Suspended particulate concentrations: Spatial correlations in the Detroit-Windsor area

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ABSTRACT

During a 14-month period in 1967–68, 24-hr suspended particulate concentrations were measured every third day at 56 stations in the Windsor–Detroit, Sarnia–Port Huron region. In this paper, spatial correlation coefficients have been computed, and isopleths have been plotted.

Using the entire data set, these correlations are rather low. By dividing the data into subsets each with similar wind direction patterns, however, the correlation coefficients are increased, and some interesting patterns emerge. It is concluded that on individual days, the particulate levels measured at a single site are not useful indicators of urban particulate loadings unless the meteorological situation is specified. Some implications for optimizing the density of air pollution networks are discussed.

1. Introduction

Spatial correlation coefficients have been used in a number of geophysical studies concerning the optimization of network densities (Nordø & Hjortnaes, 1967; Gandin et al., 1968; Karol & Myatch, 1972; Morel, 1973). Most of the published reports have dealt with geographical areas as big as countries or continents.

In the present paper, the same technique is applied to a rather small region and to observations of 24-hr suspended particulate loadings. The objective is to examine the problem of optimizing the densities of urban air pollution networks. Because the capital and operating costs of such networks can be considerable, this is a question of some consequence.

2. Source of data

The data became available with the publication of the International Joint Commission air pollution study of the Windsor/Detroit, Sarnia/Port Huron areas (IJC, 1971). The region is very flat and the only significant meso-meteorological features are the three lakes, Huron, St. Clair and Erie, and the built-up areas (see Fig. 1.) The climate has been described in some detail in the I. J. C. report (IJC, 1971). The two metropolitan areas are separated by Lake St. Clair and by large areas of farmland and bush. The distance between the two Central Business Districts is about 95 km.

Every third day during the period September 1967 to November 1968, inclusive, measurements of the 24-hr suspended particulate loadings were made at each of the 56 stations shown by open circles in Fig. 1. As is natural in a field program of this magnitude, there were a few data gaps but nevertheless, the set was reasonably complete. The monitoring activity was unique in that it included a sprinkling of stations located in the surrounding rural areas. The siting of individual stations conformed to standard practices in North America, e.g., away from short chimneys, expressways, etc.

Included in Fig. 1 are geometric mean values of suspended particulate concentrations ($\mu g\ m^{-3}$) at each station, using the entire period of record. Isopleths have been drawn, revealing the major areas of high particulate concentrations in the two metropolitan centres: Detroit-Windsor and Sarnia–Port Huron.

3. Time correlations

Classical statistical theories assume that elements of a sample have been drawn at random

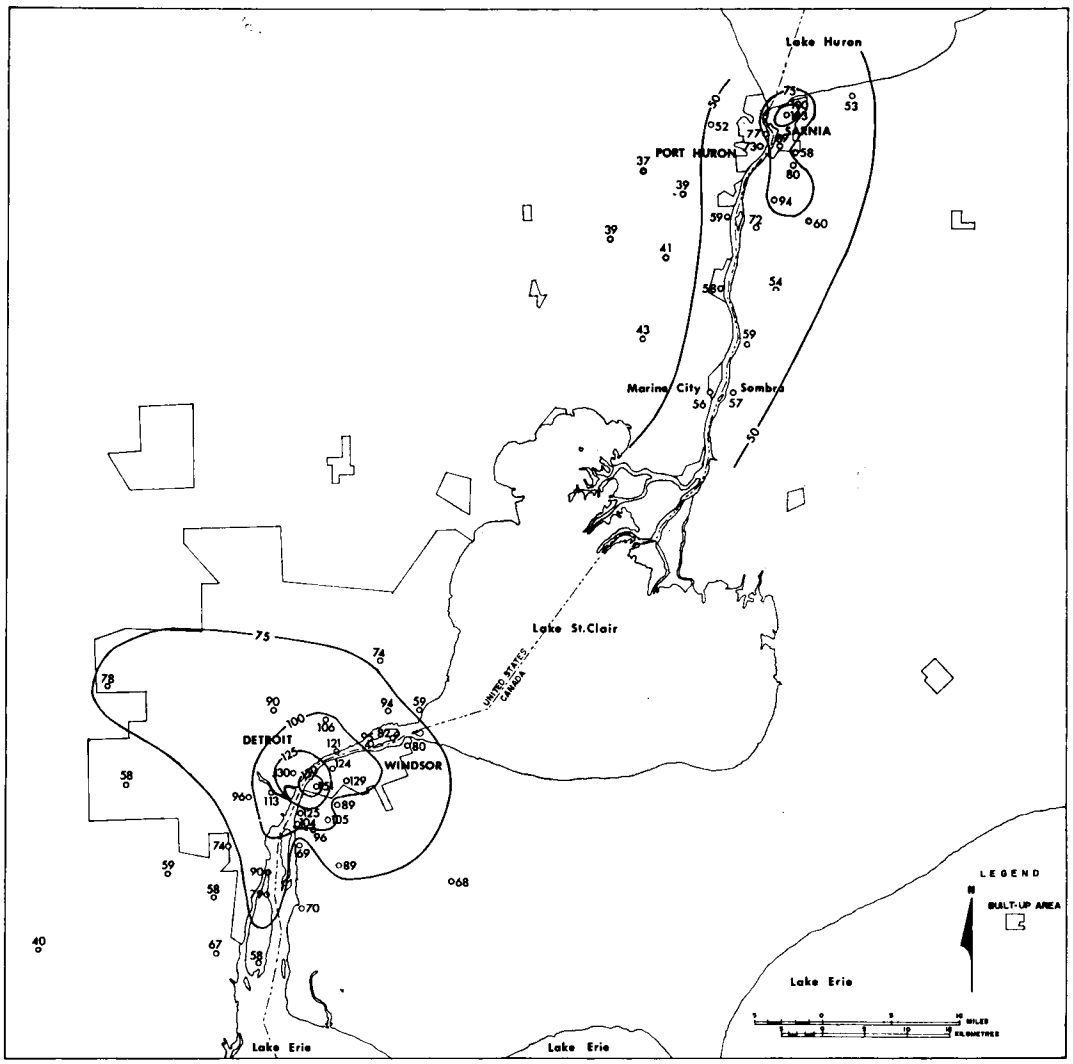

Fig. 1. Map of the study area, showing network design and including geometric mean suspended particulate concentrations ($\mu g\ m^{-3}$) at each station; isopleths of these concentrations are plotted.

Table 1. *Distribution of time-correlation values based on consecutive observations (every third day) from each of 56 stations measuring suspended particulate concentrations*

	Correlation coefficient						
	−0.14 to −0.05	−0.04 to 0.05	0.06 to 0.15	0.16 to 0.25	0.26 to 0.35	0.36 to 0.45	0.46 to 0.55
Sarnia	0	0	3	4	2	1	1
Windsor	1	3	0	6	3	0	0
Port Huron	1	4	4	1	1	0	0
Detroit	2	4	3	9	3	0	0
Total	4	11	10	20	9	1	1

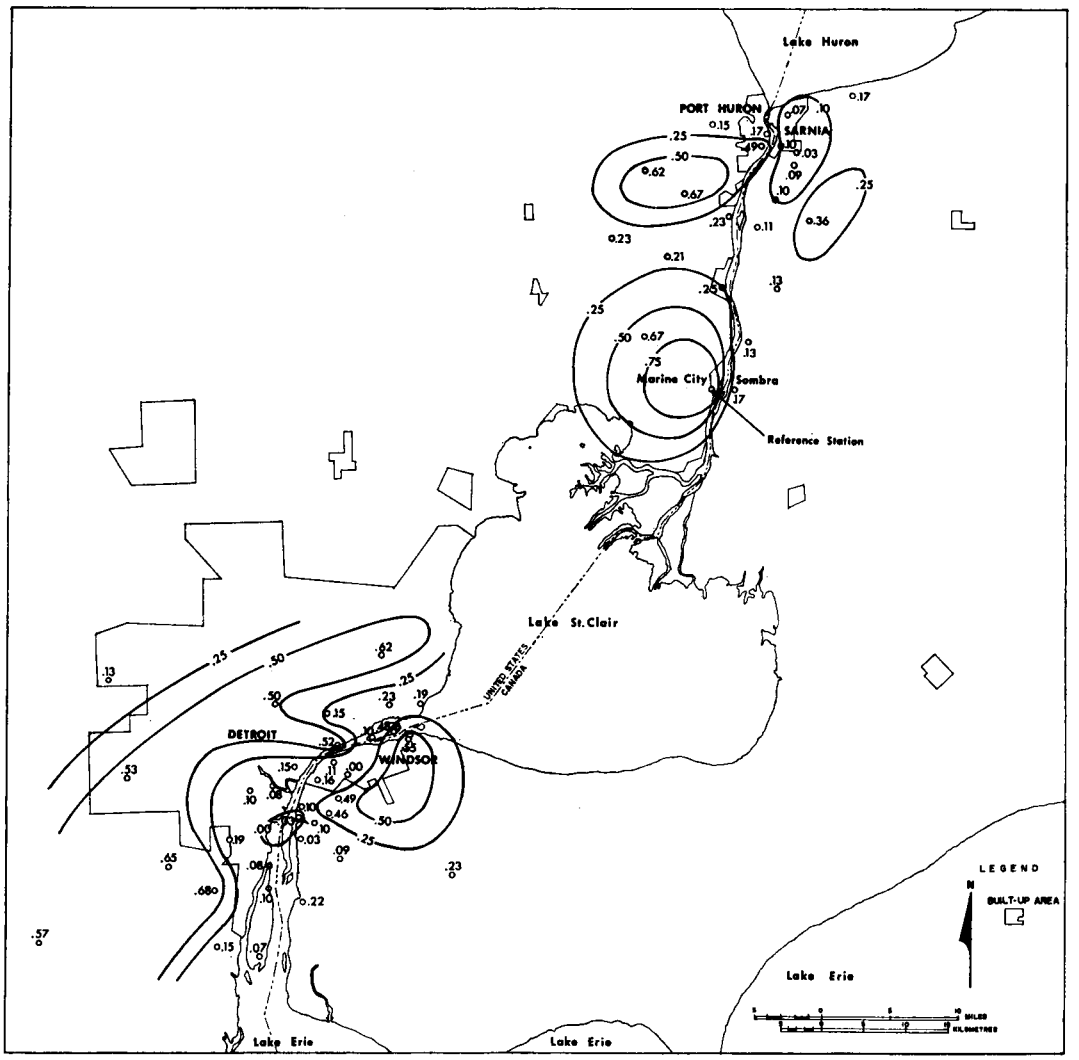

Fig. 2. Isopleths of spatial correlation coefficients using Marine City, Mich, as reference station.

from some larger population. In the case of geophysical time series, however, the elements are ordered, and each has a memory. Correlations between two such series may therefore be high, simply because of the common time correlations.

The measurements used in the present study were made every third day. This spacing should reduce the time correlations but nevertheless, it seemed desirable to calculate the coefficients for each station. The resulting frequency distributions are given in Table 1. On the average, there is a slight positive correlation (about 0.20), no doubt due to persistence of synoptic weather patterns.

4. Space correlations using a rural reference site

Using Marine City (located in Michigan to the north of Lake St. Clair) as a reference station, space correlation coefficients were computed and isopleths were plotted on maps

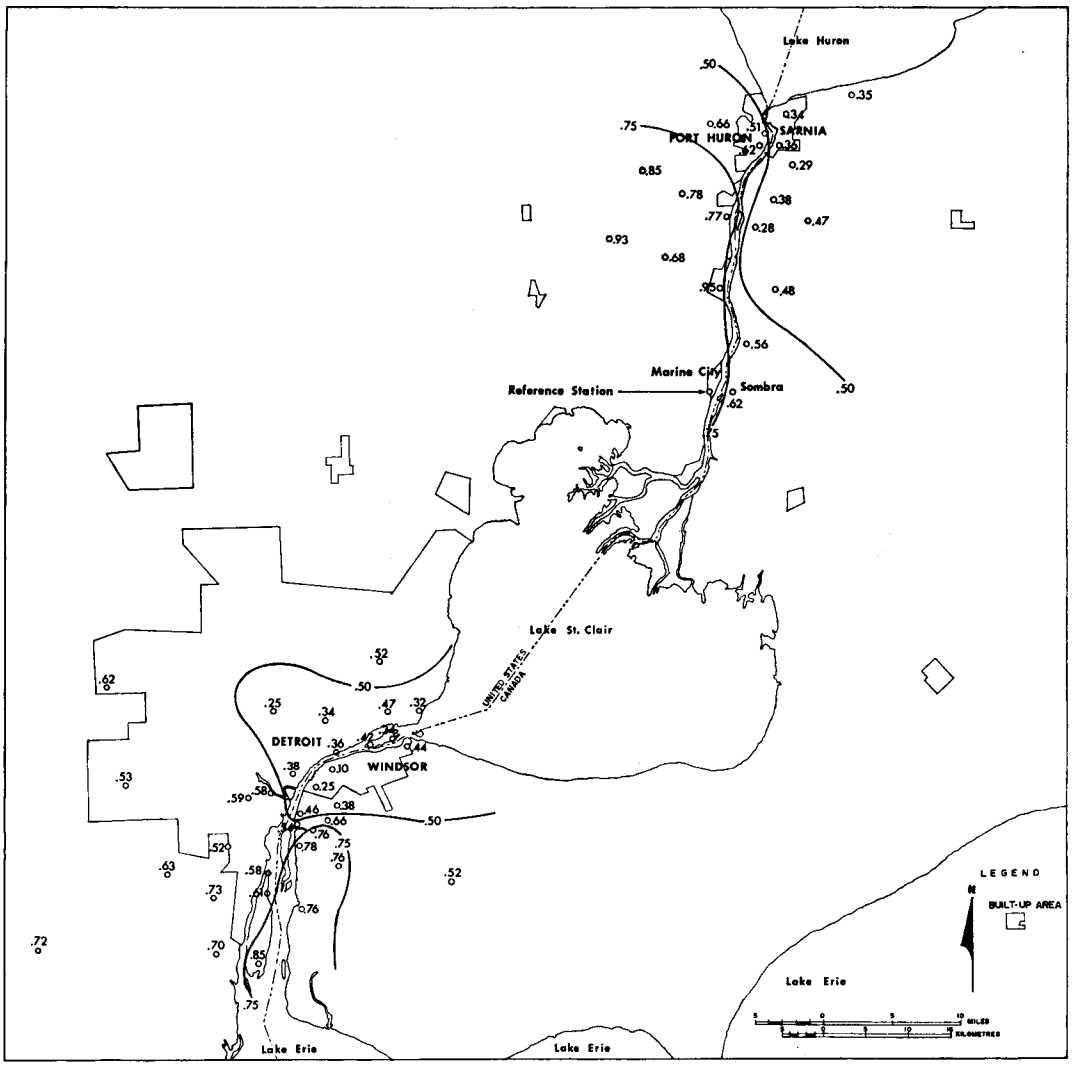

Fig. 3. Isopleths of spatial correlation coefficients using Marine City, Mich. as reference station, for the subset of days when regional surface winds remained in the sector SSE–S–SW–W.

such as Fig. 2. Before discussing the results, the following explanatory comments should be made:

(*a*) The number of observations from each pair of stations used in the calculations ranged from 18 to 125; in 85% of the cases, the number exceeded 80.

(*b*) The reference station, Marine City, is outside of the urban areas with no strong sources of particulates in the vicinity.

(*c*) The isopleths have been drawn at intervals of 0.25 units, care being taken to reproduce the observed spatial field as faithfully as possible. This seemed desirable because there were no physical guidelines that could be applied when drawing isopleths.

(*d*) Because of the non-zero time correlations existing within the data set (see Section 3), the true space correlations are probably slightly smaller than indicated in Fig. 2.[1]

[1] For this reason, too, no attempt has been made to test the statistical significance of the correlation coefficients.

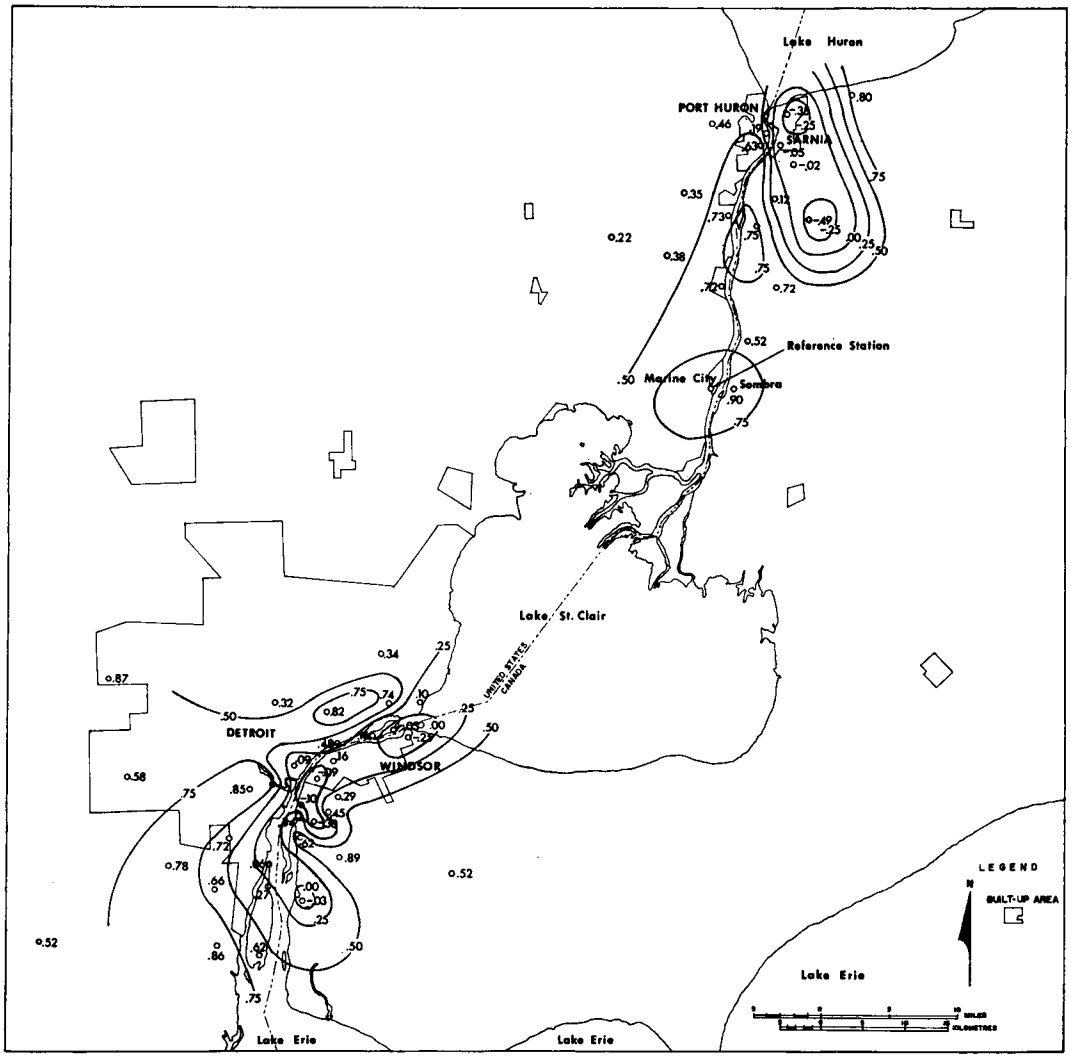

Fig. 4. Isopleths of spatial correlation coefficients using Marine City, Mich. as reference station, for the subset of days when regional surface winds remained in the sector W–NW–N.

The resulting patterns, although difficult to explain, are nevertheless internally consistent. Usually the evidence for the existence of particular isopleths is suported by the data from several stations. In addition, the patterns in Sarnia–Port Huron are somewhat similar to those in Windsor–Detroit, there being near-zero correlations in the downtown and industrial areas, with higher ones in the surrounding residential and rural areas.

The fact that particulate loadings at this rural reference station are uncorrelated with values in the two Central Business Districts and the two industrial areas is curious indeed. It is interesting to note also in Fig. 2 that particulate loadings at the reference station are poorly correlated (0.17) even with values at the nearest monitoring site just across the river in Canada.

The next step in the analysis was to subdivide the data into subsets of days with similar regional wind conditions. The method is described elsewhere (Munn, 1974). Briefly, 87 days were identified when the wind remained

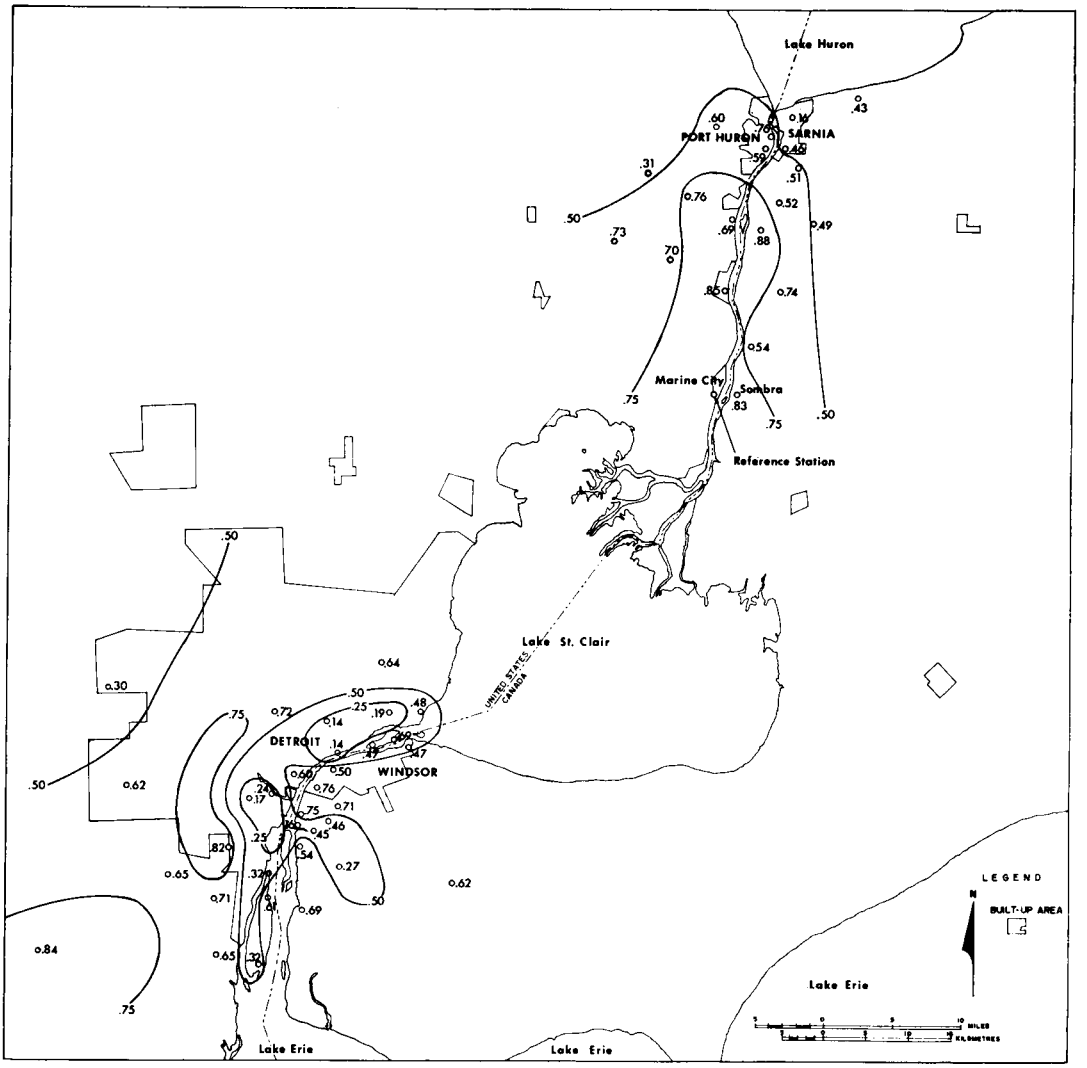

Fig. 5. Isopleths of spatial correlation coefficients using Marine City, Mich. as reference station, for the subset of days when regional surface winds remained in the sector N–NE–E–SE.

in designated sectors for the full 24 hours. In particular, Figs. 3–5 refer to subsets when the regional wind was in the sectors SSE–S–SW–W, W–NW–N, and N–NE–E–SE, respectively.

Inspection of Figs. 3–5 reveals that wind direction has a significant effect on the correlation isopleths. The most remarkable patterns occur with the subset of days with W–NW–N winds (Fig. 4). In this case there is a cell of negative isopleths in Sarnia and to the southeast, as well as along the Detroit–Windsor river-front. In Figs. 3 and 5, as was the case in Fig. 2, the lowest values of the correlation coefficients occur in the Central Business Districts of the two metropolitan areas.

Table 2 summarizes the results contained in Figs. 3–5, as well as data for other subsets of days. The region has arbitrarily been divided into 4 areas, each of which contains both urban and rural stations. The median values of the correlation coefficients are given for each area and for 6 wind direction groupings. Of particular interest is the fact that for those 31 days on which the wind direction

Table 2. *Median values of the spatial correlations (using Marine City as reference) for various subsets of days*

Wind	Sarnia network	Port Huron network	Windsor network	Detroit network	Median number of days in each subset
SSE–S–SW–W	0.37	0.78	0.60	0.54	22
SW–W–NW	0.69	0.89	0.51	0.82	7
W–NW–N	0.33	0.43	0.32	0.62	9
N–NE–E–SE	0.52	0.70	0.51	0.62	13
Light variable	0.80	0.91	0.92	0.93	4[a]
All other days	−0.05	0.00	−0.02	0.05	31

[a] Four cases at all stations.

varied markedly during the 24-hr periods (due to passages of fronts, anticyclones, etc.), the spatial correlations are near zero.

These results suggest that regional air quality is a function of large-scale wind-flow patterns. This influence is greatly diminished, however, within and immediately downwind of built-up and industrial areas, due to the close proximity of local sources. Negative isopleths occur downwind of chimneys because the flow patterns yielding high ground-level concentrations at these locations also produce excellent air quality at upwind locations such as Marine City.

5. Space correlations using an urban reference site

Fig. 6 presents the spatial field of correlation coefficients for the entire data set using a Windsor urban station (location indicated on the Figure) as reference. The values are relatively high in Windsor but are low elsewhere. In particular, the correlation coefficients in the built-up and industrial areas of Sarnia–Port Huron are small. Similarly, when a Port Huron urban station was chosen as reference, the coefficients in Windsor were generally less than 0.25 (illustrative Figure not included).

In summary, it seems that the concentrations at an urban station cannot be used to predict those in the surrounding rural area, and vice versa.

Previous urban pollution investigations have suggested that there is in fact a usefully high spatial correlation between pairs of stations (Clifton et al., 1959; Stalker et al., 1962; Munn, 1973). A reason for this different result may be the fact that consecutive daily observations were used in those other studies, introducing time correlations. In the present case, the observations were made only every third day, reducing the time correlations to very small values (see Table 1) and thus reducing the spatial correlations (Figs. 2 and 6).

6. Discussion and conclusion

Spatial variability of 24-hr suspended particulate concentrations has been examined in this paper, using observations from a mesoscale network.

An alternate approach is to use "factor analysis" employing orthogonal functions (eigenvectors). Although the spatial fields can then be dissected into several independent fields, each explaining a fraction of the variance, physical interpretation of the resulting eigenvector patterns is virtually impossible. Admittedly there are also some difficulties with the more direct method used in this paper, but the investigator can at least obtain a qualitative interpretation of his results.

The present study shows that for observations made every third day, the spatial correlation coefficients are not particularly high, probably because the time correlations are so small. However, by dividing the data into subsets, each with similar regional wind flows, the spatial correlation coefficients can be increased (see Table 2). This, perhaps, might have been expected. Because air quality is significantly correlated with large-scale meteorological fac-

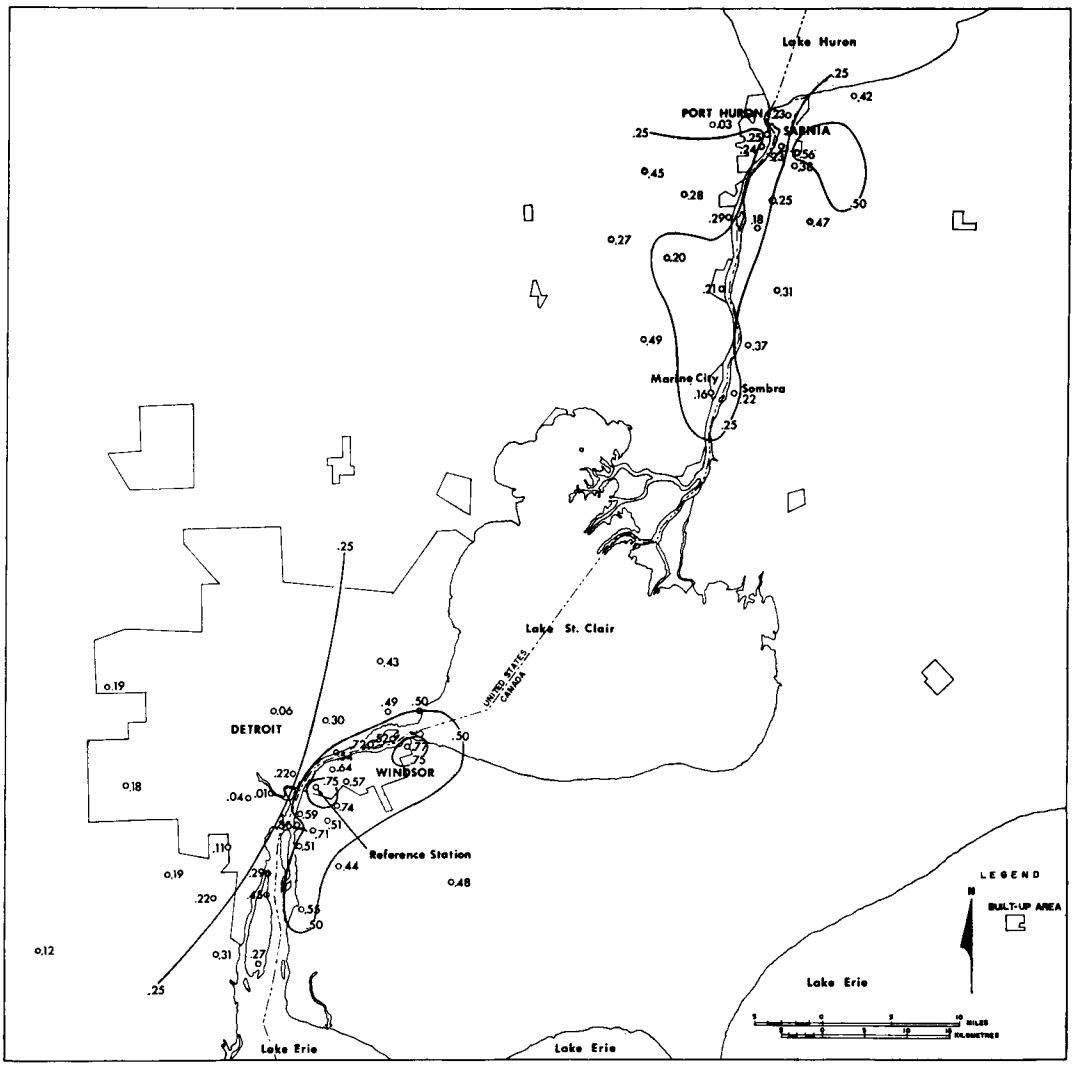

Fig. 6. Isopleths of spatial correlation coefficients for the entire data set using an urban Windsor station as reference (location indicated on Figure).

tors, spatial correlations should exist within each subset.

In North America, high-volume samplers are usually operated only one day a week, the particular day being chosen by some randomization technique. The data are used to compute annual geometric means for comparison with air quality standards.

In many cities, furthermore, only a few such stations are operated (e.g., only one in each of the following site categories: industrial, commercial and residential).

The present study suggests that:

(*a*) On individual days, the particulate levels measured at a single site are not useful indicators of area-wide particulate loadings. The observations should not be used in correlations with daily epidemiological observations, for example.

(*b*) For annual geometric means, it is appropriate to speculate that because of year-to-year climatic variability (particularly in wind direction frequencies), the location of the central isopleths of highest particulate loadings

in a city may vary from year to year. This implies that even when there is no change in emission strengths and configurations, the particulate geometric means at a single site are likely to show year-to-year variability, and may be poorly correlated with areal annual averages of suspended matter. The magnitude of this variability remains to be investigated but it may account for some of the poor correlations that have been reported between air quality (as measured at a point) and effects (obtained from data averaged over an area).

The question remains: what is an optimum density for an urban air pollution network. No guidelines can be given, apart from the general comment that the optimum network density depends to a considerable extent on the objectives of monitoring. As a supplementary observation, however, inspection of the isopleths in Fig. 1 does suggest that in order to characterize the concentration gradients in Sarnia–Port Huron in the same detail as in the Windsor–Detroit area, nearly as many sampling stations are required in the smaller metropolitan area.

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КОНЦЕНТРАЦИИ ВЗВЕШЕННЫХ ЧАСТИЦ: ПРОСТРАНСТВЕННЫЕ КОРРЕЛЯЦИИ В ОБЛАСТИ ДЕТРОЙТА–ВИНДЗОРА

В течение 14-месячного периода в 1967–68 гг. в области Виндзора–Детройта и Сарниа–Порт Гурон каждый третий день на 56 станциях измерялись в течение 24 часов концентрации взвешенных частиц. В данной статье вычислены коэффициенты пространственной корреляции и найдены изоплеты. При использовании полного набора данных эти корреляции довольно низкие. Однако при подразделении этих данных на поднаборы, каждый с аналогичными картинами направлений ветра, коэффициенты корреляции увеличиваются и возникают некоторые интересные шаблоны. Делается заключение, что в индивидуальные дни уровни концентраций частиц, измеренные в данном месте, не являются полезными индикаторами нагружения городского воздуха частицами, если метеорологическая ситуация не определена. Обсуждаются некоторые следствия для проблемы оптимизации плотности сети станций для измерений загрязнения воздуха.