

Spatial variability in airborne pollen concentrations

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Tests were conducted to determine the relationship between airborne pollen concentrations and distance. Simultaneous samples were taken in 171 tests with sets of eight rotoslide samplers spaced from one to 486 M. apart in straight lines. Use of all possible pairs gave 28 separation distances. Tests were conducted over a 2-year period in urban and rural locations distant from major pollen sources during both tree and ragweed pollen seasons. Samples were taken at a height of 1.5 M. during 5- to 20-minute periods. Tests were grouped by pollen type, location, year, and direction of the wind relative to the line. Data were analyzed to evaluate variability without regard to sampler spacing and variability as a function of separation distance. The mean, standard deviation, coefficient of variation, ratio of maximum to the mean, and ratio of minimum to the mean were calculated for each test, each group of tests, and all cases. The average coefficient of variation is 0.21, the maximum over the mean, 1.39 and the minimum over the mean, 0.69. No relationship was found with experimental conditions. Samples taken at the minimum separation distance had a mean difference of 18 per cent. Differences between pairs of samples increased with distance in 10 of 13 groups. These results suggest that airborne pollens are not always well mixed in the lower atmosphere and that a sample becomes less representative with increasing distance from the sampling location.

In most programs for sampling aeroallergens or other airborne particulates, samples are taken at only one or a few locations presumed representative of wider areas. However, variability in catch between adjacent samplers has often been reported, while samplers located at appreciable distances apart have given quite diverse results during identical time periods. Although part of this variability may be due to differences in collection efficiency among samplers of similar design and construction, or differences in exposure and surroundings, part is undoubtedly caused by actual differences in concentration. While it is usually assumed that particles which have been airborne for some time become well mixed in the lower atmosphere, this may not always be true of pollens and spores, because sources vary widely in size, intensity, and spatial distribution and they emit sporadically or intermittently in response to changes in the annual and diurnal cycles and to local meteorological conditions. Transport and dispersion between source and sampling location are also governed by constantly changing atmospheric motions. Thus it is likely that pollen often travels in more or less

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discrete clouds or puffs with regions of lesser concentration between and that thorough mixing requires considerable time even under turbulent conditions. Discrete clouds were documented in a concurrent study of mesoscale transport and dispersion of airborne pollens with the use of an aircraft-mounted sampler.¹

Although previous studies have shown that variations in concentration between nearby sampling locations occur commonly, no attempt has been made to relate variability to distance between the samplers. Thus the confidence that may be placed in a single station sample and its representativeness are unknown. This study was designed to document the spatial variability in airborne pollen concentrations measured by identical samplers over a range of separation distances at locations with no significant nearby sources. Results of a companion study of temporal variability will be reported separately. The two studies should aid in evaluating other sampling data.

METHOD

The basic plan of these experiments was to take simultaneous samples of airborne pollens at a series of separation distances on the premise that better agreement in catch would be found between nearby samplers than between those more widely separated if pollen were not well mixed in the lower atmosphere. Sampling was conducted during the spring tree pollen seasons and the ragweed pollen seasons in 1971 and 1972. Locations were chosen in which nearby sources were absent or insignificant. It was expected that spatial variability would be greater in urban than in rural locations. Thus, the following three representative sampling sites were selected.

1. *Brookhaven National Laboratory, located in central Long Island, New York, about 100 Km. east of New York City, in a region still largely rural.* The sampling line was located in a large grassy field surrounded by woods about 12 M. tall. Sampling was conducted here in both years but only for ragweed pollen seasons were too close for meaningful results. Little ragweed grew within 2 or 3 Km. of the sampling site since the land is either wooded or mowed lawns. Beyond this distance, ragweed grows in scattered fashion over much of Long Island wherever cultivated fields, gardens, roadsides, or other areas of disturbed soil occur, but no large specific source area exists to which any appreciable fraction of the concentration sampled could be attributed. Other studies suggest that some of the ragweed pollen sampled at Brookhaven originates in source areas on the mainland west of New York City.

2. *Saratoga Springs, a small city with a population of about 20,000, located in north-eastern New York.* The sampling line was located along either of two main streets. Nearby building heights were mostly five stories or less. Some street trees and vacant lots containing ragweed were present in the vicinity but tree pollens sampled were those of forest species which grow primarily outside the city. Some small ragweed sources grew near the line but their presence could not be detected in the data. Sampling was carried out during both pollen seasons in 1971.

3. *Albany, a moderate-sized urban center in east central New York, with a population of about 114,000.* The sampling line was located along Washington Avenue in the center of the city. Buildings in the vicinity ranged from 15 to 60 M. in height. Some street trees and small parks were located nearby but tree pollens sampled were primarily oak and birch, species which are uncommon within but abundant outside the city. Ragweed occurs within the city but none was located in the vicinity of the sampling line. Sampling was conducted here during both pollen seasons in 1972.

Rotoslide samplers² were used to measure pollen concentrations. Sampling height was chosen to approximate breathing level. Those used in Albany and Saratoga were mounted on portable tripods 1.5 M. tall and were AC powered from portable batteries and inverters. Those at Brookhaven were mounted on fixed stakes at the same height and were AC powered from line current. Rotoslides used in Albany and Saratoga and at Brookhaven in 1972 were

TABLE I. Number of tests in each location, year, pollen type, and wind direction category

Location	Year	Pollen type	Wind direction			
			Across line	45°	Along line	Total
Saratoga	1971	Trees	—	8	—	8
	1971	Ragweed	9	11	6	26
Brookhaven	1971	Ragweed	12	3	7	22
	1972	Ragweed	—	14	7	21
Albany	1972	Trees	—	9	29	38
	1972	Ragweed	—	25	31	56
Total			21	70	80	171

equipped with slide holders for four slides each. Those used at Brookhaven in 1971 had swing-shield³ holders with two slides each. All used in 1972 were equipped with rotation counters. Rotational speeds in 1971 were measured with a stroboscope. Silicone grease or silicone oil was used as adhesive on the slides.

In order to minimize smoothing with time and maximize differences with distance, sampling periods were kept as short as possible while still collecting an adequate sample. Each sampling period and each pollen species or group of species was considered a separate test. Of 171 tests, 124 were 10 minutes in length, 24 were 5 minutes, and the other 23 from 15 to 30 minutes. No systematic differences related to sampling period were evident so data were combined without regard to length of sampling. Beginning time of tests ranged from 7:45 A.M. to 3:29 P.M., E.S.T. but most were taken from midmorning to early afternoon.

No information was available on the dimensions of possible pollen clouds but the range of sizes of turbulent eddies in the lower layers of the atmosphere, the size of potential sampling sites, and logistics problems led to the selection of line length and sampler spacings. Each line contained 8 samplers at separation distances chosen to give the best possible distribution of spacings. From the first sampler, distances were 216, 240, 243, 244, 252, 324, and 486 M. By using all possible pairs, 28 spacings were obtained, ranging from 1 to 486 M. Although the pairs are not all statistically independent, the data obtained are considered adequate for the analyses performed.

Procedures for tests were similar in all locations. Slides were prepared in advance. Each was measured for thickness with a micrometer to the nearest 0.01 mm. and only slides of the same thickness were used simultaneously. Before a test, portable samplers were placed in previously selected positions or fixed samplers were uncovered. Slides were inserted and all samplers started simultaneously. At the end of the sampling period, all samplers were stopped and slides collected and stored for later examination. When rotation counters were used, dials were read before and after each test. Meteorological observations were recorded for each sampling period. Several tests were taken in succession on many days.

Collected pollen grains were identified and counted by the use of microscopes. Tree pollen species were counted separately, except when counts were low. In those cases, groups of species, particularly those of similar characteristics and origin, were combined into one category for analysis. Counts from the 2 or 4 slides on each sampler were added and the total corrected for rotational speed. Further data reduction and statistical analyses were performed by an electronic computer.

Several basic statistics were calculated from the 8 counts obtained in each test without regard to the spacing of the samplers. These included arithmetic mean and standard deviation (S.D.), coefficient of variation (S.D./mean), the ratio of the maximum count to the mean of the counts, and the ratio of the minimum count to the mean.

We then compared all possible pairs of counts independently of other counts or of their mean. For this purpose, the absolute value of the ratio, $A-B/A+B$, where A = any count and B = any other count, was selected. This ratio can range only from zero (if both counts are equal) to one (if one count is zero). It approaches zero if both counts are similar and one if they are diverse. It varies only with the percentage difference between the counts and not

TABLE II. Mean, standard deviation and number of cases of the coefficient of variation for each group of tests by wind direction categories

Location	Year	Pollen type	Wind direction								
			Across line			45° to line			Along line		
			Mean	S.D.	No.	Mean	S.D.	No.	Mean	S.D.	No.
Saratoga	1971	Trees	—	—	—	0.17	0.04	8	—	—	—
	1971	Ragweed	0.27	0.16	9	0.35	0.16	11	0.24	0.14	6
Brookhaven	1971	Ragweed	0.24	0.11	12	0.29	0.06	3	0.30	0.10	7
	1972	Ragweed	—	—	—	0.19	0.09	14	0.22	0.10	7
Albany	1972	Trees	—	—	—	0.21	0.08	9	0.20	0.12	29
	1972	Ragweed	—	—	—	0.10	0.15	25	0.19	0.18	31

TABLE III. Mean, standard deviation and number of cases of the ratio, maximum/mean pollen count, for each group of tests by wind direction categories

Location	Year	Pollen type	Wind direction								
			Across line			45° to line			Along line		
			Mean	S.D.	No.	Mean	S.D.	No.	Mean	S.D.	No.
Saratoga	1971	Trees	—	—	—	1.26	0.09	8	—	—	—
	1971	Ragweed	1.53	0.46	9	1.70	0.39	11	1.40	0.29	6
Brookhaven	1971	Ragweed	1.38	0.19	12	1.61	0.14	3	1.63	0.27	7
	1972	Ragweed	—	—	—	1.28	0.16	14	1.36	0.18	7
Albany	1972	Trees	—	—	—	1.43	0.23	9	1.34	0.30	29
	1972	Ragweed	—	—	—	1.36	0.19	25	1.31	0.17	31

with their magnitude. This ratio was computed for all pairs in each test arranged in the order of their separation distances.

Data were classified by year, sampling location, pollen type, and wind direction relative to the line. Measured or observed wind directions were separated into eight 45-degree sectors and grouped into 3 categories, across the line, at a 45-degree angle to the line, and along the line. The number of cases in each of the preceding categories is shown in Table I. After classification, means and standard deviations of each group were calculated for the statistics described above. All tests were used except a few in which the mean of the 8 counts was less than 10.

RESULTS

Results may be divided into two categories: (1) measures of variability without regard to sampler spacing and (2) variability as a function of separation distance. These are presented separately.

General variability

After the coefficient of variation was computed from the 8 counts obtained in each test, the mean and standard deviation of these values were found for each group of tests (Table II). Mean values range from 0.10 to 0.35 and mean standard deviations from 0.04 to 0.16. No consistent difference was found with pollen type, location, year, or wind direction. The weighted mean of all the data is 0.21 and the standard deviation is 0.13. Individual coefficients of variation as high as 0.68 and as low as 0.04 occurred. Thus, in the extreme, the standard deviation of a group of 8 samples may be very small or more than two thirds of the mean, but most are from 10 to 35 per cent of the mean.

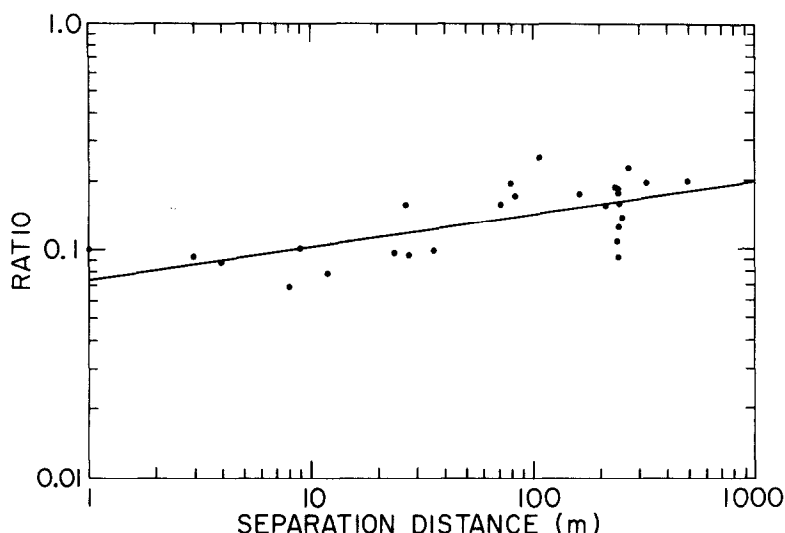


FIG. 1. Ratio $|A-B/A+B|$ as a function of separation distance for 1971 Saratoga Springs ragweed pollen concentrations with wind across the line.

TABLE IV. Mean, standard deviation and number of cases of the ratio, minimum/mean pollen count, for each group of tests by wind direction categories

Location	Year	Pollen type	Wind direction								
			Across line			45° to line			Along line		
			Mean	S.D.	No.	Mean	S.D.	No.	Mean	S.D.	No.
Saratoga	1971	Trees	—	—	—	0.72	0.09	8	—	—	—
	1971	Ragweed	0.45	0.33	9	0.58	0.13	11	0.70	0.15	6
Brookhaven	1971	Ragweed	0.67	0.16	12	0.64	0.06	3	0.65	0.11	7
	1972	Ragweed	—	—	—	0.73	0.11	14	0.67	0.21	7
Albany	1972	Trees	—	—	—	0.71	0.10	9	0.73	0.13	29
	1972	Ragweed	—	—	—	0.73	0.14	25	0.71	0.14	31

The ratio of the maximum to the mean concentration was analyzed in similar fashion. Again, no relationship with experimental conditions was evident. Mean values of the ratio range from 1.26 to 1.70 and mean standard deviations range from 0.09 to 0.46 (Table III). The weighted mean of all the data is 1.39, and the standard deviation is 0.23. Individual ratios show a greater spread, from 1.05 to 2.71. However, a maximum count greater than twice the mean was rare in these groups of 8 samples and most maxima were less than 50 per cent greater.

The ratios of the minimum to the mean concentration gave comparable results (Table IV). Mean ratios for groups of tests vary from 0.45 to 0.73 and mean standard deviations vary from 0.06 to 0.33. No relationship with pollen type or other factors could be discerned. The weighted mean of all tests is 0.69 and the standard deviation is 0.14. Individual ratios range from 0.21 to 0.93. Thus, the smallest count may be less than one quarter of the mean but most minimum counts were greater than one half of the mean.

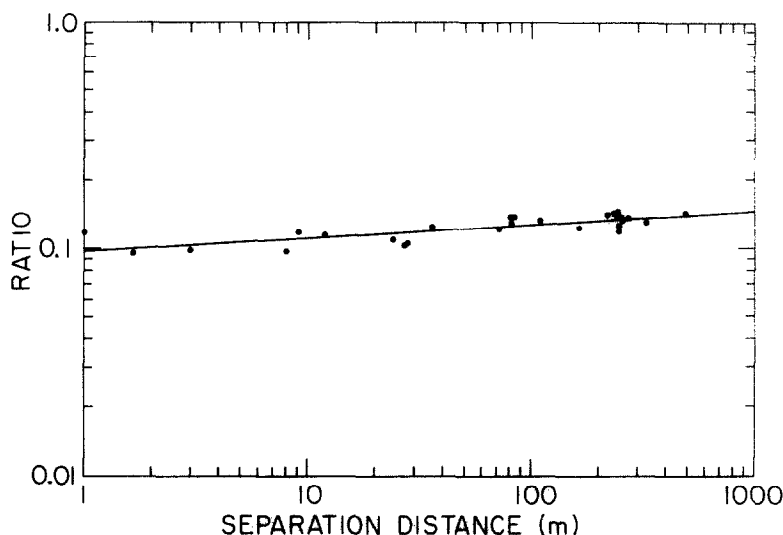


FIG. 2. Ratio $|A-B/A+B|$ as a function of separation distance for all data.

TABLE V. Values of coefficient (a) and exponent (b) in the equation $y = ax^b$ for the least-squares line of best fit to each group of tests

Location	Year	Pollen type	Wind direction	a	b
Saratoga	1971	Trees	45° to line	0.130	-0.058
	1971	Ragweed	Across line	0.073	0.146
	1971	Ragweed	45° to line	0.118	0.061
	1971	Ragweed	Along line	0.100	0.075
Brookhaven	1971	Ragweed	Across line	0.161	-0.029
	1971	Ragweed	45° to line	0.089	0.116
	1971	Ragweed	Along line	0.138	0.032
	1972	Ragweed	45° to line	0.088	0.063
	1972	Ragweed	Along line	0.092	0.083
Albany	1972	Trees	45° to line	0.063	0.141
	1972	Trees	Along line	0.094	0.030
	1972	Ragweed	45° to line	0.121	0.000
	1972	Ragweed	Along line	0.035	0.191
All data				0.099	0.055

Variability with distance

Mean values of the ratio $|A-B/A+B|$ were found at each sampler spacing for each group of tests and plotted as a function of separation distance (Fig. 1). The curve through the data points was fitted by the least-squares method and has an equation of the form

$$y = ax^b \quad (1)$$

where y = the ratio $|A-B/A+B|$ and x = separation distance.

For individual tests results were variable, as might be expected for such short-period samples. In many cases, the ratio showed a general increase with distance but in others no real trend was evident. When grouped and averaged, however, the ratio showed a clear increase with distance in 10 of the 13 groups

of tests and no trend or a slight negative slope in the other three groups. Values of a and b in the equation are given in Table V for each group of tests.

No consistent relationship was found between slope and location, year, pollen type, or wind direction relative to the line. No evidence was found suggesting that the results were influenced by nearby sources. Results from tree pollen tests did not differ systematically from those of ragweed pollen tests even though the former often included data from several species combined. It had been expected that the ratio for cases with wind across the line would show a greater change with distance than for the other two direction categories, but rather few cases were obtained with wind across the line. In the two instances in which data were available from all three direction groups, no significant differences were found. This may be because directions were usually quite variable during tests, even in the open terrain at Brookhaven, so that pollen approached the line over a range of angles. Directions fluctuated even more in the cities. In Albany, opposing directions were frequently observed at different points along the line. This is typical of wind within cities where air flow is channeled along streets and through openings between buildings and may form large eddies in the wake of obstacles.

Since no significant differences were found with experimental conditions, all data were combined and the mean ratio found for each separation distance. Results are plotted in Fig. 2, where the least-squares regression line has the equation

$$y = 0.099 x^{0.055} \quad (2)$$

This curve represents the best available estimate of the effect of separation distance on the difference between airborne pollen concentrations over short sampling periods. Since $y = |A-B/A+B|$, the most likely value of a count at any selected distance from another can be computed if a value of the first count is known or assumed.

DISCUSSION

In summary, the data show that pollen concentrations measured by 8 similar samplers over short time periods vary appreciably even when analyzed without regard to spatial separation. The mean coefficient of variation is 0.21, the average ratio of the maximum to the mean concentration is 1.39, and the average ratio of the minimum to the mean is 0.69. Variability in individual tests may be much greater.

Data from all cases show that counts taken at the minimum spacing of 1 M. have an average difference of 18 per cent. Differences between counts from pairs of samplers increase with separation distance but at a rather slow rate. Counts from the maximum separation distance differ by an average of 25 per cent. These results indicate some, but not excessive, nonuniformity in low-level airborne pollen concentrations over the range of distances studied. No consistent relationships were found with sampling location, year, pollen type, or wind direction relative to the line of samplers. Thus, the results should be more or less representative of other regions and other sampling seasons.

The 18 per cent difference in counts between adjacent samplers could be due

to actual differences in concentration sampled or to differences in collection efficiency between supposedly identical samplers. Earlier tests of the roto-slide sampler^{2, 3} showed that differences in catch between adjacent samplers and even between the two slides on a single sampler were usual. The percentage difference between slides in earlier tests varied with the care used in applying adhesive. Means of short-exposure test series ranged from 6 to 15 per cent. Thus variability between adjacent samplers is only slightly greater than variability between slides on a single sampler. However, adhesives were carefully applied in these tests to minimize differences between slides, which, in any case, would not vary systematically with separation distance. It is not possible, with the data available, to make a rigorous comparison between variability among samplers at a single point and variability due to distance, but variability at the 1 M. spacing probably approaches the former. Therefore, any variability above this level can be attributed to distance.

Although this increase in variability with distance appears to be caused by actual differences in pollen concentrations, these differences could be attributed to either of two factors. They may be due to inequalities in emission which atmospheric mixing has not yet smoothed out or they may be caused by the action of local obstacles in modifying the pollen content of previously well-mixed air. The data make the first possibility more plausible, since the variability at Albany with many large, local obstacles was not significantly different from that at Brookhaven, where the terrain is relatively smooth and major obstacles are absent.

The effect of sampling time must also be considered in applying these results to other sampling data. At a wind speed of 1 M. per second, 600 M. of air will pass a sampling station in a 10-minute period and low-level wind speeds usually exceed that value by a factor of 2 to 5. Thus, enough air passes a sampler at normal wind speeds to smooth out the effects of varying pollen content in individual gusts or eddies whose dimensions are typically less. If pollen is poorly mixed, differences due to distance will be decreased by longer sampling periods, but if concentration differences are due to local effects, sampling time may not matter. Our data do not cover a wide enough range of sampling periods to define the effect of sampling time, but it is reasonable to expect more uniformity with distance during longer periods where local sources are absent.

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