Atmospheric Environment Vol. 15, No. 9, pp. 1733–1737, 1981
Printed in Great Britain.

0004-6981/81/091733-05 $02.00/0
Pergamon Press Ltd.

TEMPORAL VARIATION OF PARTICLE SCATTERING COEFFICIENTS AT BROOKHAVEN NATIONAL LABORATORY, NEW YORK

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(*First received* 27 *November* 1979 *and in final form* 17 *February* 1981)

Abstract—Real-time measurements of scattering coefficients of particles in the atmospheric boundary layer were continuously measured during 1975 and 1976 at a height of 106 m at Brookhaven National Laboratory, Long Island, New York to study their variations with meteorological parameters and in relation to upwind source regions. Short and long time scales of fluctuations, frequency distributions, stagnation periods, and effects on incoming solar radiation were investigated. Results indicate seasonal dependence and variations due to the upwind location of sources.

1. INTRODUCTION

A delicate balance exists between the growth of the population, technological advances and subsequent polluting influences on the environment. It is imperative that monitoring the state of the environment be required to guard against physical degradation of plant, animal and human life. For example, Morgan *et al.*, (1970) and Bibbero (1971) have reported surveillance systems and trends in air pollution levels in the city, state and national areas. Cyclic trends in particle concentrations over a forty year span in Los Angeles, California was described by Porch and Ellsaesser (1971).

Atmospheric transport and diffusion involving regional scale distances have become important problems due to possible increases in the use of coal for energy development. The United States Department of Energy supported a program called the Multi-State Atmospheric Power Production Pollution Study (MAP3S) to develop guidelines for the most efficient management of pollutant emissions from existing and proposed new sources. One of the goals of the MAP3S program was to determine short and long-term trends in urban and rural atmospheric polluting substances in the northeastern United States. As part of this program, measurements of scattering coefficient (B_{SCAT}) were made continuously at Brookhaven National Laboratory (BNL) for two years to study the variations in particle concentrations. Figure 1 shows BNL in relation to New York City, New Jersey and Connecticut. Long Island, in the vicinity of the tower, is typically rural with two fossil fuel power plants located along the northern shore at distances of 25 and 40 km from BNL.

2. MEASUREMENTS

Data pertaining to the atmosphere and the particle concentrations were obtained using a 126-m me-

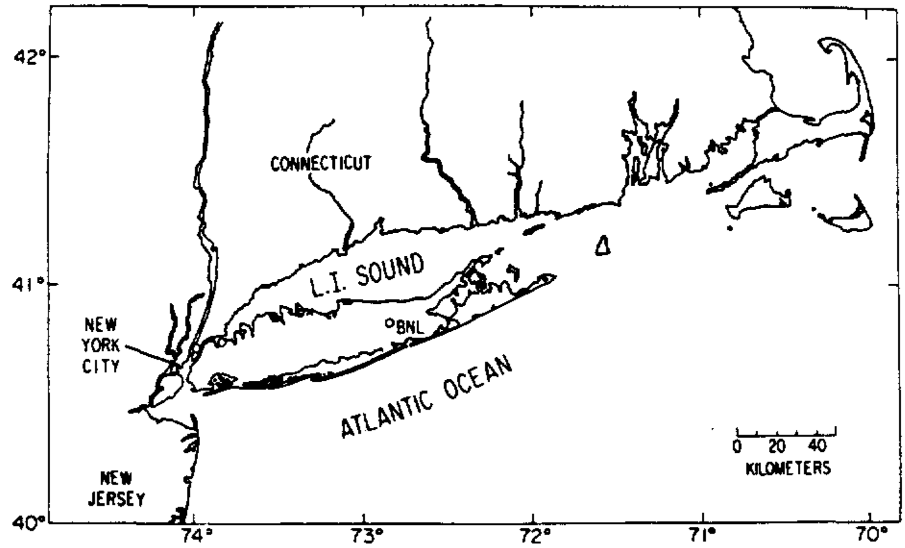

Fig. 1. Map showing the location of the meteorological tower (BNL) in relation to New York City, Central New Jersey, and Connecticut.

teorological tower at BNL. An Integrating Nephelometer (Model 1550, Meteorology Research Inc.) was used to obtain particle data at a height of 106 m above the surface. The instrument measures the visual quality of the air as it passes through it, producing a "light scattering coefficient (B_{SCAT})" after a simple computation performed internally. The analog output from the instrument representing B_{SCAT} was recorded on chart paper continuously for a period of two years during 1975 and 1976. Hourly mean values were then obtained from the charts for further analysis.

Horizontal wind speed and direction were continuously measured at heights of 10 and 106 m with a directional vane (Aerovane, Bendix Corporation) and recorded on charts. Other meteorological measurements at the site include total solar radiation with a pyranometer (Eppley) and observations of air temperature, precipitation and relative humidity. These observations form part of a 30-y climatological data at BNL (Nagle, 1975) which shows the prevailing winds to be from the northwest in the winter and southwest in summer. Due to the proximity of the Atlantic Ocean, sea breezes occur frequently during the spring and summer seasons.

3. SEASONAL VARIATIONS OF SCATTERING COEFFICIENTS

In order to determine the variability of the particles, their mean and standard deviation for each season in 1975 and 1976 were computed as shown in Table 1. A chi-square test for normality was made on the data to determine whether the distribution is at least approximately normal (SethuRaman and Tichler, 1977). The chi-square values were very large indicating that the observations did not have a normal distribution. The test for skewness gave values between + 1.0 and + 1.5 showing the observations to be positively skewed. Values of Kurtosis were about 4.5 indicating long tails. However, the means and standard deviations indicate the central tendencies and the variability of the scattering coefficients respectively.

The results shown in Table 1 indicate the mean scattering coefficients were about the same for all seasons except the spring of 1976 which had an increase by a factor of two. Their mean and the standard deviation was maximum in the spring season for both years. Geometric means of the values gave similar results. Relative standard deviations were high during the spring and summer of 1975 and during the winter and spring of 1976. Peak values were found to be about 3 to 5 times the mean. The increase in the mean and the variance in the spring and summer are probably due to the increase in photochemical oxidation. The trends in the mean temperature recorded at BNL for the two years also seem to support this possibility. Photochemical oxidation is known to increase particle concentration in the atmosphere (Haagen-Smit and Wayne, 1968).

4. DIRECTIONAL DISTRIBUTION

One of the parameters that should affect the scattering coefficients observed at the tower is the source strength. Due to the low magnitude of local sources, a directional dependence of particle concentration is to be expected if there is any long-range transport. The pollution rose for 1975 based on the mean annual concentrations at sectors of 20 degrees, is shown in Fig. 2. The mean annual concentration for a southwesterly wind direction between 220 and 280 degrees was about 75 per cent higher than that for the other wind directions indicating long range transport from industrial areas around New York City and from Central New Jersey. The other increase corresponding to a N–NW direction is probably due to the transport from the industrial areas in Connecticut on the shores of Long Island Sound. The standard deviation of the scattering coefficients was in the range 0.49 to 0.78 ($10^{-4}\,m^{-1}$) for 1975 and between 0.44 and 1.55 ($10^{-4}\,m^{-1}$) for 1976. The mean and variance for 1976 was higher than that for 1975, particularly in Spring. The larger variances occurred for a westerly direction for both years.

Two atmospheric processes that affect the particle concentration are transport and diffusion. Transport is essentially by the mean wind and an annual transport T per square meter computed from hourly mean concentration $\bar{c}$ and hourly mean wind speed $\bar{u}$ will be useful. When computed for each of the 18 sectors it takes into account both the source strength and the mean wind speed that transports the material. In order to present concentration values in terms of quantity per unit volume, an approximate formula to convert

Table 1. Seasonal values of B_{SCAT}

Year	Season	Mean	Std. Dev.	Peak	Std. Dev./Mean
		B_{SCAT} ($10^{-4}\,m^{-1}$)			
1975	Winter	0.94	0.49	3.20	0.51
	Spring	0.98	0.78	3.89	0.80
	Summer	0.88	0.74	4.70	0.84
	Fall	0.92	0.52	3.30	0.56
1976	Winter	1.09	0.90	6.36	0.83
	Spring	1.90	1.55	10.50	0.82
	Summer	1.18	0.68	4.90	0.58
	Fall	0.86	0.44	2.70	0.51

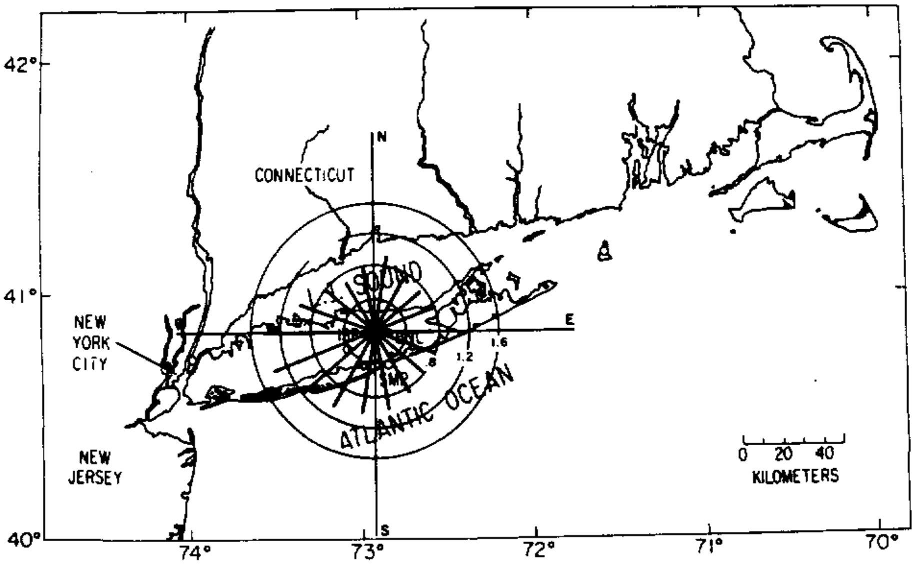

Fig. 2. Particle pollution rose for 1975 at Brookhaven. Concentric rings are in B_{SCAT} (10^{-4} m^{-1}).

B_{SCAT} (10^{-4} m^{-1}) to μg m^{-3} was used as provided by the manufacturer of the Integrating Nephelometer. The authors realize there are assumptions concerning particle size and shape that affect such conversions. Although the absolute values may be questionable, the relative values have more meaning. Total yearly flux m^{-2} for different wind direction quadrants is given in Table 2.

The results indicate that the maximum transport of particulate matter is with northwesterly and southwesterly directions due to the combined effect of the increase in source strength and prevailing wind directions.

5. A TYPICAL EPISODE

The Clean Air Act of 1970 and general public concern in environmental problems have contributed substantially over the past decade to lower background pollutant levels in the atmosphere. However, there are stagnating high pressure systems that develop several times each year over large areas of the United States which cause pollution levels to build to high levels. Table 3 shows the concentration values and associated wind directions during a stagnation period that lasted fifteen days. The values are unusually high for this rural area (see Table 1 for comparison).

Table 2. Directional variation of total flux

Wind direction	Total flux (g m^{-2}) 1975	1976
NE	65.5	55.0
SE	65.4	70.8
SW	200.6	428.0
NW	204.3	251.3

6. VARIANCE SPECTRA

Information on how frequently the concentrations reach a maximum value due to the movement of air masses across the area is of considerable interest. A spectral analysis was performed on the data to determine the frequency of maximum concentration. Variance spectra for the year 1975 is shown in Fig. 3 which indicates the maximum concentrations at Brookhaven to occur at a frequency of about 4 days. A smaller peak is noticeable for a time period corresponding to 9 h which may be the result of changes in the dispersion characteristics of the atmosphere between daytime and nighttime conditions. Reasons for the smaller peak at 6 h are not known at present. Spectral analysis of the entire data by seasons gave essentially similar values. The time period of 4 days corresponds to an average period between the passage of two successive cold fronts through the area which generally results in precipitation and washout of the particles.

7. VARIATION OF CONCENTRATION WITH WIND SPEED

An important meteorological parameter that may influence the value of the mean concentration of particles is mean wind speed. In order to determine the effect of wind speed on the particles, mean B_{SCAT}'s and their variances were computed for each sector. Wind speed classes of 1 m s^{-1} were used and plotted as shown in Fig. 4 for one wind direction sector. This eliminates the variability in source distribution. Circles represent the mean values and the vertical lines correspond to concentrations within one standard deviation. Number of hourly observations for each wind speed class are also indicated in the figure. The data shown pertain to 1976 for a southwesterly sector.

For mean winds ranging from 4 to 10 m s^{-1}, mean

Table 3. Stagnation period 1630 August 1976 daily averages at Brookhaven

Date		Average B_{SCAT} (10^{-4} m^{-1})	Average wind direction
August	16	0.67	297
	17	0.74	345
	18	0.73	043
	19	0.59	077
	20	1.22	265
	21	2.22	288
	22	3.40	311
	23	3.98	281
	24	1.26	081
	25	2.24	254
	26	4.90	225
	27	1.71	181
	28	2.54	205
	29	1.73	248
	30	0.57	321

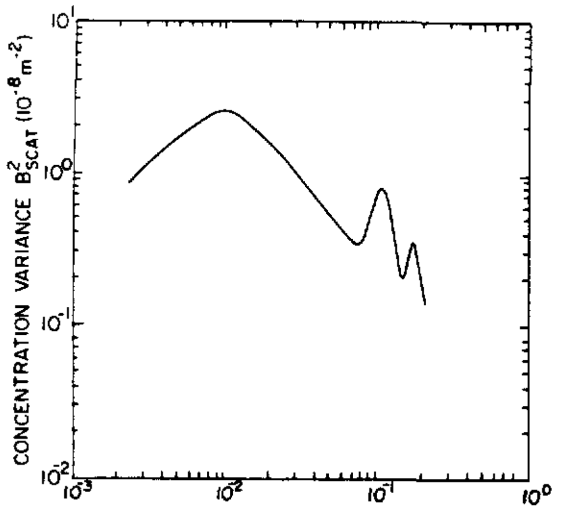

Fig. 3. Variance spectrum of particles for 1975.

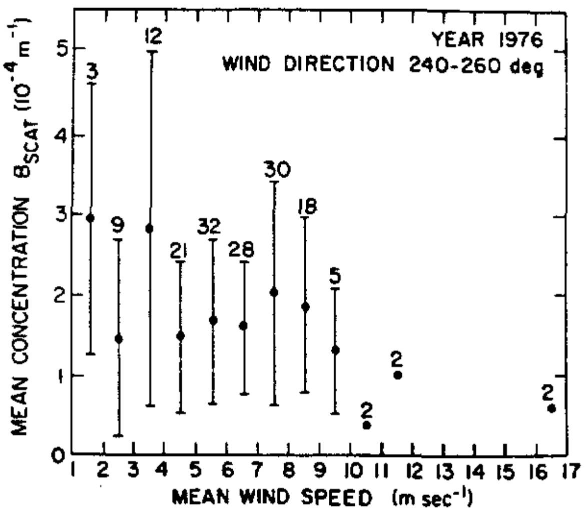

Fig. 4. Variation of annual mean concentration with mean wind speed for one of the sectors. Circles indicate the mean values. Vertical lines indicate the standard deviation. Number of observations are noted for each wind speed class.

scattering coefficients were about the same and the variability was also small. Above 10 m s^{-1}, the particle concentration values seem to decrease rapidly, probably due to increased transport, turbulence and mixing. Holzworth (1974) found similar results for high wind speeds. For winds less than 4 m s^{-1}, there seems to be a tendency for higher mean concentration, but larger variability. Higher concentration can be explained in terms of stagnation high pressure systems that cause air pollution episodes. Larger variability is probably due to extreme changes in stability (for example, both convective and stable conditions can occur) and large directional variations. In summary, hourly mean particle concentration values do not seem to depend on the hourly mean wind speed directly, but there appear to be three different ranges of wind speed which indirectly affect the particle concentration through atmospheric stability and other factors.

8. CONCLUSIONS

Analysis of the particle concentrations measured for a period of two years at BNL indicate that maximum values occurred with southwesterly winds. Mean and variance of the concentrations were maximum during spring and summer indicating the possibility of contribution due to photochemical oxidation. A periodicity of about four days for concentration variance was noticed. There seems to be a general decrease in solar radiation with increase in atmospheric particles.

Acknowledgements—C. Henderson and J. Glassman assisted in the data analysis. Several helpful discussions with P. Michael are appreciated. This research was performed under the auspices of the United States Department of Energy under contract No. DE-ACO2-76CH00016.

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