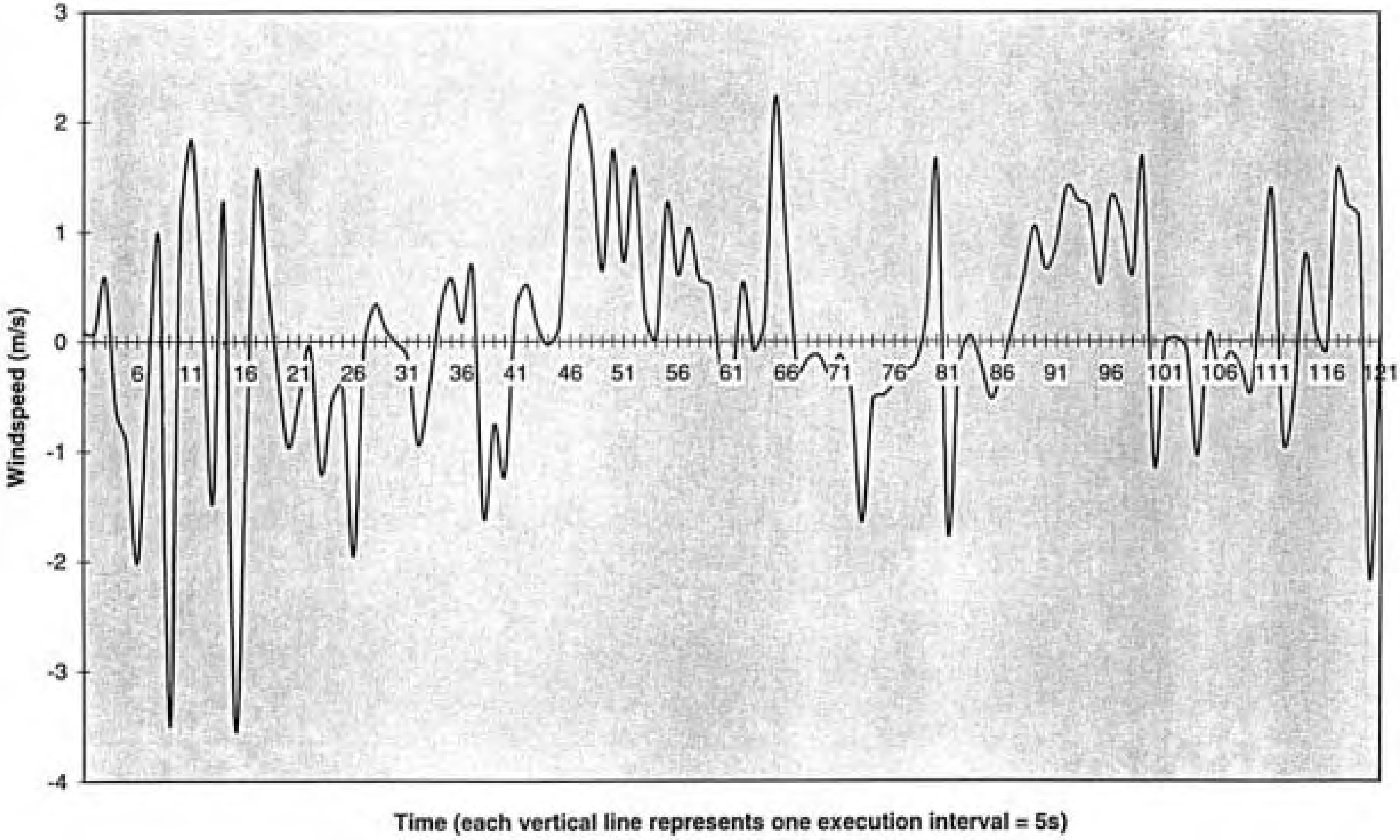
	Bigelow (5th Floor)	Fifth (5 th Floor)	Forbes (5 th Floor)	Fifth (16 th Floor)	Forbes (16 th Floor)
Apr25	0.091	1.958	1.777	-	-
Apr 29	0.762	0.702	0.930	-	-
Apr 30	0.0	2.041	2.204	-	-
May 2	-0.235	1.180	1.464	-	-
May6	3.202	-0.169	1.929	-	-
May 8	0.647	0.558	0.4 18	-	-
May9	-0.386	1.679	0.145	2.054	-

Table 2: Average windspced in mis for 1996. Values represent data collected over periods ranging from 7 minutes to 1 hour

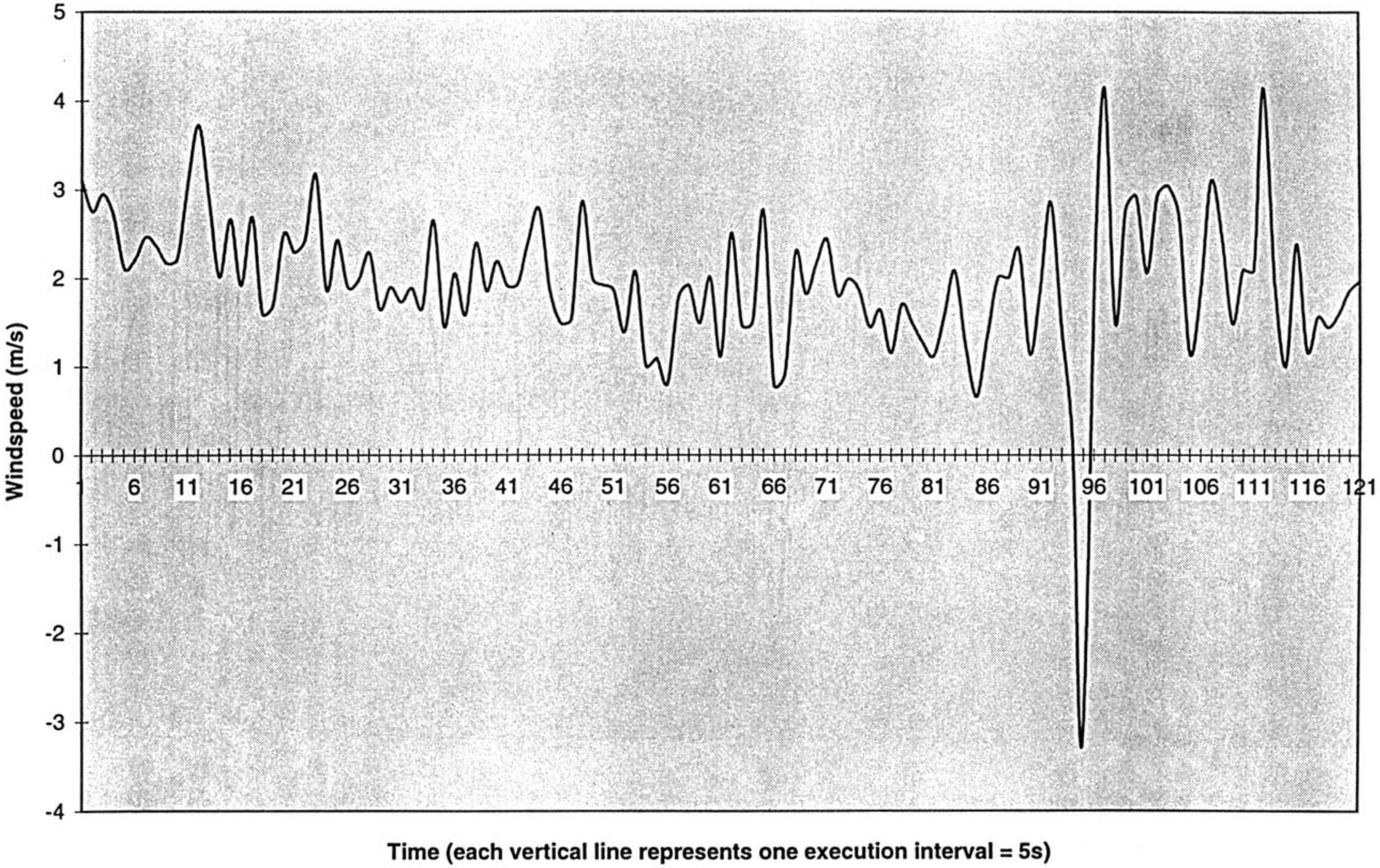
Graph 1: Average daily windspeed on the Bigelow Blvd side versus the Fifth Ave side. Each point represents one day of testing. Dates are April 25, April 29, April 30, May 2, May 6, May 8, May 9 arranged in ascending order on Fifth Ave side.



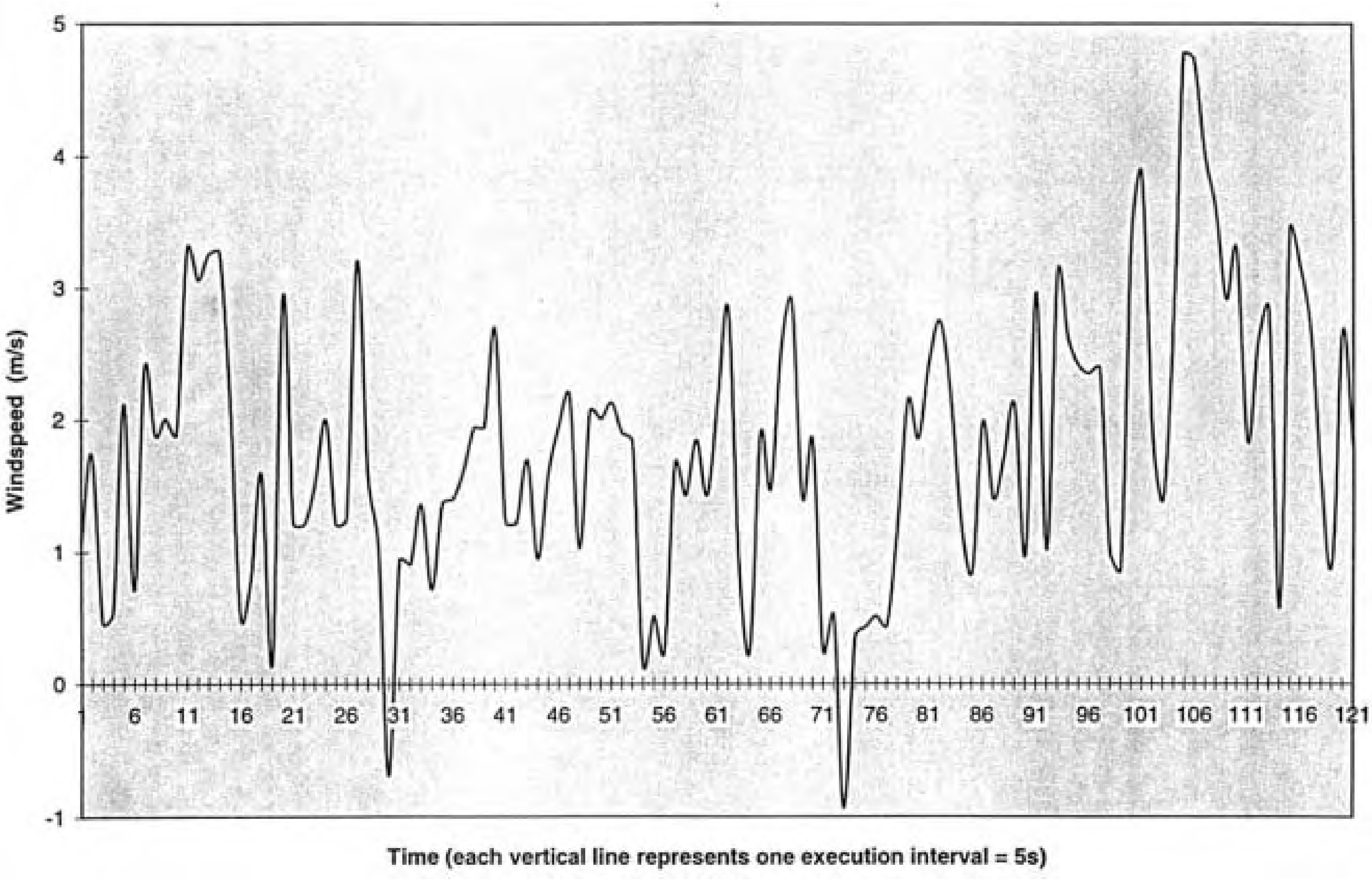
Graph 2: Windspeed versus time on the BigeloW Boulevard side (5th floor) on April 25, 1996



Graph 3: WindSPeed versus time on the Fifth Avenue side (5th floor) on April 25,1996



Graph 4: Windspeed versus time on the Forbes Avenue side (5th floor) on April 25, 1996



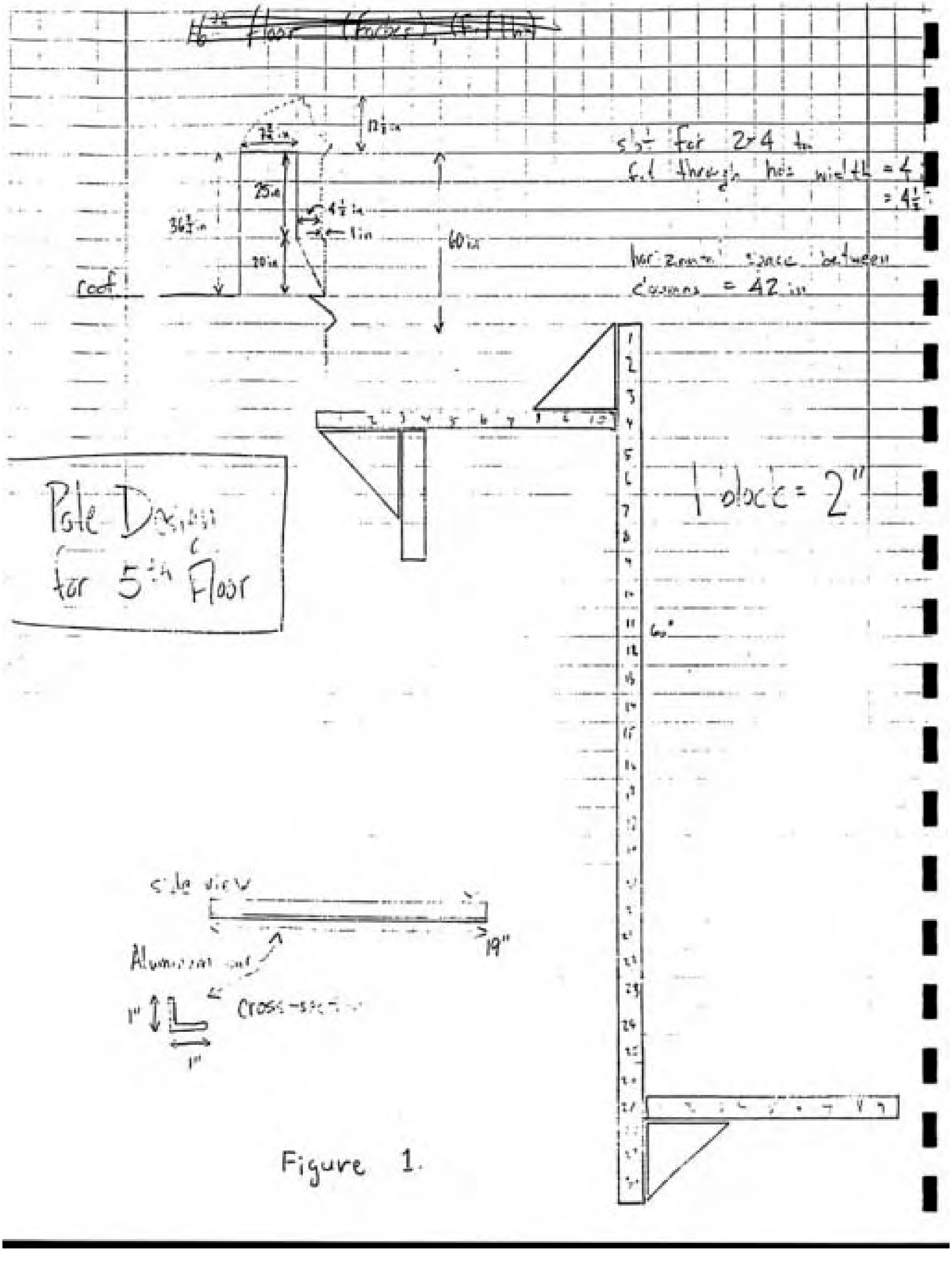

~~6th Floor (Facade) (Full)~~
7¾ in
12½ in
25 in
36¼ in
4½ in
1 in
20 in
60 in
roof
5½" for 2×4 to
fit through hole width = 4"
= 4½"
horizontal space between
columns = 42 in
Pole Design
for 5th Floor
1 block = 2"
60°
side view
19"
Aluminum cut
1"
1"
cross-section

Figure 1.

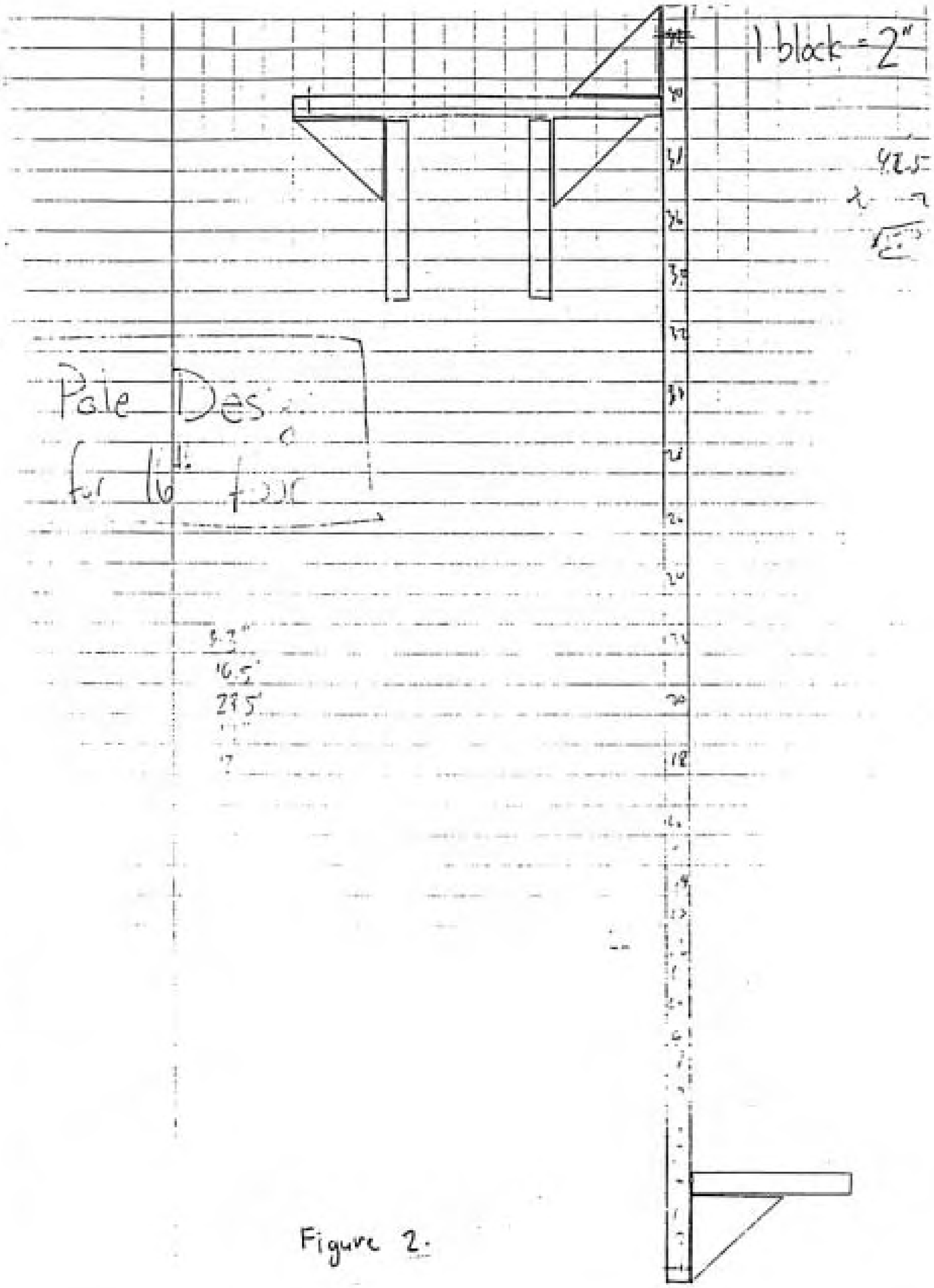

1 black = 2"
42.5
Pole Design for 16" floor
3.3"
16.5"
29.5"
17"
40
38
36
34
32
30
28
26
24
22
20
18
16

Figure 2.

Appendix E

Airborne SO_2 Concentrations at the Cathedral of Learning: Comparison with Concentrations Measured by the Allegheny County Monitoring Network

Brett J. Fontaine

AIRBORNE SO_2 CONCENTRATIONS AT THE CATHEDRAL OF LEARNING: COMPARISON WITH CONCENTRATIONS MEASURED BY THE ALLEGHENY COUNTY MONITORING NETWORK

Submitted by: Brett J. Fontaine
Advisor: Cliff I. Davidson
Spring 1996

Introduction

The Cathedral of Learning in Pittsburgh, PA has been the focus of a case study involving the deterioration and soiling patterns on a limestone structure. A twostep mechanism is responsible for these effects. First, airborne sulfur dioxide (SO_2) reacts chemically with the limestone to form gypsum (calcium sulfate, $CaSO_4$). Second, the presence of black carbon in the form of soot deposits more easily on the rough surface where gypsum has formed, causing soiling. Gypsum has a greater volume than limestone which results in cracking of the stone, and has a higher solubility in the rainwater which results in washoff leading to pitting of the surface.

Problem Definition

SO_2 monitoring has been conducted on the Cathedral from 12/92 through 7/95. A variety of collection methods have been employed on the fifth and sixteenth floors. The Allegheny County Bureau of Air Pollution Control (BAPC) has also conducted continuous monitoring of SO_2 at three different locations in the area. One station is located downtown at Flag Plaza, while the other two stations are located near LTV coke works in the Hazeiwood area (Figure 1). The Flag Plaza station monitors air quality in downtown Pittsburgh. The stations near LTV are known as the Hammerfield and Hazeiwood Stations, referred to as Stations 2 and 3, respectively, and are used to track local emissions from LTV and other sources in the Monongahela Valley.

It is desired to compare our Cathedral data with values from the BAPC. If LTV is an important source of 502 influencing the Cathedral, then higher concentrations should be measured at the Cathedral when LIV is upwind. There *may* be correlations between the BAPC data and Cathedral data, depending on the locations of the BAPC monitors relative to the wind direction and locations of sources. Furthermore, comparing concentrations provides a measure of quality assurance using two different methods of SO_2 measurement: The BAPC uses continuous monitors, while sampling at the Cathedral uses filterpacks for timeintegrated concentrations as described in the next section.

Procedure

I. Data Set Refinement

SO_2 airborne concentrations and deposition fluxes have been monitored at the Cathedral. We are concerned only with airborne concentrations in this paper. A Whatman filter impregnated with potassium carbonate (K_2C0_3) is used for sampling. Measurements have been conducted on the fifth floor patio, sixteenth floor patio, and the roof of the Cathedral. The airborne concentration sampling times have varied from a single day to three weeks. However, on average sampling has occurred on a weekly basis (See Table 1). The analysis for SO_2 concentrations is done by ion chromatography.

The averaging time for the BAPC continuous monitoring of airborne SO_2 concentrations is one hour. We have used the BAPC data to determine overall average concentrations for each time-integrated value obtained at the Cathedral. For some time periods, BAPC hourly data points are missing due to equipment failure. In these cases, the remaining data points have been averaged over the number of hours that the data are available. The manipulation of the data sets has been accomplished with Microsoft Excel 5.0.

Comparisons between the BAPC and Cathedral datasets are illustrated through time series plots and include data from August 1993 through January 1995. Several comparisons are shown to comprehensively represent the information. The concentrations at the Cathedral and each of the three Bureau locations have been plotted for the entire data set. To enhance the clarity of the graphs, this time period was arbitrarily broken up into four intervals. The points on the graphs represent different averaging periods, so re-averaging would be needed for rigorous statistical analysis. The differences between the Cathedral and each location have also been plotted for the entire time interval.

II. Meteorological Data

To address the differences in SO_2 concentration measured at the Cathedral and those measured at the surrounding BAPC stations, meteorological data have been studied to characterize wind patterns. It is of particular interest to determine the fraction of time that the wind is from each direction.

A variety of meteorological inputs have been recorded at the Cathedral since 6/93. These inputs include wind speed and wind direction, which are measured on the roof. A Campbell Scientific 21X datalogger is responsible for recording half hour averages of the meteorological data. The data have been periodically downloaded from the datalogger memory and compiled for graphical analysis.

A computer program has been written to reduce the raw meteorological data into useable information. The program, written in C, requires the user to provide a file of wind data and the interval of dates to be averaged. Analogous to the BAPC data averaging, the wind directions have also been averaged over the dates corresponding to the sampling intervals at the Cathedral. The program output is a table of eight 45 degree sectors, each with its respective weighted average. These data are stored in file w_frac.xls. An example is shown below:

Date: 10/8/93 (48 hours)

Degrees	Weighted Average
0	0.083
45	0.062
90	0.021
135	0.083
180	0.146
225	0.542
270	0.042
315	0.021

Zero corresponds to true north and it encompasses all directions between 337.5 degrees and 22.5 degrees. Therefore, these results indicate that from 10/8/93 to 10/10/93 the wind was blowing at 225 degrees +1- 22.5 degrees for 54.2% of the time.

The refined wind data have been used to gauge the predominant direction during each of the sampling intervals at the Cathedral. The wind data have been integrated into Excel and correlated with SO_2 concentrations measured at the Cathedral and Bureau stations.

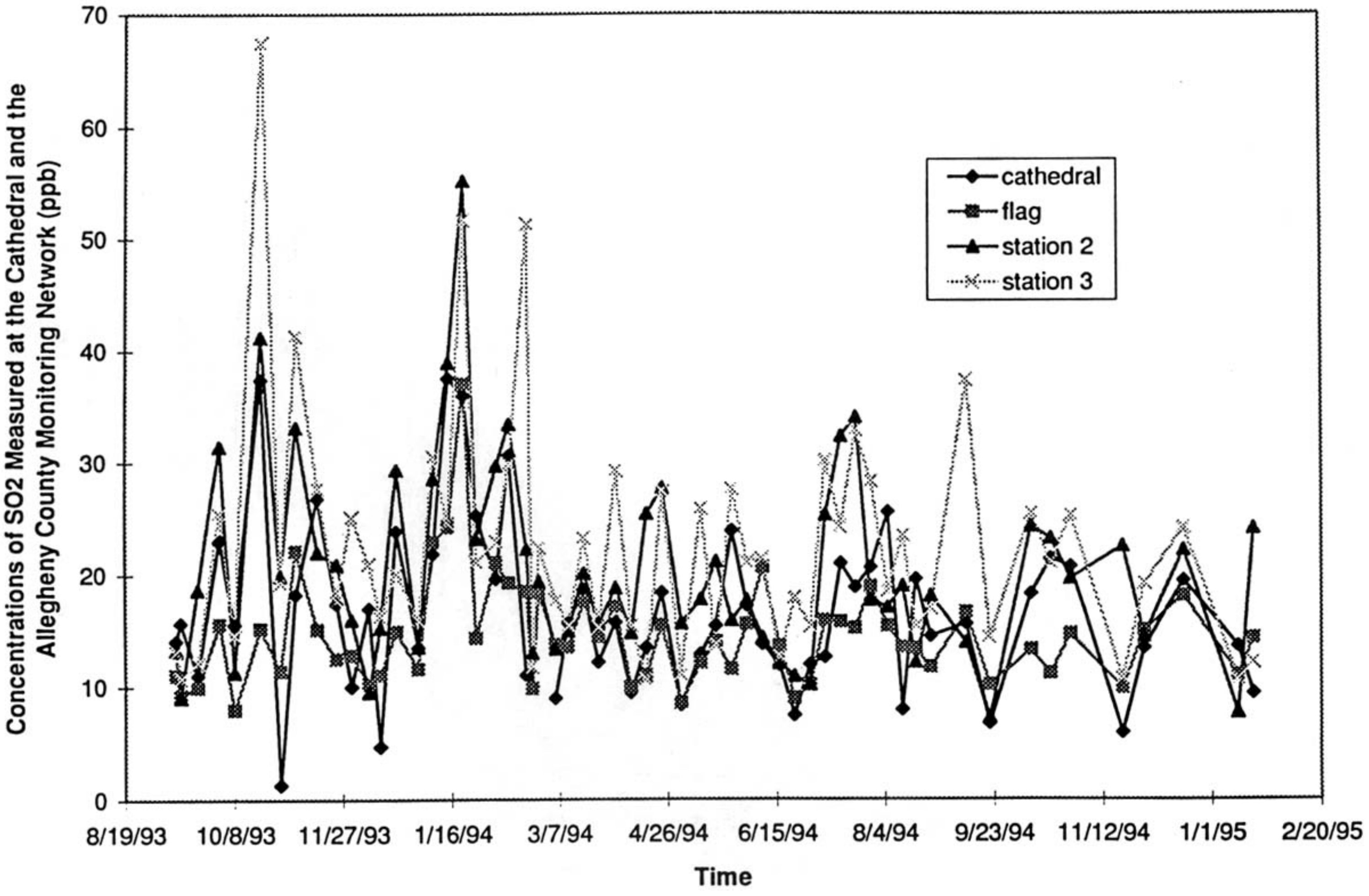
Conclusions

These comparisons have shown the Cathedral sampling of SO_2 to correlate well with that of the Bureau (Graphs 1-4). Time weighted averages of all four locations show the average concentration at the Cathedral to be slightly higher than at the Flag Plaza station, but lower than at the stations in the Hazeiwood area (Graphs 8-11). The correlation between the Cathedral and each of the Bureau stations seems to differ from season to season. However, a single concentration spike recorded at either of the point source monitoring stations is sufficient to significantly influence the correlation with the Cathedral.

LTV does not appear to be significant source of airborne SO_2. There is no correlation between high concentrations of SO_2 measured at the Cathedral and time intervals when LTV is predominantly upwind (Graphs 12-17). Furthermore, there are no appreciable correlations between high concentrations of SO_2 measured at Stations 2 or 3 and times when LTV is upwind of either of these stations. Therefore, local deviations in SO_2 concentrations between monitoring stations are left to be explained by studying other possible sources such the Bellefield Steam Plant and traffic emissions in the Oakland airshed.

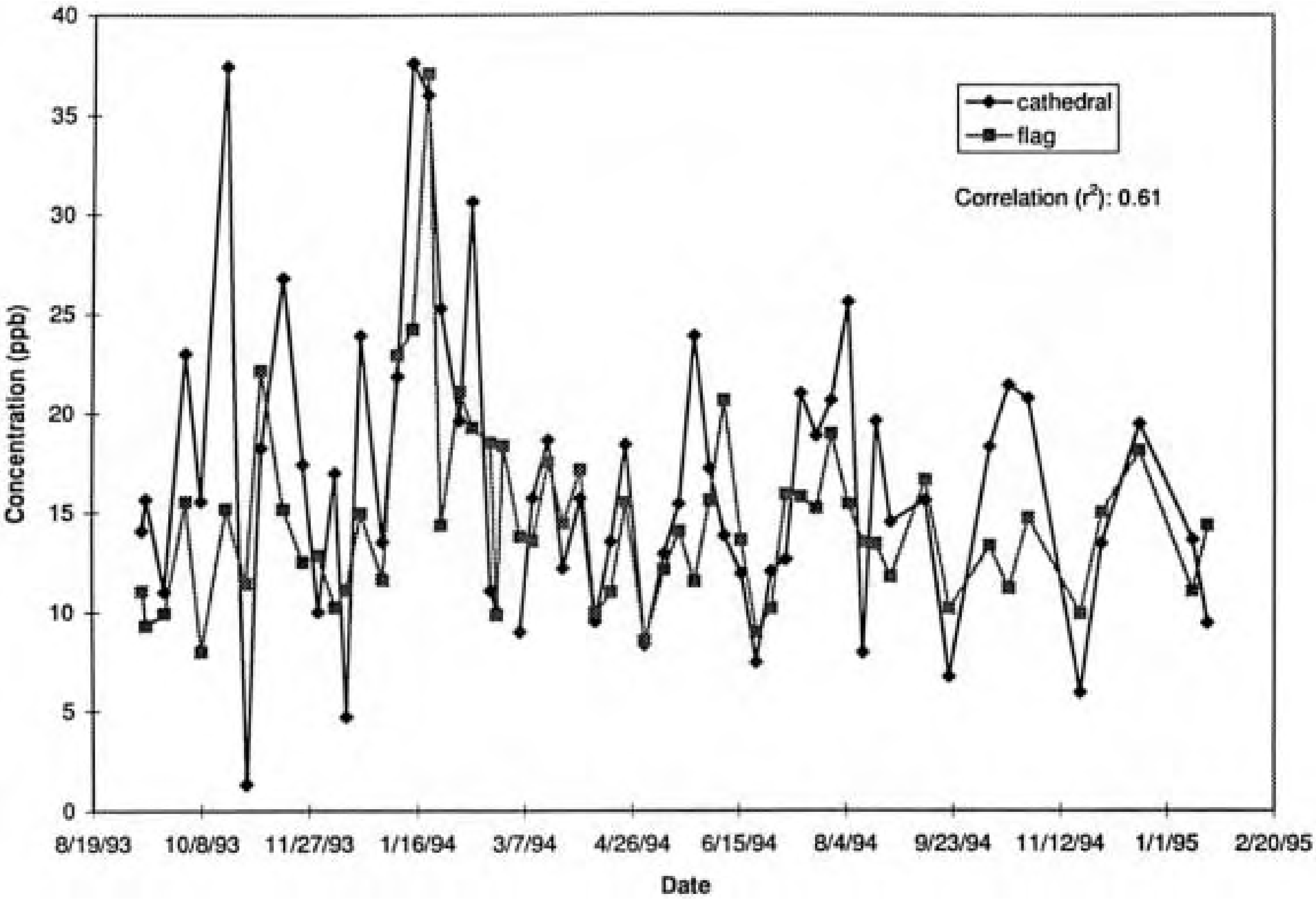
Graph 1

Concentrations of S02 Measured at the Cathedral and the Allegheny County Monitoring Network vs. Time



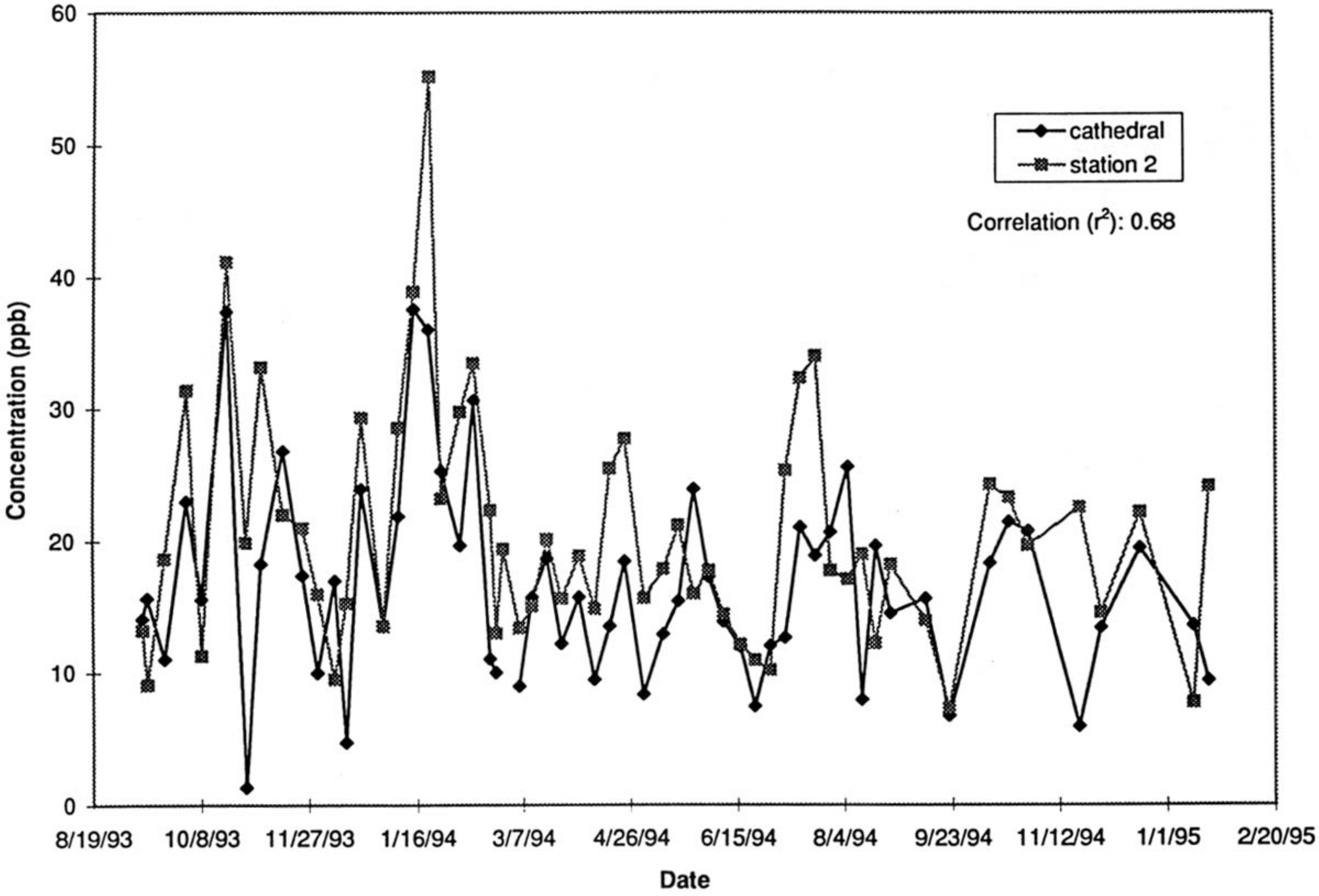
Graph 2

SO_2 Concentration Comparison
Cathedral vs. Flag Plaza



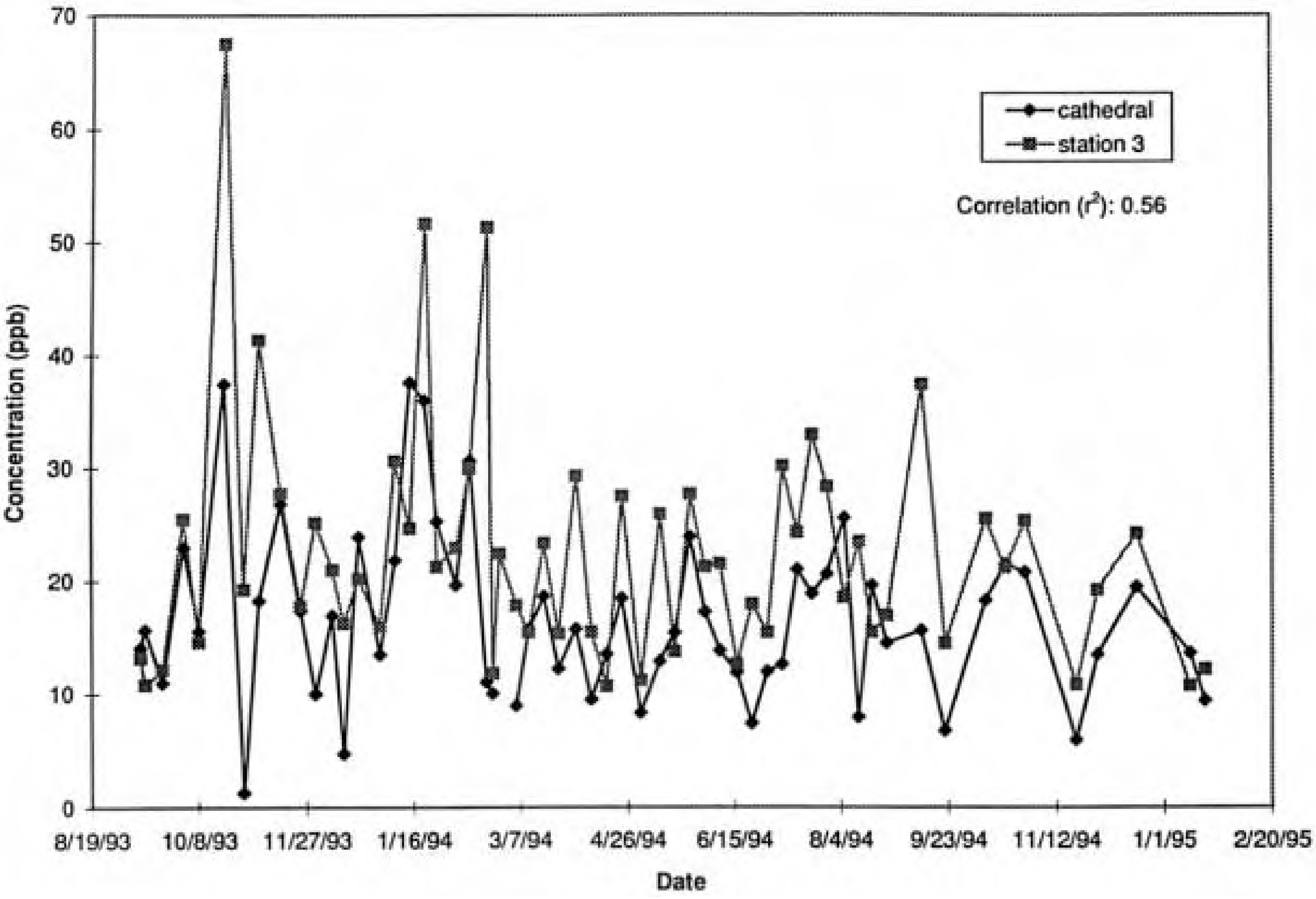
Graph 3

S02 Concentration Comparison
Cathedral vs. Station 2



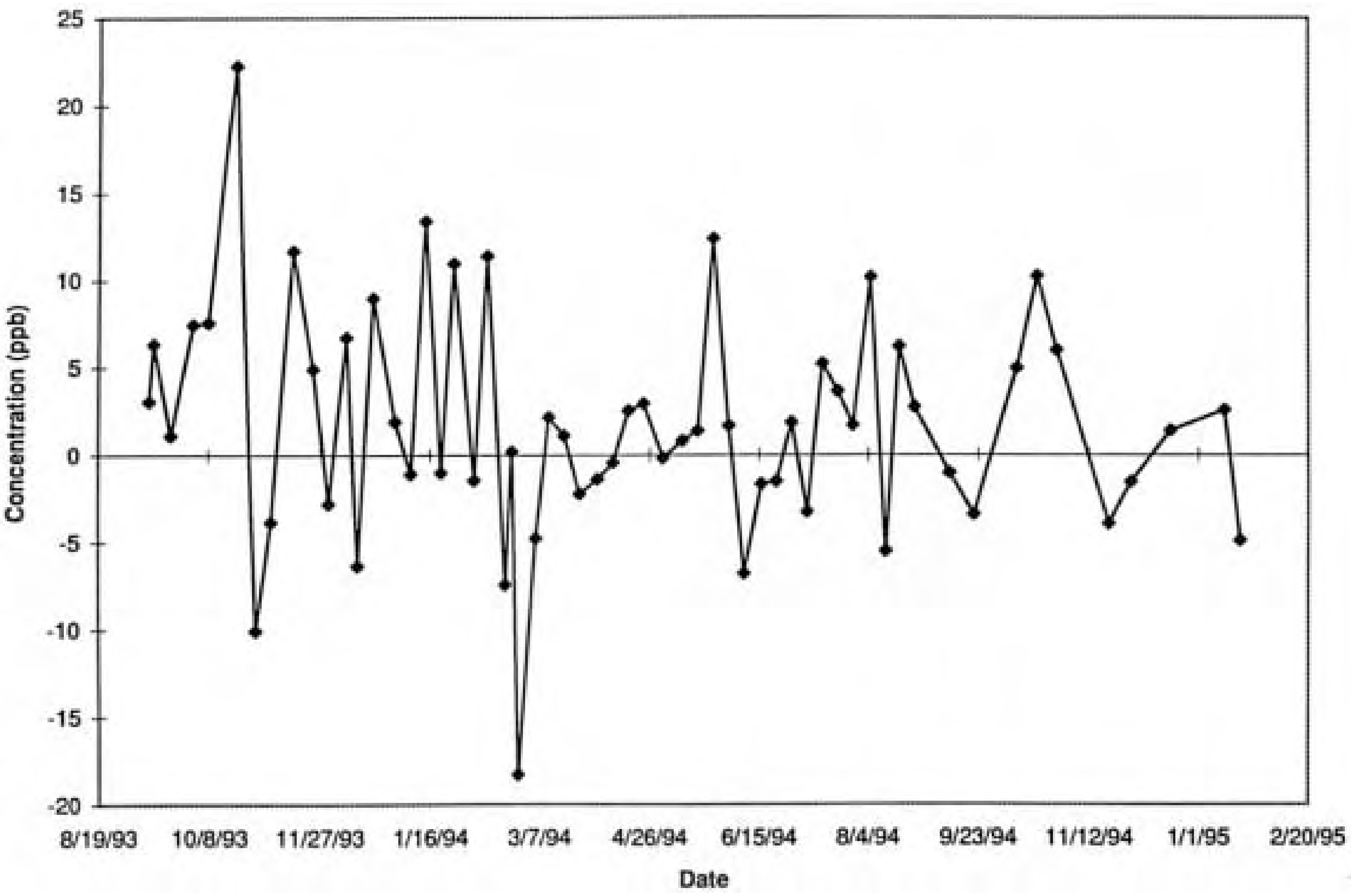
Graph 4

S02 Concentration Comparison Cathedral vs. Station 3



Graph 5

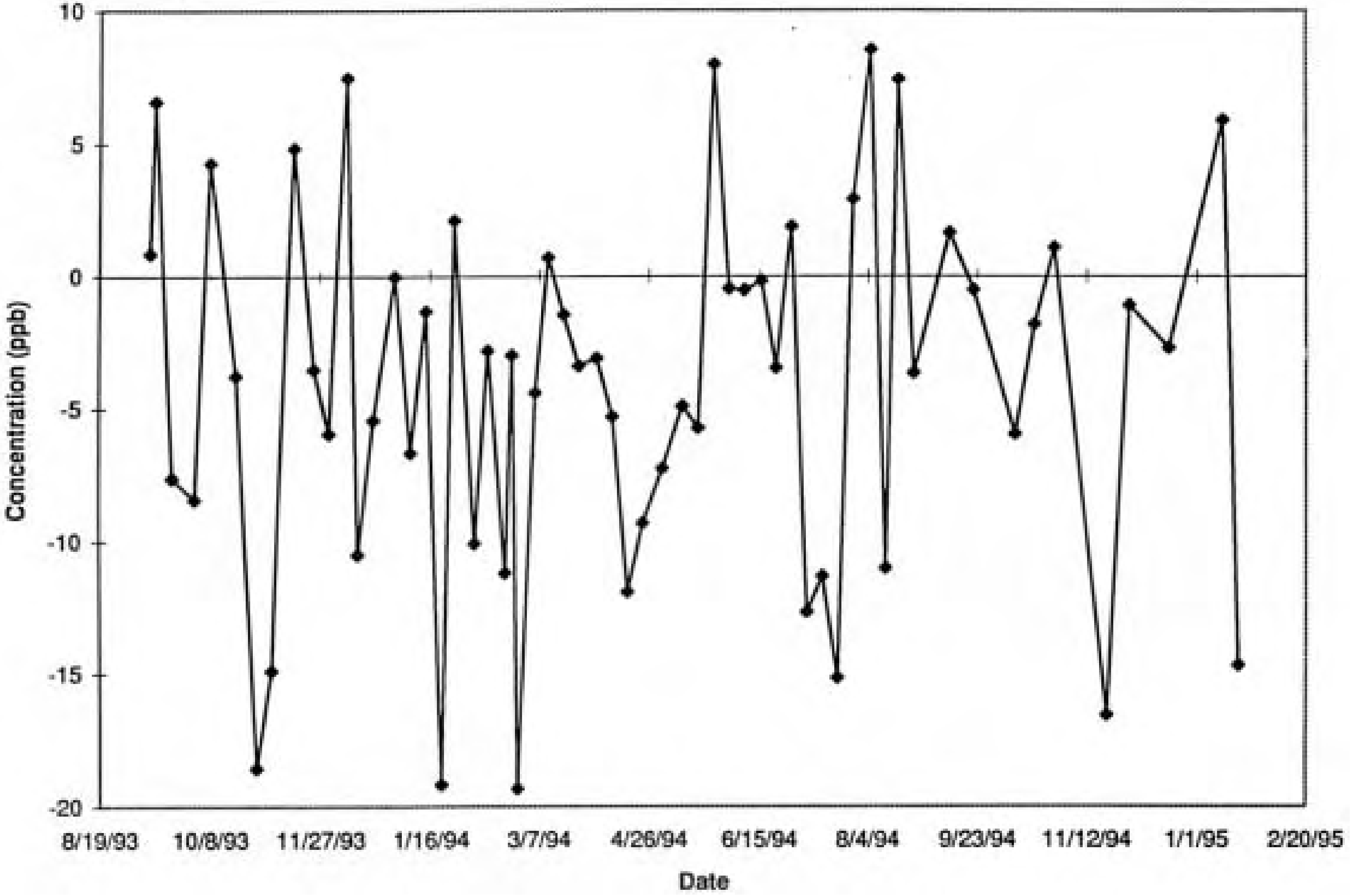
SO_2 Concentration Difference
Cathedral Concentration Minus Flag Plaza Concentration



Date

Graph 6

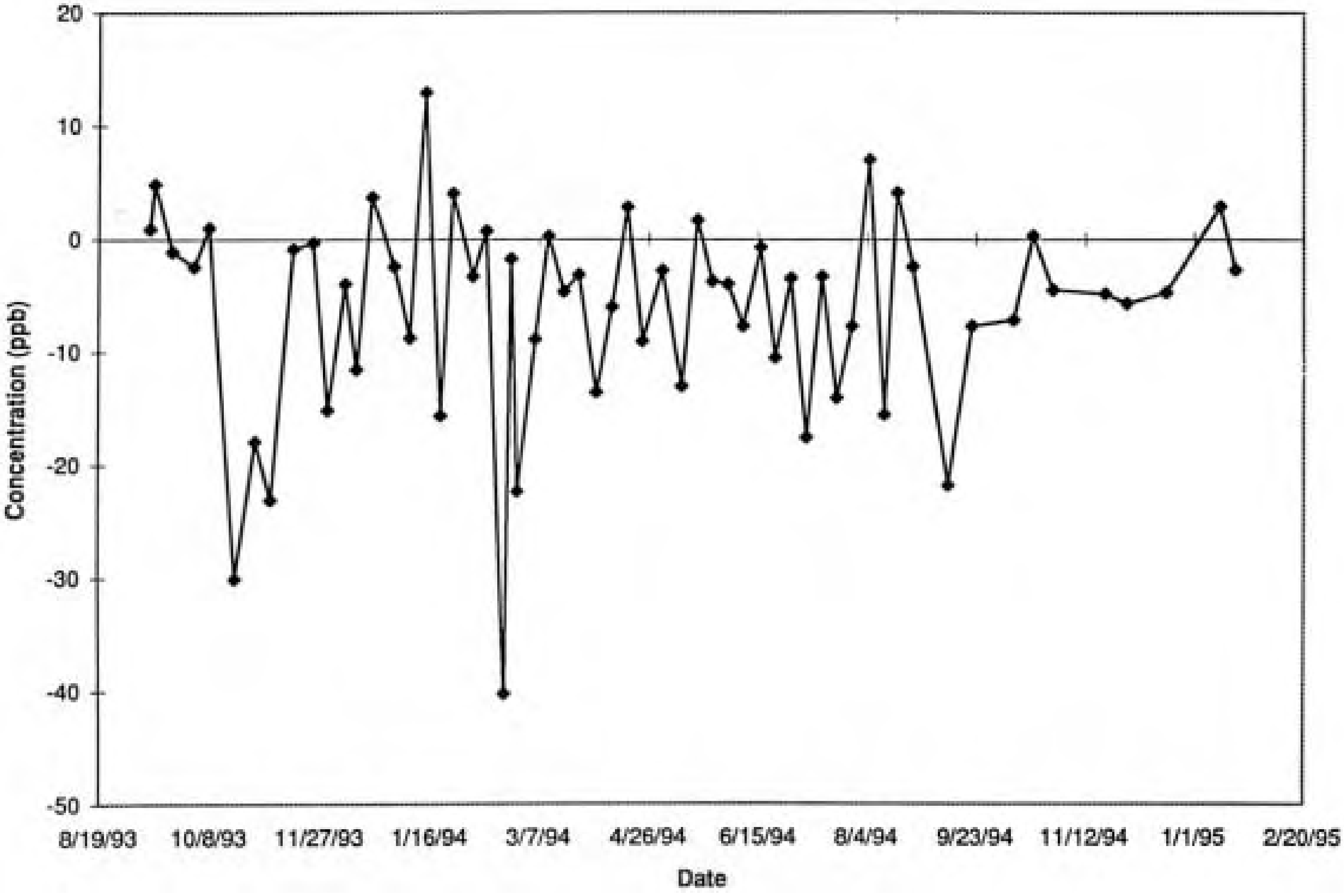
SO2 Concentration Difference
Cathedral Concentration Minus Station 2 Concentration



Date

Graph 7

SO Concentration Difference
Cathedral Concentration Minus Station 3 Concentration



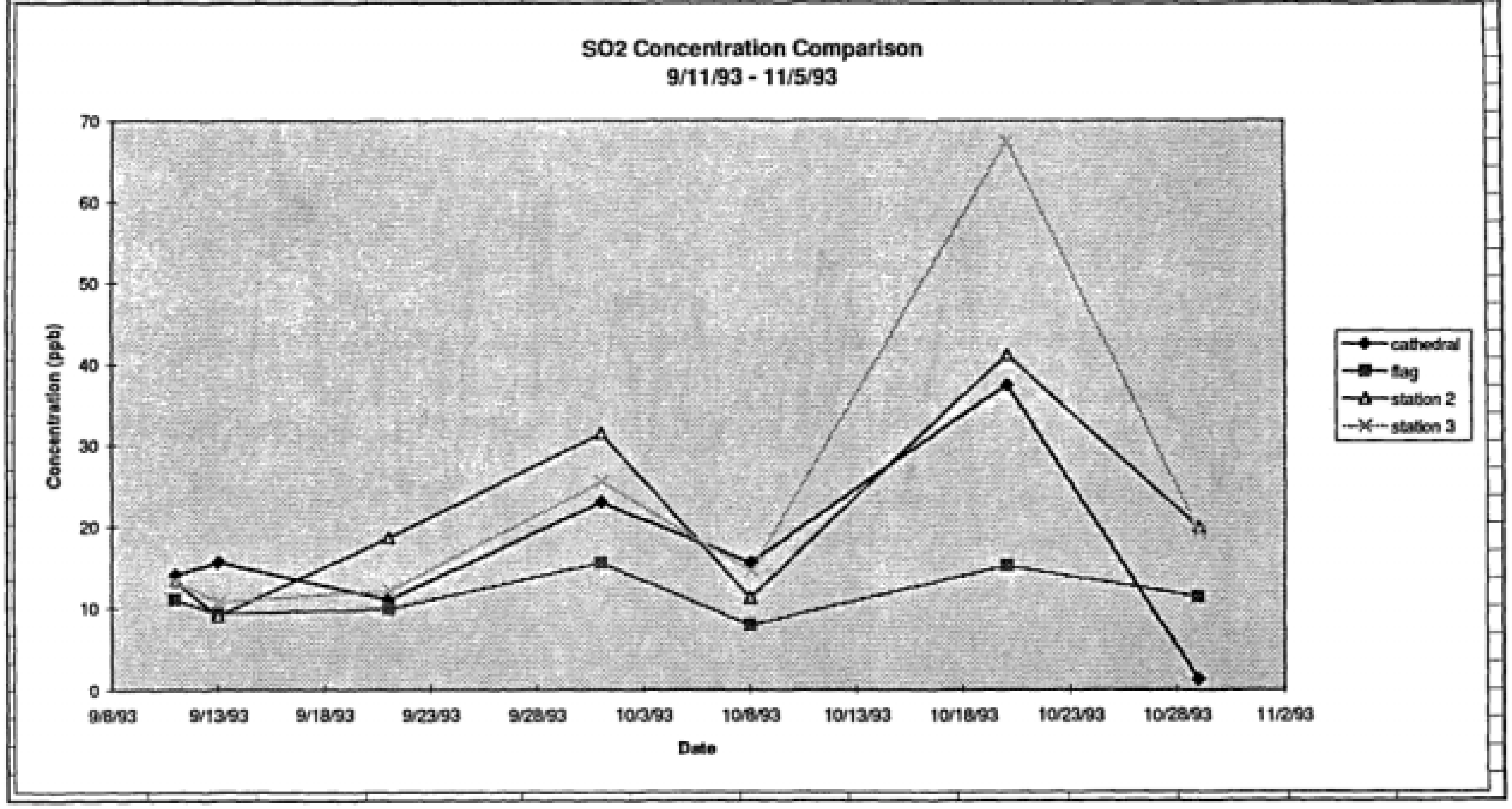
Date

Graph 8

Correlations:	
flag v. stat2	0.91
flag v. stat3	0.72
stat2 v. stat3	0.89
cath. v. flag	0.62
cath. v. stat2	0.71
cath. v. stat3	0.82

Time weighted Averages:

cathedral	flag	stat2	stat3
17.4	11.2	20.9	24.2


SO2 Concentration Comparison
9/11/93 - 11/5/93

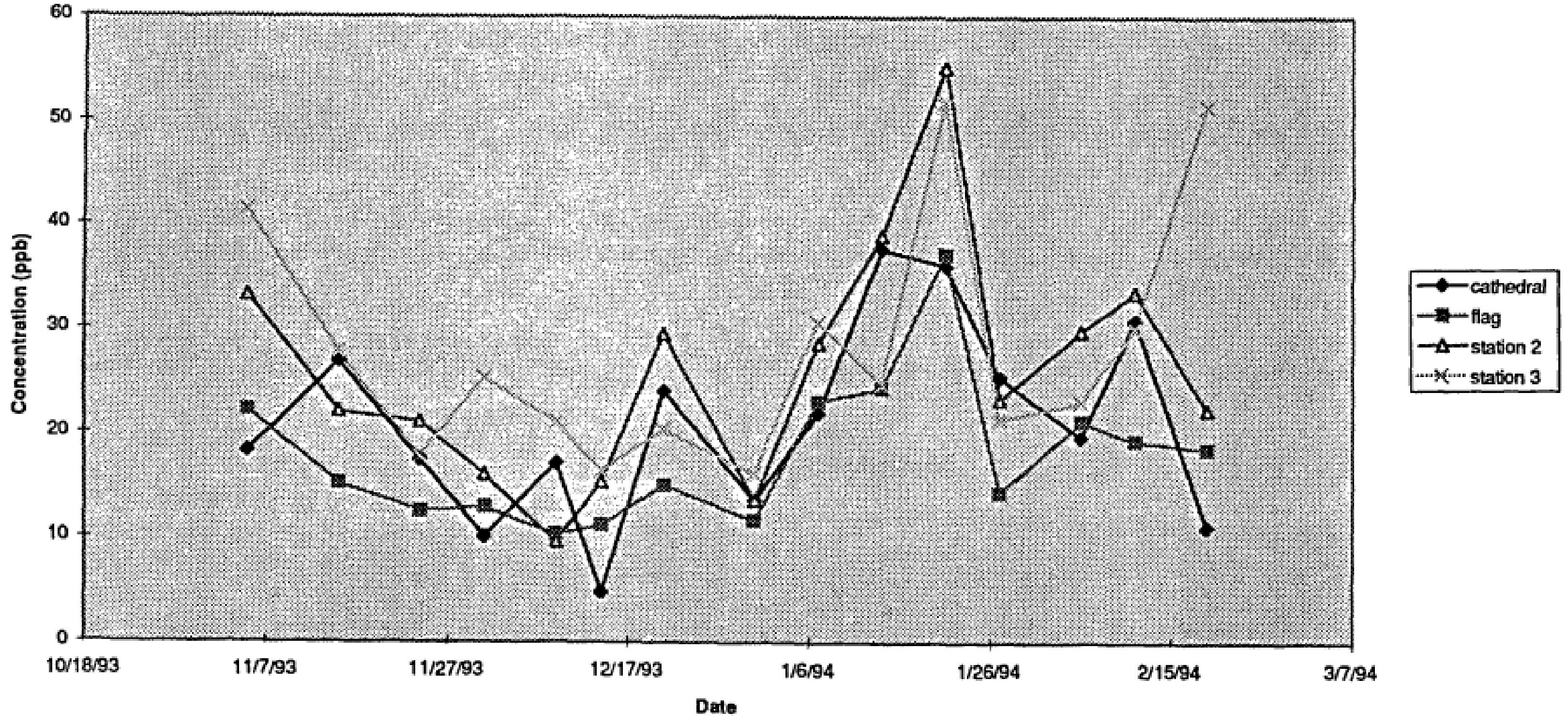
Graph 9

Correlations:	
flag v. stat2	0.94
flag v. stat3	0.73
stat2 v. stat3	0.60
cath. v. flag	0.66
cath. v. stat2	0.78
cath. v. stat3	0.25

Time weighted Averages:

cathedral	flag	stat2	stat3
21.4	17.6	26.3	27.0

SO2 Concentration Comparison
11/5/93 - 2/19/94



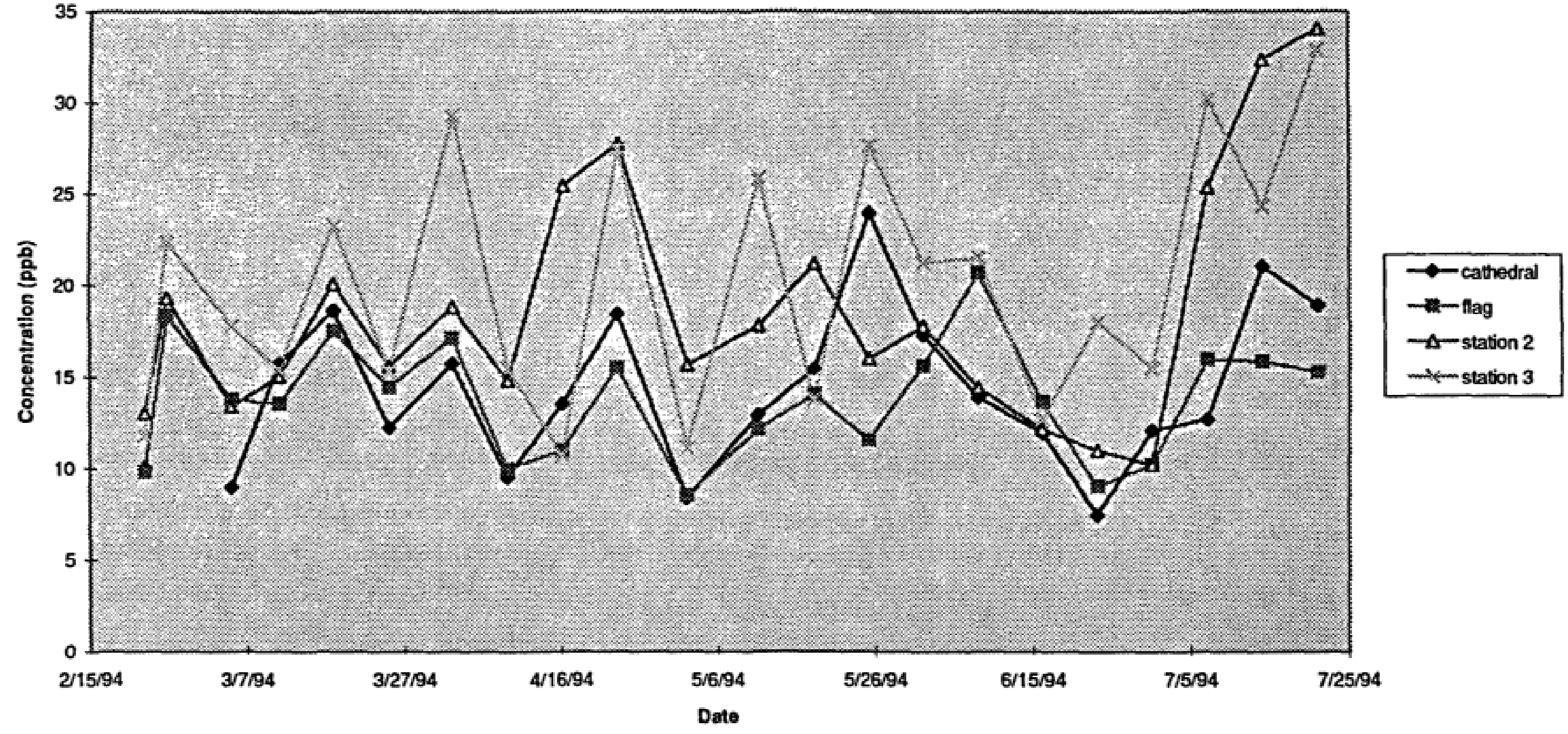
Graph 10

Correlations:	
flag v. stat2	0.37
flag v. stat3	0.54
stat2 v. stat3	0.56
cath. v. flag	0.38
cath. v. stat2	0.11
cath. v. stat3	0.17

Time weighted Averages:

cathedral	flag	stat2	stat3
20.7	13.9	18.9	20.3

SO2 Concentration Comparison
2/22/94 - 7/28/94

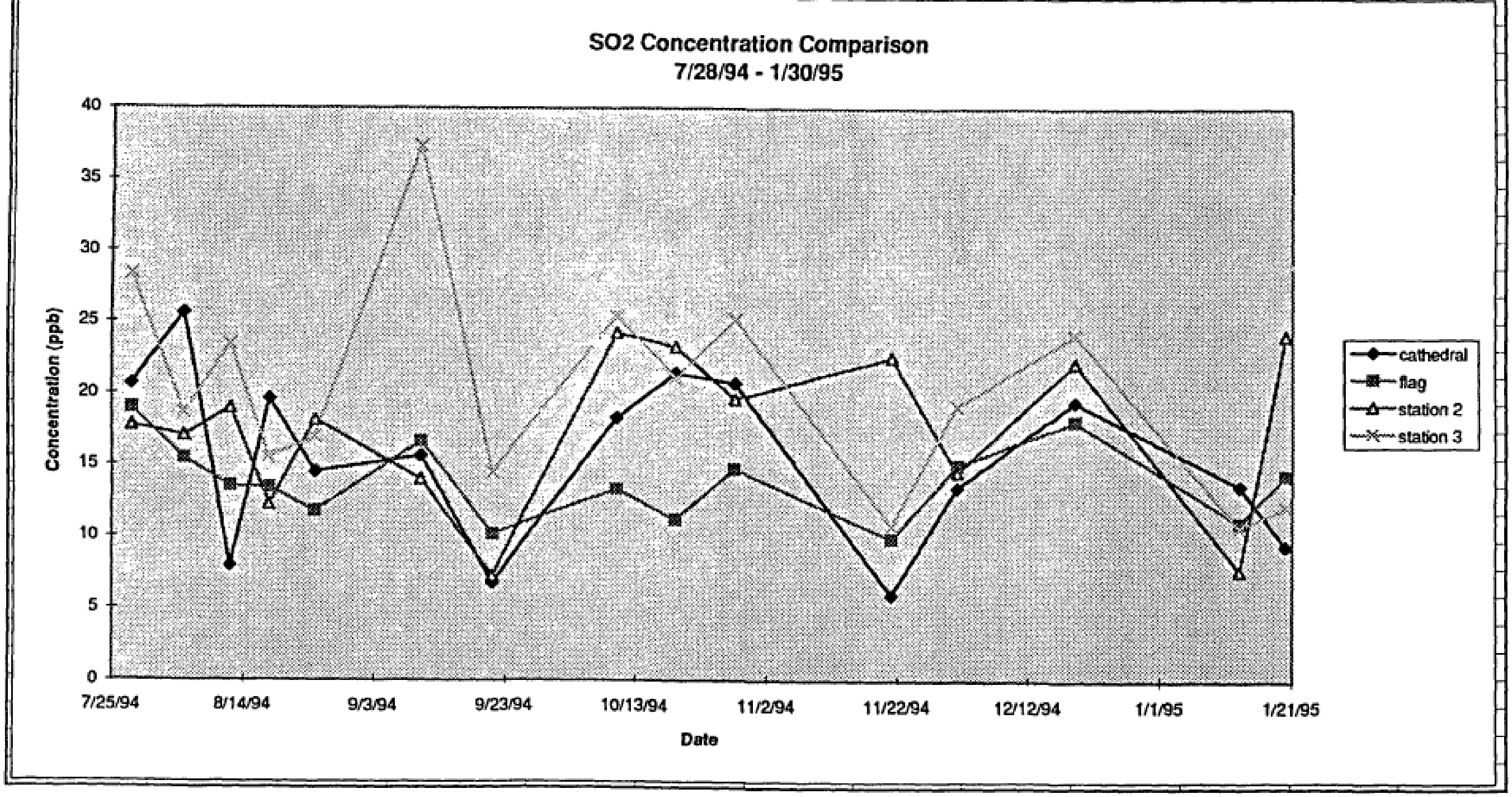


Graph 11

Correlations:	
flag v. stat2	0.18
flag v. stat3	0.68
stat2 v. stat3	0.17
cath. v. flag	0.52
cath. v. stat2	0.15
cath. v. stat3	0.42

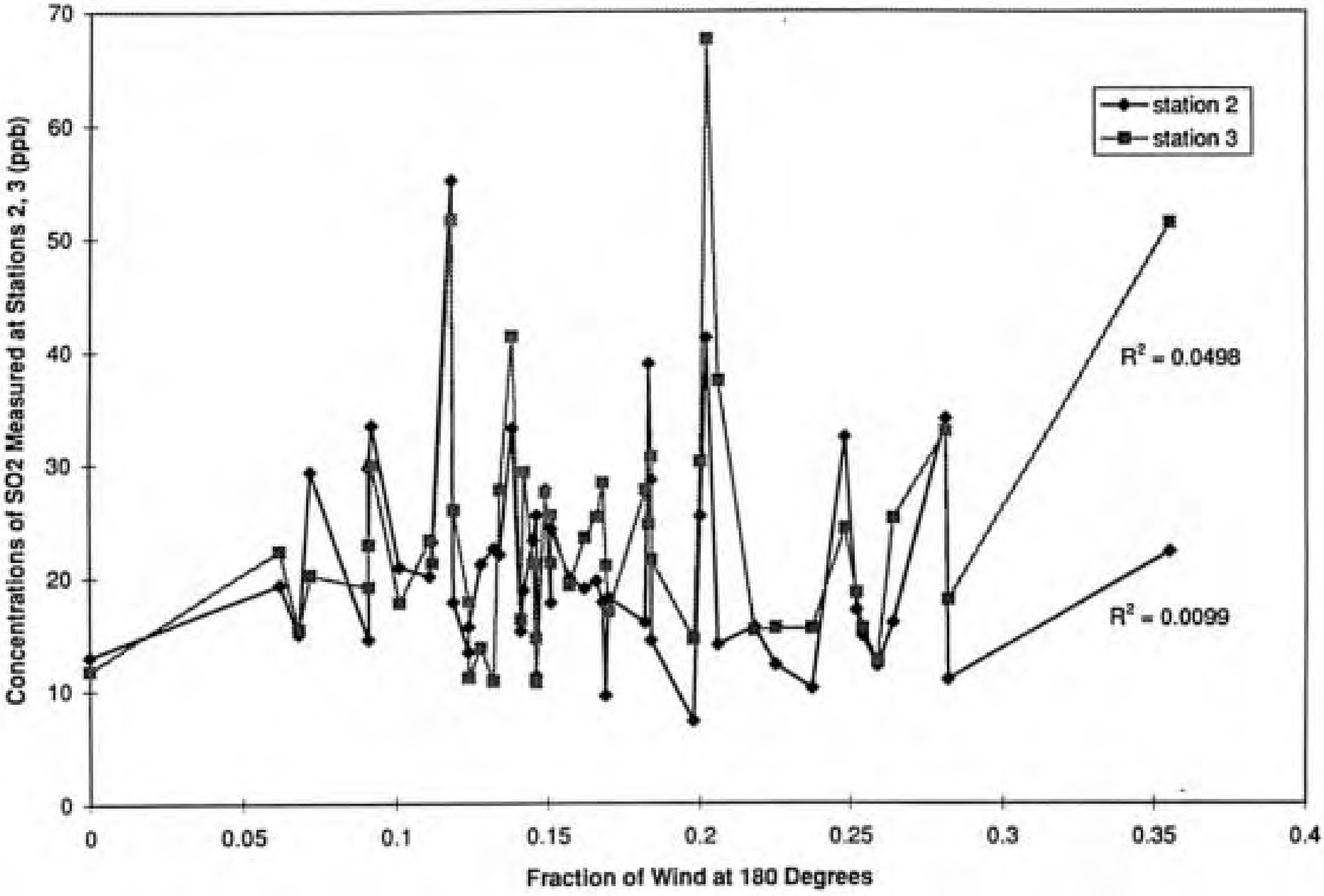
Time weighted Averages:

cathedral	flag	stat2	stat3
15.5	14.0	17.6	20.6



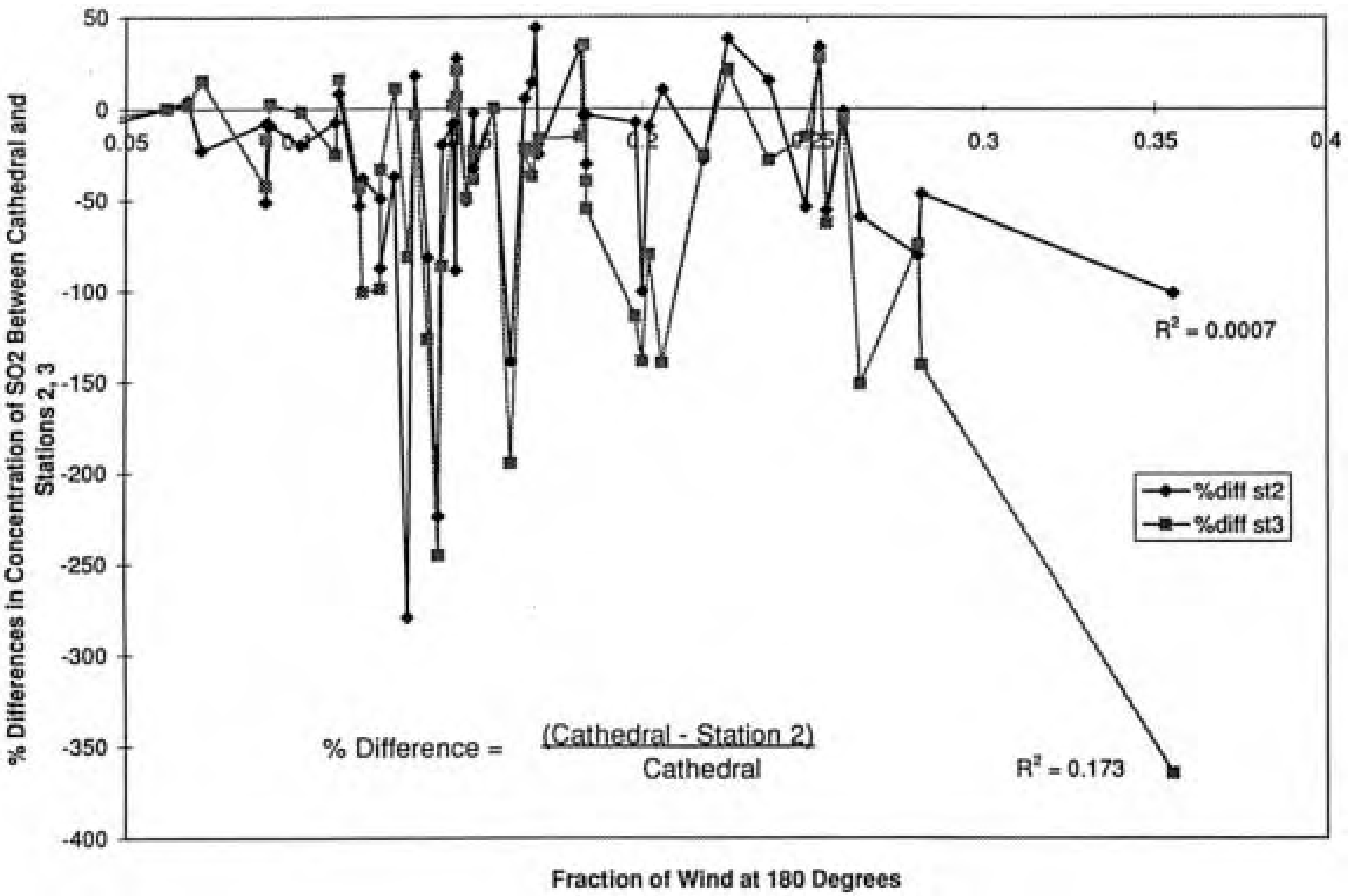
Graph 12

Concentrations of 502 Measured at Stations 2, 3 vs. Fraction of Wind at 180 Degrees



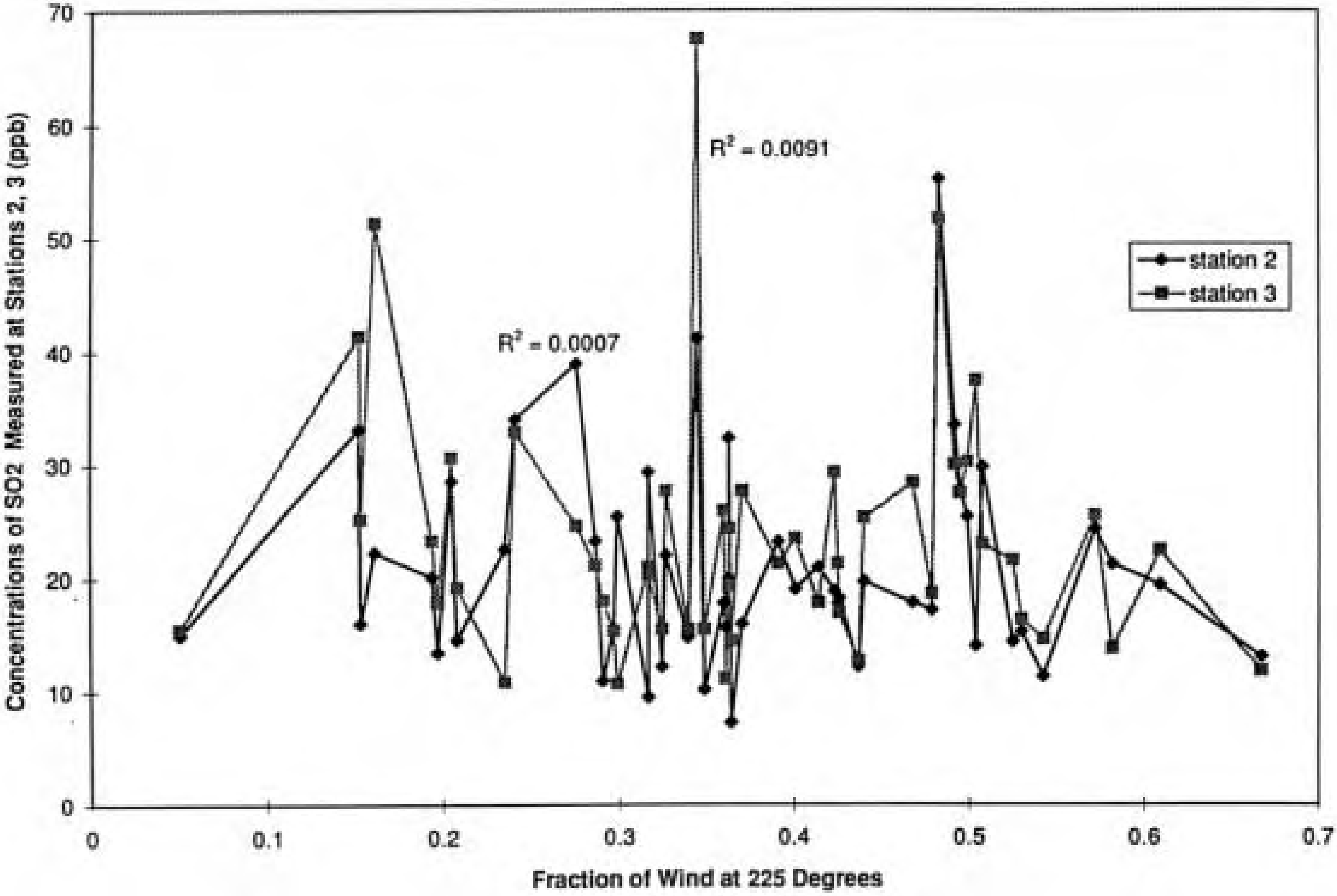
Graph 13

% Differences in Concentration of SO2 Between Cathedral and Stations 2, 3 vs. Fraction of Wind at 180 Degrees



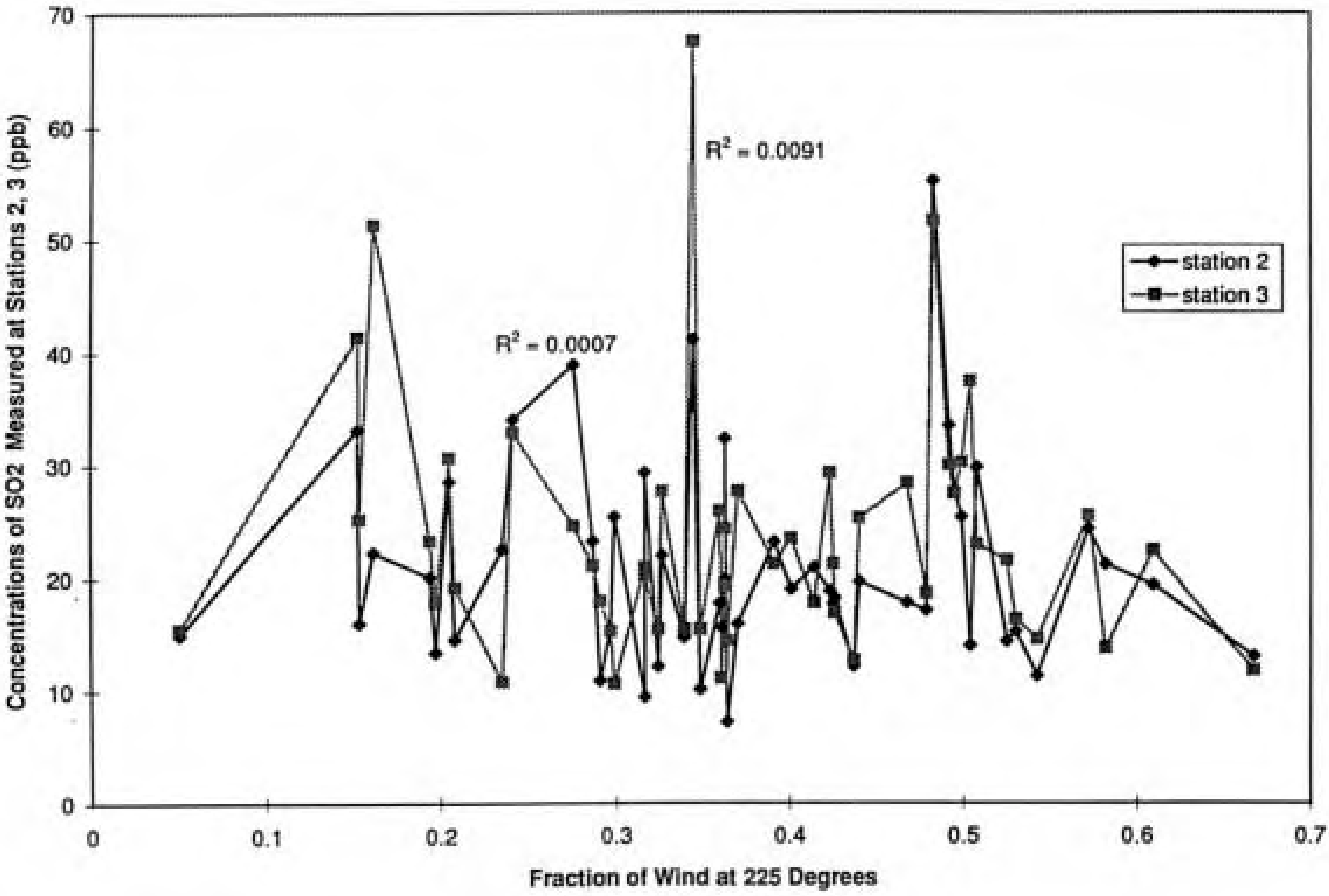
Graph 14

Concentrations of SO2 Measured at Stations 2, 3 vs. Fraction of Wind at 225 Degrees



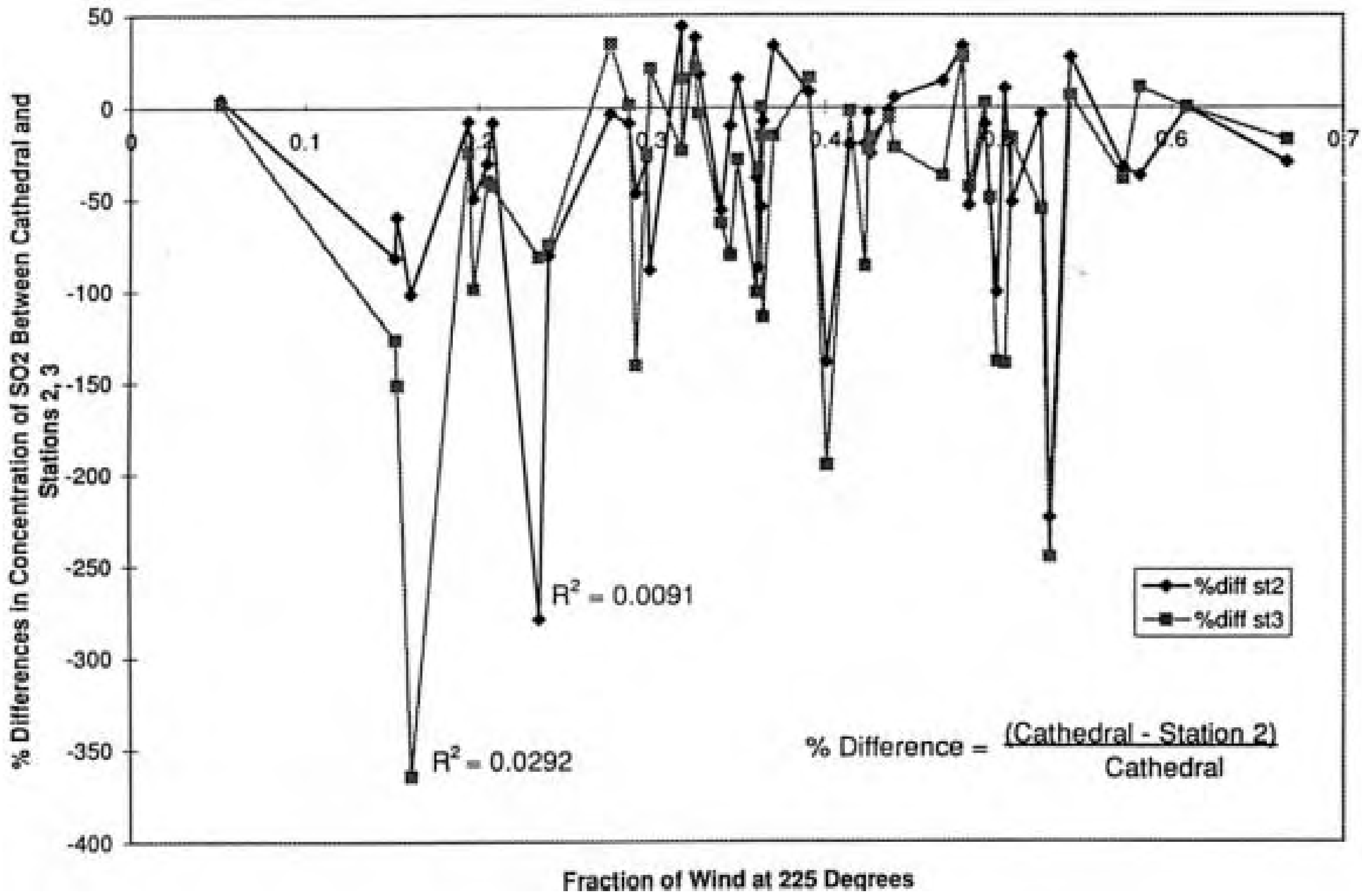
Graph 15

% Differences in Concentration of SO2 Between Cathedral and Stations 2, 3 vs. Fraction of Wind at 225 Degrees



Graph 16

Concentrations of SO2 Measured at Stations 2,3 vs. Fraction of Wind at 270 Degrees



Graph 17

% Differences in Concentration of SO2 Between Cathedral and Stations 2, 3 vs. Fraction of Wind at 270 Degrees

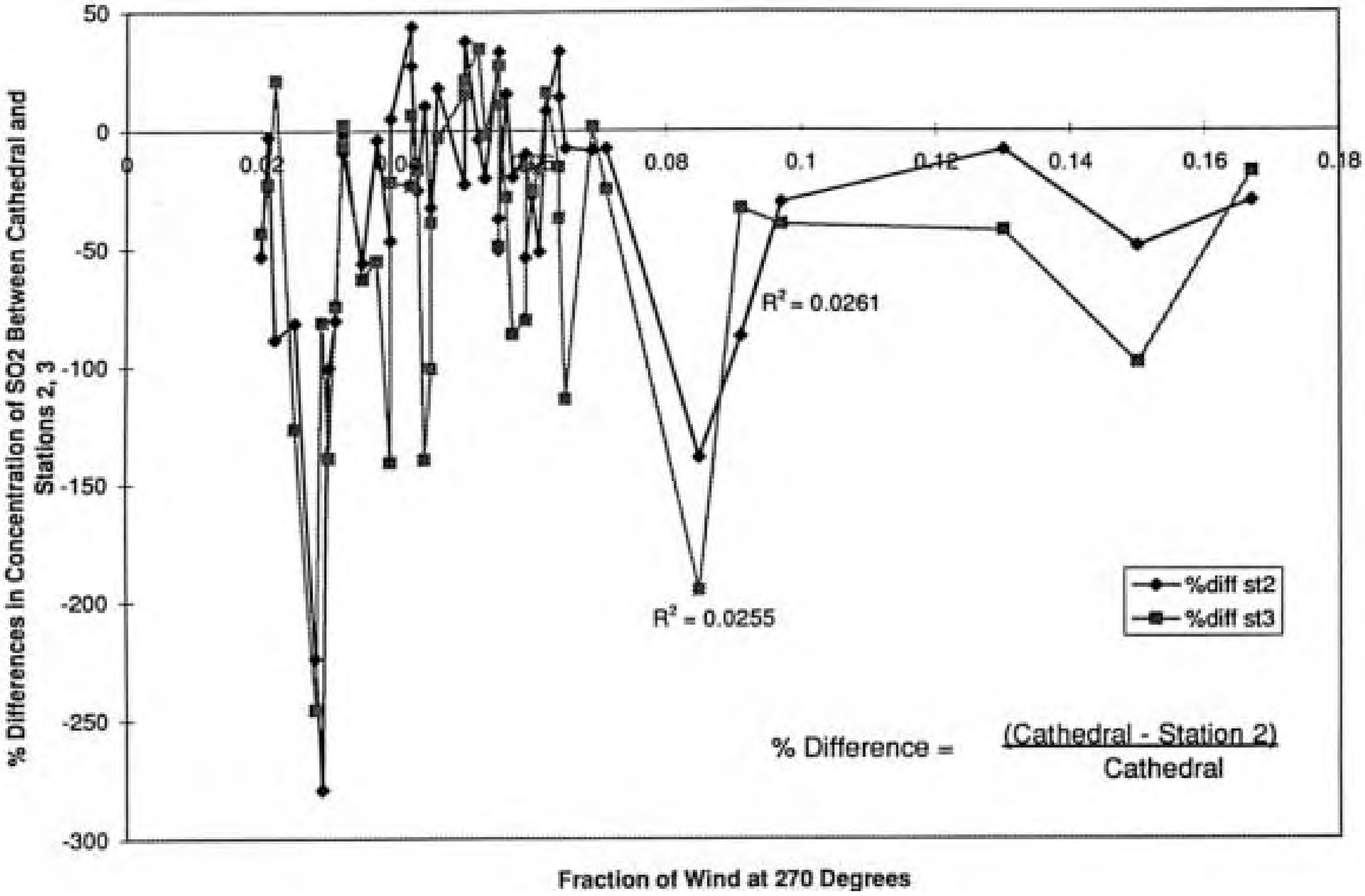


Table 1

The time represents the duration of each sampling interval.

Date	Time (hr)	Date	Time (hr)	Date	Time (hr)
12/1/92	169	6/18/93	96	4/23/94	215
1219/92	24	6/22/93	24	5/2/94	217
12/10/92	95	6/23/93	47	5/11/94	167
12114/92	28	6/25/93	143	5/18/94	169
12/15192	188	7/8/93	171	5/25/94	168
12123/92	168	7/15/93	73	6/1/94	166
12/30/92	215	7/18/93	71	6/8/94	194
1/8/93	144	7/21/93	191	6/16/94	194
1/14/93	192	7/25/93	95	6/23/94	170
1/22/93	147	7/29/93	92	6/30/94	166
1/28/93	120	8/2/93	99	7/7/94	193
2/3/93	24	8/6/93	143	7/14/94	146
2/5/93	26	8/12/93	188	7/21/94	168
2/6/93	116	8/20/93	242	7/28/94	189
2/11/93	167	8/30/93	219	8/5/94	171
2/1 8/93	171	9/8/93	191	8/1 2/94	146
2/25/93	187	9/11/93	24	8/18/94	167
3/5/93	167	9/13/93	192	8/25/94	359
3/12193	167	9/21/93	237	9/10/94	288
3/20/93	123	10/1/93	167	9/21194	453
3/27/93	71	10/8/93	293	10/10/94	220
3/31/93	30	10/20/93	213	10/19/94	216
4/1/93	144	10/29/93	169	10/28/94	575
4/8/93	95	11/5/93	241	11/21/94	240
4/1 2/93	23	11/15/93	213	12/1/94	431
4/13/93	16	11/24/93	171	12119/94	60j
4/14/93	41	12/1/93	194	1/13/95	168
4/16/93	151	12/9/93	120	1/20/95	243
4/22/93	23	12/14/93	163	1/30/95	189
4/23/93	18	12/21/93	239	2/7/95	170
4/25/93	51	12/31/93	171	2/14/95	168
4/27/93	20	1/7/94	166	2/21/95	168
4/28/93	23	1/14/94	168	2128/95	169
4/29/93	167	1/21/94	145	3/7/95	169
5/6/93	212	1/27/94	217	3/14/95	168
5/15/93	147	2/5/94	143	3/21/95	168
5/21/93	115	2111/94	192	3/28/95	168
5/26/93	147	2119194	141	414195	168
6/1/93	24	2122/94	73	4/11/95	193
6/2/93	142	2/25/94	195	4/19/95	312
6/10/93	23	3/5/94	143	5/2/95	192
6/11/93	23	3/11/94	170	5/10/95	169
6/12/93	23	3/18/94	163	5/17/95	169
6/13/93	49	3/25/94	194	5/24/95	364
6/15/93	24	4/2/94	167	6/9/95	167
6/16/93	23	4/9/94	170	6/16/95	263
6/17/93	23	4/16/94	168	6/27/95	213

Table 2

date	cathedral	flag	station 2	station 3
The numbers represent the measured airborne concentrations of SO2 in ppb.				
9/11/93	14.1	11.0	13.2	13.2
9/13/93	15.6	9.3	9.1	10.8
9/21/93	11.0	9.9	18.6	12.1
10/1/93	23.0	15.5	31.4	25.5
10/8/93	15.6	8.0	11.3	14.5
10/20/93	37.4	15.2	41.2	67.5
10/29/93	1.3	11.4	19.9	19.2

Table 3

The numbers represent the measured airborne concentrations of SO2 in ppb.

date	cathedral	flag	station 2	station 3
11/5/93	18.2	22.1	33.1	41.3
11/15/93	26.8	15.1	22.0	27.7
11/24/93	17.4	12.5	20.9	17.7
12/1/93	10.0	12.8	16.0	25.2
12/9/93	17.0	10.2	9.5	20.9
12/14/93	4.7	11.0	15.2	16.2
12121/93	23.9	14.9	29.3	20.2
12131/93	13.5	11.6	13.5	15.9
1/7/94	21.8	22.9	28.5	30.6
1/14/94	37.6	24.2	38.9	24.6
1/21/94	36.0	37.0	55.2	51.6
1/27/94	25.3	14.3	23.2	21.2
2/5/94	19.6	21.1	29.7	22.9
2/11/94	30.6	19.2	33.5	29.9
2/19/94	11.0	18.5	22.3	51.3

Table 4

The numbers represent the measured airborne concentrations of SO2 in ppb.

date	cathedral	flag	station 2	station 3
2/22/94	10.0	9.8	13.0	11.8
2/25/94		18.3	19.3	22.3
3/5/94	8.9	13.7	13.4	17.8
3/11/94	15.7	13.5	15.0	15.4
3/18/94	18.6	17.5	20.1	23.3
3/25/94	12.2	14.4	15.6	15.3
4/2/94	15.7	17.1	18.8	29.3
4/9/94	9.5	9.9	14.8	15.4
4/16/94	13.5	11.0	25.4	10.7
4/23/94	18.4	15.5	27.7	27.4
5/2/94	8.3	8.5	15.6	11.1
5/11/94	12.9	12.1	17.8	25.9
5/18/94	15.4	14.0	21.2	13.7
5/25/94	23.9	11.5	15.9	27.6
6/1/94	17.2	15.6	17.7	21.2
6/8/94	13.8	20.6	14.4	21.5
6/16/94	11.9	13.6	12.1	12.6
6/23/94	7.4	9.0	10.9	17.9
6/30/94	12.0	10.2	10.2	15.4
7/7/94	12.6	15.9	25.3	30.2
7/14/94	21.0	15.8	32.4	24.3
7/21/94	18.9	15.2	34.0	32.9

Table 5

The numbers represent the measured airborne concentrations of SO_2 in ppb.

date	cathedral	flag	station 2	station 3
7/28/94	20.6	18.9	17.7	28.3
8/5/94	25.6	15.4	17.1	18.6
8/12/94	7.9	13.5	19.0	23.4
8/18/94	19.6	13.4	12.2	15.5
8/25/94	14.5	11.7	18.2	16.9
9/10/94	15.6	16.6	14.0	37.4
9/21/94	6.7	10.2	7.3	14.4
10/10/94	18.3	13.3	24.3	25.4
10/19/94	21.4	11.2	23.2	21.1
10/28/94	20.7	14.7	19.6	25.2
11/21/94	5.9	9.9	22.5	10.8
12/1/94	13.4	15.0	14.5	19.1
12/19/94	19.4	18.1	22.1	24.1
1/13/95	13.6	11.0	7.7	10.7
1/20/95	9.4	14.3	24.1	12.1

Table 6

			The numbers represent the fraction of time that the wind is blowing from each respective direction										
Degrees	Date	10/8/93	10/10/93	10/29/93	11/5/93	11/15/93	11/24/93	12/1/93	12/9/93	12/14/93	12/21/93	1/7/94	1/14/94
0	Degrees	0.083	0.057	0.09	0.331	0.102	0.03	0.083	0.07	0.044	0.058	0.032	0.024
45	Degrees	0.062	0.07	0.12	0.072	0.113	0.036	0.056	0.085	0.053	0.079	0.032	0.072
90	Degrees	0.021	0.111	0.087	0.105	0.074	0.041	0.139	0.049	0.094	0.266	0.2	0.21
135	Degrees	0.083	0.084	0.08	0.085	0.151	0.107	0.222	0.218	0.075	0.094	0.157	0.083
180	Degrees	0.146	0.202	0.157	0.138	0.134	0.101	0.264	0.169	0.141	0.072	0.184	0.183
225	Degrees	0.542	0.3451	0.3631	0.152	0.327	0.414	0.153	0.3171	0.53	0.317	0.205	0.276
270	Degrees	0.o42	o.059	0.02	0.025	0.046	0.053	0	0.0421	0.028	0.051	0.097	0.052
315	Degrees	0.021	0.071	0.083:	0.094	0.053	0.219	0.083	0.0491	0.034	0.065	0.092	0.1
Degrees	Date	1/21/94	1/27/94	2/5/94	2/11/94	2/19/94	2/22/94	2/25/94	3/5/94	3/11/94	3/18/94	3/25/94	4/2194
0	Degrees	0.0591	0.053	0	0.059	0.075	0	0.074	0.052	0.203	0.086	0.039	0.063
45	Degrees	0.044	0.068	0.045	0.043	0.1721	0	0.029	0.093	0.254	0.096	0.071	0.079
90	Degrees	0.079	0.118	0.114	0097	0.129J	0	0.053	0.135	0.119	0.16	0.10?	0.047
135	Degrees	0.192	0.084	0.03	0.103]	0.0971	0	0.049	0.067	0.034	0.099	0.094	0.073
180	Degrees	0.118	0.112	0.091	0.0921	0.355	0	0.062	0124	0.068	0.111	0.218	0.142
225	Degrees	0.4831	0.391	0.508	0.492	0.161	0.667	0.609	0.197	0.051	0.194	0.297	0.423
270	Degrees	0.02	0.062	0.061	0.032	0	0.167	0.016	0.15	0	0.071	0.06	0.057
315	Degrees	0.005	0.112	0.152i	0.081	0.011	0.167	0.107	0.181	0.271	0.182	0.118	0.117
Degrees	Date	4/9/94	4/16/94	4/23/94	5/2/94	5/11	5/18/94	5/25/94	6/1/94	6/8/94	6/16/94	6/23/941	6/30/94
0	Degrees	0.038	0.067	0.047	0.056	0.071	0.043	0.094	0.063	0.058	0.019	0.075	0.05
45	Degrees	0.105	0.064	0.057	0.049	0.033	0.012	0.07	0.054	0.042	0.008	0.075	0.075
90	Degrees	0.089	0.15	0.104	0.091	0.113	0.021	0.073	0.075	0.031	0.053	0.078	0.081
135	Degrees	0.114	0.111	0.07	0.049	0.065	0.061	0.082	0.123	0.092	0.157	0.108	0.09
180	Degrees	0.254	0.146	0.149	0.124	0.119	0.128	0.182	0.151	0.184	0.259	0.282	0.237
225	Degrees	0.34	0.299	0.495	0.361	0.36	0.582	0.37	0.425	0.525	0.437	0.291	0.349
270	Degrees	0.035	0.022	0.055	0.091	0.045	0.055	0.064	0.021	0.037	0.032	0.039	0.056
315	Degrees	0.025	0.14	0.022	0.178	0.193	0.098	0.067	0.087	0.031	0.035	0.051	0.062

Table 6

Degrees	Date	7/7/94	7/14/94	7/21/94	7/28/94	8/5/94	8/12/94	8/18/94	8/25/94	9/10/94	9/21/94	10/10/94	10/19/94
0	Degrees	0.045	0.036	0.066	0.052	0.032	0.074	0.069	0.068	0.024	0.061	0.033	0.046
45	Degrees	0.021	0.065	0.072	0.0551	0.019	0.018	0.078	0.05	0.034	0.089	0.031	0.071
90	Degrees	0.078	0.0881	0.094	0.0781	0.016	0.103	0.066	0.09	0.07	0.061	0.007	0.201
135	Degrees	0.101	0.1051	0.156	0.095	0.084	0.107	0.087	0.095	0.068	0.062	0.041	0.127
180	Degrees	0.2	0.2481	0.281	0.168	0.252	0.162	0.225	0.17	0.206	0.198	0.151	0.145
225	Degrees	0.499	0.363’	0.241	0.468	0.479	0.401	0.325	0.426	0.504	0.364	0.572	0.287
270	Degrees	0.03	0.0591	0.031	0.064	0.055	0.085	0.05	0.043	0.044	0.065	0.045	0.069
315	Degrees	0.027	0.036	0.059	0.021	0.061	0.051	0.1	0.059	0.05	0.1	0.12	0.056
Degrees	Date	10/28/94	11/21/94	12/1/94									
0	Degrees	0.092	0.044	0.286									
45	Degrees	0.084	0.124	0.052									
90	Degrees	0.064	0.208	0.039									
135	Degrees	0.049	0.162	0.052									
180	Degrees	0.166	0.132	0.091									
225	Degrees	0.44	0.235	0.2081									
270	Degrees	0.039	0.029	0.13									
315	Degrees	0.067	0.065	0.143									

Appendix F

Patterns of Moisture on the Walls of the Cathedral of Learning: Pilot Study on Fluorescence Analysis

Kyle Driscoll

Introduction

Certain air pollutants such as sulfur dioxide are known to react with limestone and cause soiling of the surface only in the presence of moisture on the limestone. However, moisture can also act to decrease soiling: the force of raindrops washes pollutants off the surface and in some cases removes the deposited material that causes soiling. It is unclear from looking at the walls of the building during and after a rain which portions are wet. Therefore, it is not known whether areas which become wet most often are those areas that are cleanest or those that are most soiled.

Objective

We wish to be able to visually detect moisture patterns on the limestone surfaces of the Cathedral of Learning to understand how wetness affects both pollutant deposition and rain washoff. This project was a pilot study to develop methods of identifying wetness on the limestone. Eventually, the method will be used to compare moisture on soiled surfaces and moisture on unsoiled surfaces. This will allow us to determine whether moisture is a significant factor in the soiling and/or cleaning of the limestone.

Background Information

We needed to develop a method to allow for moisture patterns to be visibly detectable on the walls of the Cathedral of Learning. Two options were considered to accomplish this goal. We first attempted to use absorption spectroscopy (absorption data collection and analysis) but finally decided on fluorescence spectroscopy (fluorescence emission data collection and analysis).

We first thought that utilizing the absorption spectrum of water would lead to a successful method. This involved determining the maximum absorption wavelength of light for water. The absorption spectrum is a graphical display of the probability of absorption of light versus the corresponding wavelength of the light. This spectrum for water peaks at about 1500 nm. This wavelength is in the near-infrared range. Therefore, it was thought that all wavelengths of light except this near-infrared range should be filtered out which would allow the wet limestone to be easily differentiated from the dry. A near-IR filter camera lens could be used for this purpose, and a photograph could then record the wetness patterns. Unfortunately, a gallium arsenide camera would need to be used. These are very expensive and in high demand on campus. So, we concluded that purchasing both the camera and lens was economically infeasible for the project.

The second method chosen was more successful. Light energy can be absorbed only when its constituent molecules move to a higher energy level. This occurs at a unique energy level (i.e., wavelength) for different molecules. The absorbed energy is greater than that necessary to move the molecule from its ground energy state (lowest) to its first energy state. The excess energy takes the form of molecular vibration. This vibration is dissipated quickly in the form of heat resulting from collision with solvent molecules (water). The excited molecule then returns to its lowest energy level (ground state). Fluorescent molecules accomplish this through the emission of light (fluorescence). The energy of the emitted light is less than that of the absorbed light due to the energy lost as heat. Therefore, the emitted light has a longer wavelength. This is because E=hc/A, where h is Planck’s constant, c is the speed of light, and ?~ is the wavelength of light. We needed to find a fluorescent dye which would fluoresce in the visible range when exposed to water. From the above discussion, this implies that the dye must absorb light of a lower wavelength than visible light. In addition, the dye had to be non-toxic and non-corrosive to the limestone. For aesthetic reasons, the solution of the dye (of a concentration that fluoresces) when dried on the limestone (a stain) could not be visible from within about *500* feet. The dye uranine fits the specifications required. Its maximum absorbance is in the UV range. So, a UV light was purchased to analyze its fluorescence.

Experimental Method

A set of fluorescent solutions of varying concentrations was first created. An initial saturated solution of the dye and water was prepared. This was used to create nine additional solutions of incrementally decreasing concentrations. The saturated solution was composed of .36 grams of crystalline dye mixed with 30 ml of water. A pipette was then used to siphon off exactly 10 ml of this solution, which was mixed with water to produce another 30 ml solution. The process was repeated with this solution to make another. We arbitrarily chose to repeat this process nine times resulting in the ten test solutions. These solutions were next examined under a UV lamp to determine which of them fluoresced. It turned out that the first six solutions fluoresced noticeably. We hypothesized that if the dye did not fluoresce in solution it would probably not fluoresce when diluted by rainfall. Basically, we anticipated that the water that would mix with the uranine stain would be greater than the water used as solvent in our solutions.

The six separate fluorescing solutions of decreasing concentration (1 being the saturated solution) were applied to three sample slabs of limestone. We applied four samples of each solution on each slab and labeled each stain separately. Two of the four were simply painted on with a fine paint brush. The other two were first painted on, allowed to dry, and then dabbed with a wet paper towel. They were each dabbed until no visible trace of the solution came off on the towel. Each type of stain was duplicated to allow for greater confidence in the results. If for some reason either stain of a particular concentration reacted differently to the environment, we would know that the conditions of exposure were not the same. If the duplicate stains returned conflicting results the experiment could then be repeated in an attempt to correct the problem. The dabbing process was performed in order to simulate surface washoff beyond that of the other stains. We had hoped that this would indicate whether or not varying washoff would affect the resulting fluorescence of the stains.

Each of the three slabs was exposed to a different environment:
one was left inside; one was placed outside exposed to precipitation; and the last was placed outside but protected from precipitation. A scale from one to ten has been used to measure the brightness (i.e., intensity) of fluorescence (ten being the highest). After a rain, the relative fluorescence was examined using a UV light.

A second experiment was performed in the lab to verify the effect of washoff on the fluorescence of the stains. The slab left inside was chosen for this. We applied water from a water bottle to the stains on the slab. We then examined these and measured the brightness of fluorescence. These results were then compared to the results from the slab exposed to a rain.

We anticipated that the water in the air may cause considerable fluorescence of the stains on humid days. Therefore, two dry slabs were used in a third set of experiments to determine whether relative humidity affects fluorescence. Using a sling psychrometer to measure the relative humidity, the fluorescence of the dry slab outside was examined on days of varying relative humidity. In addition, controlled experiments inside with a wide range of relative humidities were conducted.

Experimental Results

Some of the untreated stains (i.e., those which were not dabbed) on the slab that was outside but protected from the rain noticeably fluoresced. The same is true of the untreated stains on the dry slab kept inside. The most concentrated sample (solution #1) did not fluoresce uniformly. Rather, a few sparsely scattered pinhead sized dots fluoresced fairly brightly in this sample (brightness level = 7). Similarly, the stains corresponding to solutions #2 and #3 also fluoresced only in dots. The solution #2 stain fluoresced with a brightness level = 8, while the solution #3 stain fluoresced with a brightness level = 6. These exhibited the same sized dots as those examined on the solution #1 stain but with greater frequency. The estimated average distance between dots was measured as being four to five millimeters. These observations were constant across all relative humidities both inside and outside. No noticeable deviations occurred between the two replicate stains in each case. The relative humidity outside ranged from *53%* to 72%. Inside we measured a range of humidity from 50% to 92%.

The treated stains on the slabs both inside and outside that were not exposed to water or rain fluoresced differently from those that were not treated. The treated solution #1 stains fluoresced similarly to the untreated solution #2 stains. These exhibited the same brightness spots as the untreated #1 stains but with a denser pattern. The estimated average distance between dots was measured as being six millimeters. The treated #2 stains fluoresced in a dense pattern of very bright dots. The dots were separated on average by a distance of about three millimeters and exhibited a brightness level = 9. The treated #3 stain fluoresced less than the corresponding untreated stain. It had a brightness level = *5* and the fluorescing dots were sparsely spaced (approximately eight millimeters apart). We concluded that the dabbing in effect decreased the amount of dye in each stain. The fluorescence brightness of the dry slabs seemed to peak with the concentration of dye in the treated solution #2 stain. This is shown by the fact that the untreated solution #2 stains, which had greater concentration, fluoresced to a lesser degree than the treated solution #2 stains, which had a lower concentration. In contrast, the untreated solution #3 stains fluoresced less than the treated solution #2 stains; we hypothesize that the untreated solution #3 stains had lower concentration than the treated #2 stains. This implies that there is an optimum concentration at which maximum fluorescence occurs. We could have tested different concentrations marginally less than the #2 solution concentration in an iterative fashion to determine the exact solution concentration that results in maximum dry stain fluorescence, but this would not have facilitated the attainment of our goal. The #1 and #2 solution stains fluoresce when dry to a small degree, which is the trait we require.

On the outside slab exposed to rain, only the solution #1 and solution #2 stains fluoresced. The solution #1 stain fluoresced with a brightness level = 8, and the solution #2 stain fluoresced with a brightness level = 7. In this case, the treated and untreated stains fluoresced in the same way. Thus, it appears that the dabbing method does not accurately represent increased washoff. In contrast to the results from the dry slabs, the fluorescence was continuous over the stain rather than limited to scattered dots of fluorescence.

The fluorescence of the stains which were wet in the lab was greater than the fluorescence of the stains which were wet by rainfall. In the lab, the stains fluoresced in a continuous pattern as was evident with the stains outside. However, the #1 and #2 solution stains on the inside slab were one brightness level higher than the corresponding stains outside. In addition, the #3 solution stain inside fluoresced with a brightness level = 3 when it had not fluoresced at all outside. Therefore, it seems that washoff does affect fluorescence. This conclusion is verified by the fact that the time of exposure to rain greatly affected the fluorescence of the slab, as explained below.

We repeated the process of exposing a slab outside to rain several times under various conditions. The severity of the storm did not seem to affect results. However, after the slab was exposed to rain for about an hour, none of the stains fluoresced. In addition, within forty five minutes after the end of a rain, the stains fluoresced to a noticeably lesser degree. Fortunately, the stains continued to fluoresce (albeit with less brightness) for about an hour and fifteen minutes. During this time period, the moisture patterns could be detected on the solution #1 and #2 stains. After this period, the fluorescence was no longer continuous over the stains.

Table: Fluorescent Brightness of Varying Concentration Stains in Different Environments

	Concentration #1	Concentration #2	Concentration #3
Untreated:			
In, Dry	7 - dots	8 - dots	6 - dots
Out, Dry (Protected)	7 - dots	8 - dots	6 - dots
Out, Wet (Rain)	8 - continuous	7 - continuous	No Fluorescence
In, Wet	9 - continuous	8 - continuous	3 - continuous
Treated:			
In, Dry	7 - dots	9 - dots	5 - dots
Out, Dry (Protected)	7 - dots	9 dots	5 - dots
Out, Wet (Rain)	8 - continuous	7 - continuous	No Fluorescence
In, Wet	9 - continuous	8 - continuous	3 -continuous

Implications of this Work

Either the solution #1 or solution #2 could be applied to the Cathedral of Learning to determine the moisture patterns on the walls. Solution #2 seems to be preferable because it is less noticeable to passers by. Two major limitations on this method exist. One is the washoff time constraint. Basically, after the solution is applied, its fluorescence patterns must be analyzed within an hour after the onset of rain. The other limitation is the evaporation time constraint. The moisture pattern caused by a rain cannot be determined after about an hour and fifteen minutes following the end of the rain. So, if it rains in the middle of the night, either someone has to go to the Cathedral at that time, or the process must be repeated at a later time.

It may seem odd intuitively that solution #1 fluoresced to a lesser degree than the solution #2 on the dry slab. However, this phenomenon can be explained. Energy transfer can occur between identical fluors (fluorescent molecules). This is because the absorption and emission spectra of this type of fluor overlap. As the amount of fluors increase in the sample, the fluorescence intensity decreases. Basically, due to the closeness of the fluors in the most concentrated solution, the fluorescent emissions of some are absorbed by others. The solution did fluoresce but the stain did not because the water had evaporated when the stain dried. So, a stain moistened only by the water in the air is in effect more concentrated than the corresponding solution. Since the rain dilutes the concentration of dye in the stain, the solution #1 stain had almost maximum fluorescent intensity when wet. However, for this analysis maximum intensity is not necessary. The solution #2 stain is adequate since the discrepancy in fluorescence between its dry and wet state is obvious. A noticeable difference between the two states is all that is required.