Environment Canada Imaging Cover Page

Report N.: *TEC-605*

SKP Box Number: 672572427

CANADA

DEPARTMENT OF TRANSPORT
METEOROLOGICAL BRANCH

TORONTO WEATHER OFFICE
BOX 159
TORONTO A.M.F. ONTARIO

-AIR POLLUTION- METEOROLOGICAL RELATIONSHIPS AT VANCOUVER BRITISH COLUMBIA

BY

J. H. EMSLIE and J. SATTERTHWAITE

TORONTO ONTARIO

U.D.C.: 551.508.91
551.510.42

CIR. 4396
TEC. 605
7 MAR. 66

CANADA - DEPARTMENT OF TRANSPORT - METEOROLOGICAL BRANCH
315 Bloor Street, West,
Toronto 5, Ontario.

AIR POLLUTION - METEOROLOGICAL RELATIONSHIPS AT VANCOUVER, BRITISH COLUMBIA*

by

J. H. Emslie
and
J. Satterthwaite

ABSTRACT

The Vancouver air pollution measurement network and instrumentation are described.

Seasonal "heavy" air pollution measurements are related to seasonal values of a number of meteorological variables to obtain the gross picture of correlation. Wind speed appears to bear the only consistent relationship to "heavy" pollution values, for the time-scale considered.

A number of recommendations are presented regarding future requirements of the Vancouver measurement and abatement program.

* Presented at the 1965 National Meteorological Congress, Royal Meteorological Society, 8 June, 1965.

CANADA - MINISTÈRE DES TRANSPORTS - DIRECTION DE LA MÉTÉOROLOGIE
315 ouest, rue Bloor,
Toronto 5e (Ont.)

RELATIONS MÉTÉOROLOGIQUES DE LA POLLUTION DE L'AIR À VANCOUVER' COLOMBIE-BRITANNIQUE*

par

J. H. Emslie
et
J. Satterthwaite

RÉSUMÉ

Les auteurs décrivent le réseau et les instruments de mesure de la pollution de l'air utilisés à Vancouver.

Ils établissent la relation entre les mesures des pollutions saisonnières "intenses" de l'air et les valeurs saisonnières d'un certain nombre de variables météorologiques afin d'obtenir l'image brute des corrélations. La vitesse du vent semble présenter la seule relation consistante avec les valeurs de pollution "intense", pour ce qui est de l'échelle temporelle utilisée.

Les auteurs présentent un certain nombre de recommandations relatives aux besoins futurs du programme de mesure et de réduction de la pollution de l'air à Vancouver.

* Communication présentée au Congrès météorologique national (1965) de la Société météorologique royale, le 8 juin 1965.

AIR POLLUTION - METEOROLOGICAL RELATIONSHIPS AT VANCOUVER, BRITISH COLUMBIA

by

J. H. Emslie*
and
J. Satterthwaite*

(Manuscript Received August 9, 1965, In Revised Form November 29, 1965)

1. Introduction

The dispersion of air pollution, once it has left the source, is governed by the interaction of meteorological variables. It is generally acknowledged that wind velocity and wind direction play the major role in horizontal dispersion, while turbulence, either of a mechanical nature due to terrain roughness and wind, or of a thermal nature due to differential solar heating, determines the vertical spread of the pollutant. These, then, with their variations in space and time, form the basis of the standard Canadian air pollution meteorological tabulation as prepared by the Meteorological Branch (1).

Many other variables such as surface temperature, precipitation, bright sunshine, and visibility, are also measured routinely at meteorological and climatological stations. It would be interesting to obtain a gross picture of their correlation with air pollution measurements to indicate if additonal data should be included in the routine seasonal studies, or if they should be considered by the local Pollution Control Officer in his analyses of the tabulations.

> "A universal question posed by Smoke Abatement Officials is as follows: average pollution levels this year are different from those of last year - is the change caused by meteorological factors, or by a decrease (or increase) in emissions? Although no firm conclusions are reached in this paper, we believe it to be an important question for meteorologists to consider".

---

*NOTE: Mr. Emslie is a Meteorological Officer at the British Columbia Weather Office, Vancouver International Airport.
Mr. Satterthwaite is the Chief Air Pollution Inspector, Engineering Department, City of Vancouver.

2. Instrumentation

A network of air pollution measurement stations was begun in Vancouver in 1957 by the Vancouver City Engineering Department for the continuous measurement of air quality within the city (Figure 1).

Instrumented with Hemeon A.I.S.I. smoke samplers (2), measurement procedures and data abstraction conformed with the recommendations of the Federal Occupational Health Division and the Meteorological Branch of the Department of Transport, while processing of the data to standard seasonal tabulations was undertaken by the Data Processing Unit of the Meteorological Branch.

The smoke samplers at Stations A, B, C, D and E yield a soiling index for each two-hour sampling period. The sampler draws in air at a constant flow rate through a filter tape and suspended particulate matter is deposited on the tape. An automatic timer shifts the filter tape forward every two hours so that two-hourly COH values are obtained continuously. The extent of darkening, or soiling, of the filter tape is measured by light transmittance, and expressed in terms of COH/1000 linear feet of air sampled. One COH unit is defined as "that quantity of light scattering solids producing an optical density of 0.01, when measured by light transmission" (3). The COH values are considered to be roughly indicative of the quantity of fine airborne particulates representing smoke and haze particles. In general, such smoke particles are less than five microns in diameter and most are sub-micron size.

Meteorological parameters are measured at the Vancouver Weather Office at the International Airport on Sea Island and, additionally, a fairly dense network of Climatological Stations throughout the metropolitan area record daily precipitation and extremes of daily temperature (4).

Since January 1959, in excess of 110 thousand Vancouver air pollution measurements have been tabulated by the Meteorological Branch.

3. Air Pollution Summary

For this particular study, "heavy" pollution measurements, as defined conventionally (5), have been expressed as a percentage of the total seasonal measurement at each Station. Figure 2 displays these seasonal percentages for the twenty-one seasons. (Note that Station E is not included since measurement began only in January, 1962)

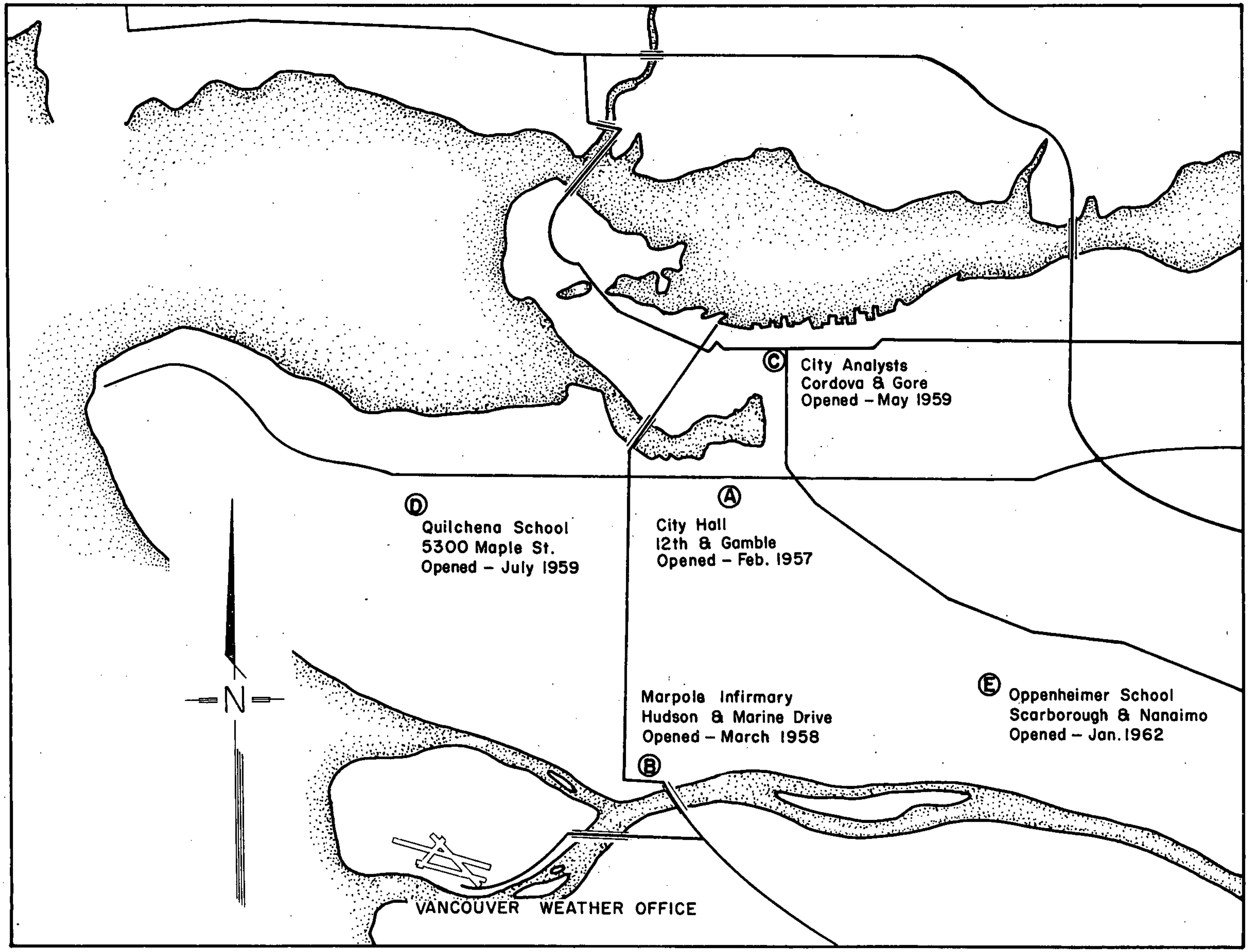

Fig. 1 – Air pollution measurement network, Vancouver City, Engineering Department.

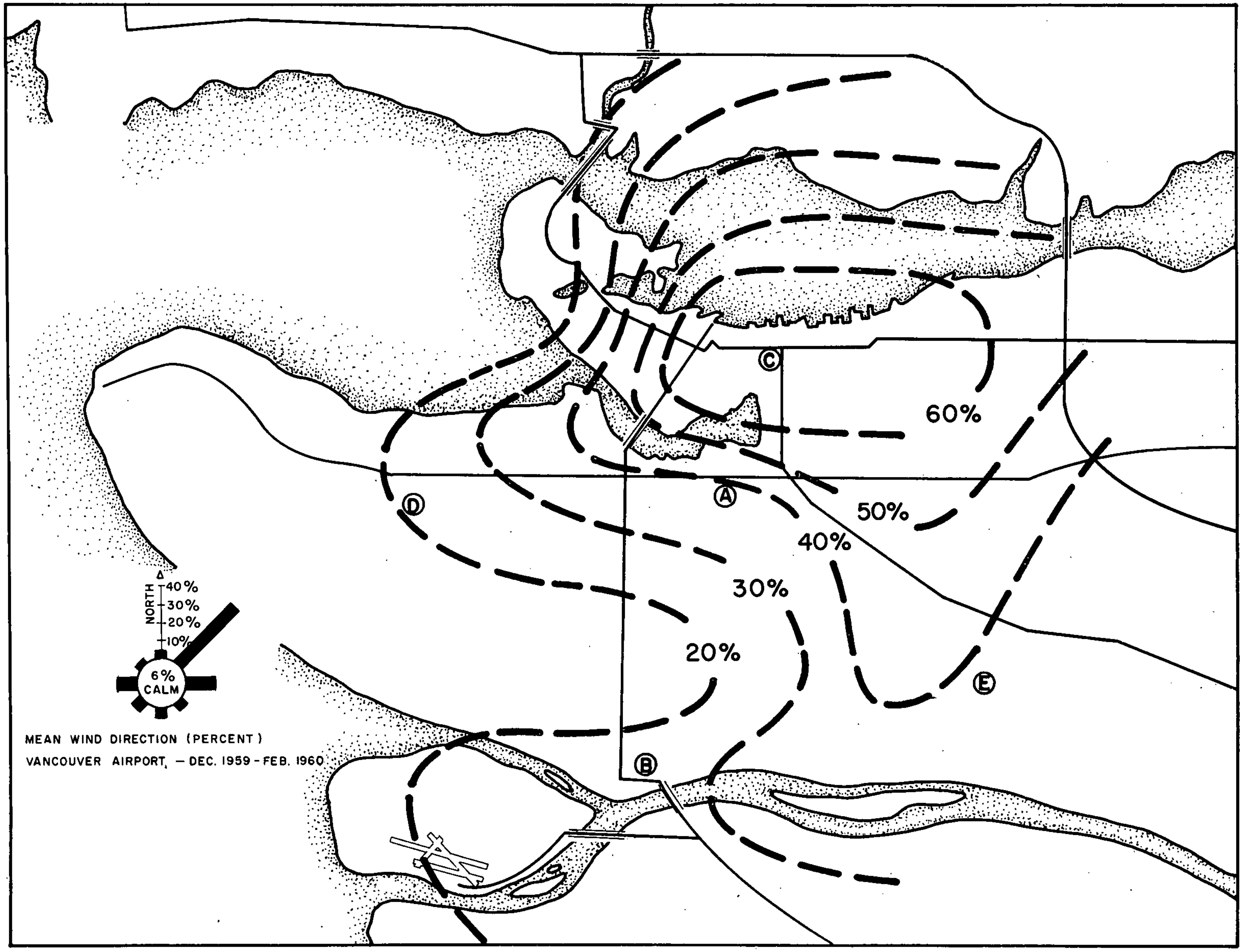

Fig. 2 – Percentage occurences of "heavy" air pollution (aerosol) in Vancouver City, December 1959 – February 1960.

The figure illustrates the seasonal variation in pollution amount throughout the network, with a maximum during the winter season, and a minimum during the summer, in conformity with results from other Canadian urban measurement programs.

It is noted that a consistent overall reduction in the "heavy" classification of pollution is evident during the period, due to a number of factors: firstly, to the conversion of industrial and home heating plants from coal and wood products to natural gas; secondly, to the growing awareness of industry of their responsibility to the community in the reduction of the indiscriminate release of waste products; thirdly, to the more efficient industrial use of forest by-products resulting in, for example, the reduction in the number of waste sawdust burners; and fourthly, to the vigilance of the Pollution Control Branch of the Vancouver Engineering Department in following up complaints against industrial and private offenders.

Additionally, there may well have been a consistent shift in frequency of certain meteorological variables, during this period of air pollution measurement, which resulted in improved dilution of the emitted waste products. To completely analyse this possibility would require study of in excess of forty-five thousand hourly measurements of each meteorological parameter. Accordingly, it has been the intention here to, initially, obtain the gross picture by restricting comparisons of seasonal air pollution data to those meteorological variables available in Monthly Summaries. As well, these summaries are readily available to the local Pollution Control Officer for his considerations.

Short-term case studies of individual, interesting seasons or situations using hourly and daily meteorological data will be the subject of later papers.

4. Meteorological Summary

In each case, the seasonal mean for the meteorological variable has been compared to the long-term seasonal climatological figure, and expressed as a percentage of that climatological figure. Thus, for example, the precipitation ranged from a minimum of 86% of the seasonal normal for the winter of 1962/63, to a maximum of 154% of the seasonal normal for the summer of 1964. Similar comparisons were prepared using hours of bright sunshine, mean daily temperature, days of fog, and wind speed in the light ($<$ 5 mph) and strong ($>$9 mph) classifications.

(1) Precipitation

Figure 3A displays the recorded precipitation for each season of the period, expressed as a percentage of the long term seasonal mean. As mentioned, a large number of Climatological Stations in greater Vancouver record daily precipitation (6). While precipitation amounts vary considerably over the city, seasonal departures from the seasonal mean at each Climatological Station are in fair agreement.

(2) Bright Sunshine

Figure 3B displays the recorded seasonal bright sunshine at the Vancouver Airport expressed as a percentage of the long-term seasonal mean.

(3) Mean Temperature

Figure 3C displays the average of the mean daily temperatures for each season, expressed as a percentage of the long-term seasonal temperature.

(4) Days of Fog

Figure 3D displays the observed days of fog, as so defined climatologically, expressed as a percentage of the long-term seasonal mean. Since a "day of fog" is recorded if at least one hourly observation of surface visibility of less than 5/8 mile occurs, due to fog, the effect of this parameter on the overall vertical dispersion of pollution is masked, since no distinction is made between one hourly observation of fog and twenty-four, in any given day.

(5) Wind Speed

Figure 3E displays the seasonal variation in light and strong winds, as defined conventionally in air pollution literature, expressed as a percentage of the long-term seasonal mean at the Vancouver Airport. It is recognized that the wind as recorded at the Airport may not reflect the wind flow over the city as a whole, in fact, may have little similarity to the flow over some areas due to the proximity of mountains and sea. Analysis of wind data from new or planned instrumentation at a number of locations in greater Vancouver will provide a better picture of the flow over the city and, at that time, will be applied to the air pollution tabulations.

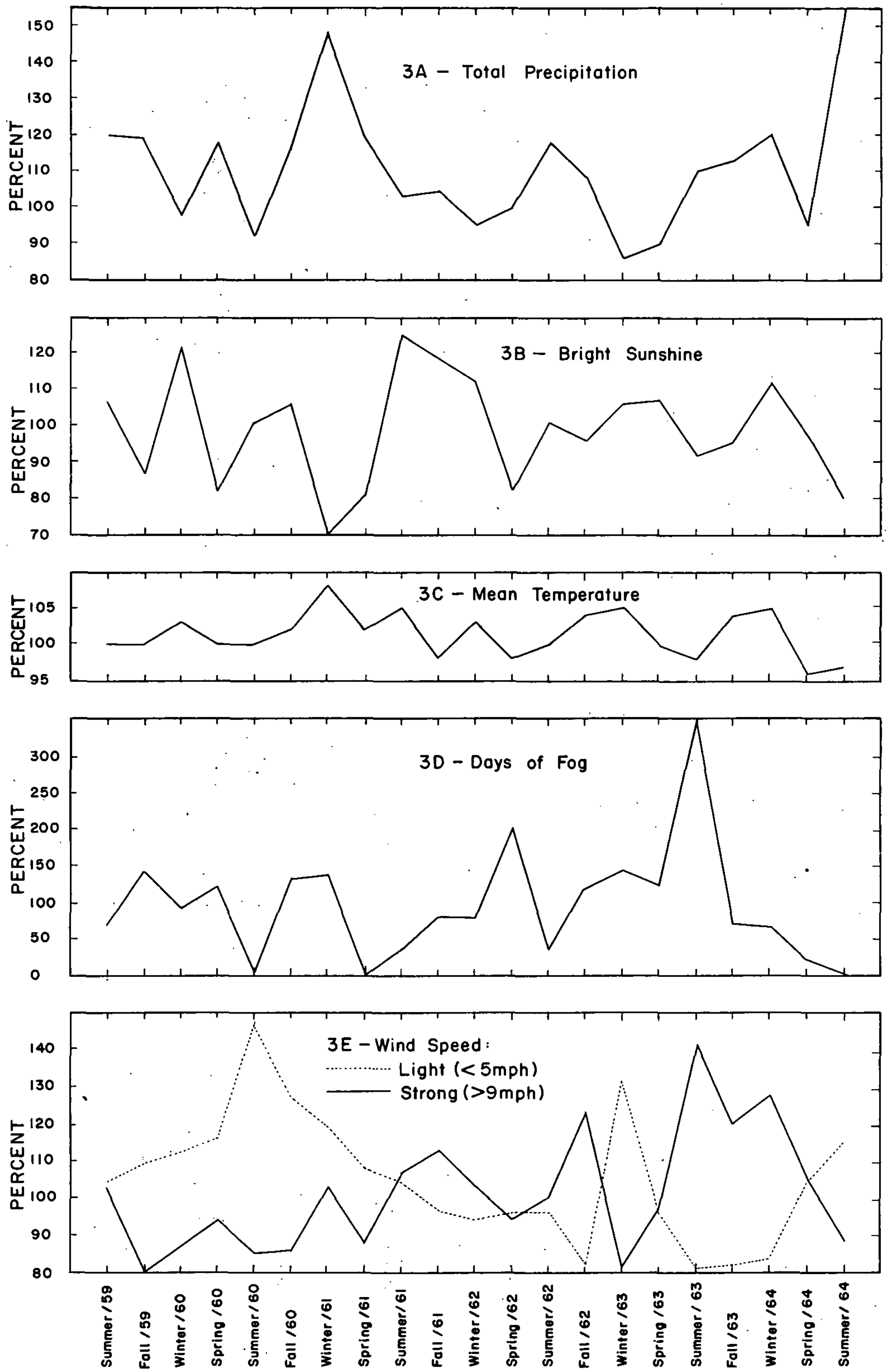

Figure 3 – Seasonal Variation in Meteorological Parameters as a Percentage of the Seasonal Climatological Mean (Summer 1959 – Summer 1964).

5. Results

It is evident that there is little correlation between the patterns of the meteorological parameters, precipitation, sunshine, temperature and fog, and the patterns of "heavy" pollution.

Numerous consistencies, however, are evident among these meteorological parameters. This in itself is noteworthy in that the persistence of such anomalies should appear over three-month periods. For example, during the winter 1960/61, the very wet season was reflected in a minimum of bright sunshine, with excessive cloud cover preventing radiative cooling, resulting in high seasonal mean temperature. A similar inter-relationship is evident during the summer 1964, as with a number of other seasons.

The only consistent pattern evident between a meteorological parameter and the measured "heavy" pollution, is that of wind speed. There is a general increasing frequency of strong winds during the period, suggesting increased horizontal ventilation in agreement with the decreasing measurement of "heavy" pollution.

Two exceptions to the trend of increasing strong winds are worthy of note. During the winter 1962/63, strong winds occurred only 81% of seasonal normal. During this period, Station B recorded the highest frequency of "heavy" pollution measurement at that Station to date. Similarly, during the summer 1964, the greatest frequency of summer "heavy" pollution measurement occurred at Station C, with only 89% of normal strong winds. During other seasons of the period, the upward seasonal trend of strong winds was in agreement with the general downward seasonal trend in the "heavy" pollution measurement.

During the winter 1959/60, excessive "heavy" pollution was recorded at all Stations. Figure 4 displays, on a topographical outline of Vancouver, the probable distribution of percentage of "heavy" pollution measurement in the city. To supplement the small measurement network, all available information on pollution sources, and areas of consistently good and poor air quality throughout the city (as recognized by the City Engineering Department staff) were examined, as well as all Pollution Wind Rose diagrams (1). The objective was to draw isopleths conforming to observed cross-sections of air quality under similar meteorological conditions. For example, Pollution

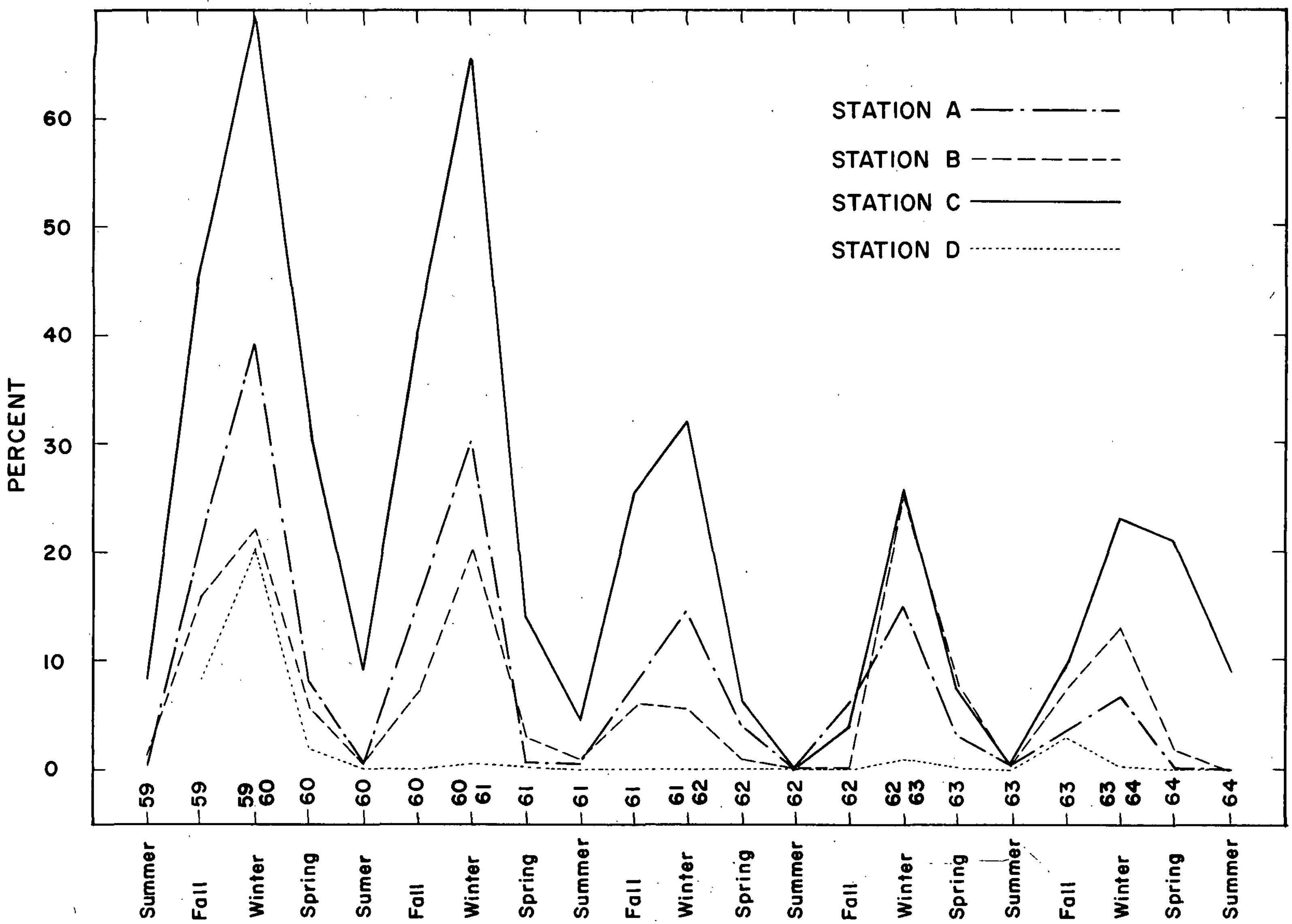

Fig. 4 – Percentage of Seasonal Distribution of Heavy COH (Summer 1959 – Summer 1964).

Wind Rose diagrams indicate "heavy" pollution sources to the west and northwest of Station E, while the concentration of industry along the north arm of the Fraser River is reflected in "heavy" pollution orientation east and west of Station B, compared to consistent, relatively clean air flow from the south. Clean air along the wooded, residential ridge southwest, south and southeast of Station D, and fairly clean air over similar topography northeast, east and southeast of Station E is recognized, and confirmed by Pollution Wind Rose analyses.

Included is the actual percentage wind direction distribution frequency for the period. Reference to Figures 3A-E shows that precipitation and days of fog were near, or slightly below, normal that winter, mean temperature was above normal, and hours of bright sunshine were much above, while the frequency of strong winds was considerably below normal. Interesting, too, is the observation that the prevailing wind direction was from the northeast, which is counter to the normal, east, for the winter season. The highest concentration of "heavy" pollution appears to have been in the downtown district, with spread of this high concentration downwind of the centre, following lower ground contours.

6. Discussion of Results

Considerable variability is noted in the individual occurrences of "peak" values at each Station, although all, in general, followed the mean trend.

Routine Topographic Analyses (1) of the standard tabulations, indicate consistent point sources of pollution in the vicinity of each Station, identifiable over the general background intensity. These point sources show up with wind flow from specific directions, and, thus, all Stations may not "peak" during the same short period, depending upon the orientation of these point sources from the Stations.

A further complication is the variability of source strength, particularly with industrial sources. Many investigations have shown regular and predictable diurnal and weekly cycles attributed to the pattern of industrial activity (7).

The seasonal figures for precipitation, bright sunshine, fog and wind give an indication, indirectly, of the probable departure from the normal frequency of low-level inversions which affect the vertical dilution of pollution. However, since there is, at Vancouver, no instrumentation to measure, directly, the low-level inversion intensity and frequency, as at many other Canadian centres (8), an estimation of the low-level stability and its effect on the dilution of pollution can only be conjectured, and this with a minimum degree of confidence, due to the intensely complex interaction of sea breeze, radiation, drainage, subsidence and frontal inversions.

The effect of rain-out and wash-out of airborne pollutants has been discussed by many investigators (9). Presence of these factors is not evident from examination of the seasonal data presented here. It is doubtful if rain-out could be detected by sampling within the source area, since the pollution particles would be a considerable distance downstream before they would be lifted, by turbulence, to an elevation sufficiently high to act as condensation nuclei.

Figure 4, the topographical display of the distribution of one season's "heavy" pollution, brings out the difficulty of relying on wind flow only, to explain excesses in pollution amount, general over an entire area. The high frequency of hours of bright sunshine is a clue that clear skies would allow excessive nocturnal radiation and, hence, there would be a correspondingly high frequency of radiation inversions, but inversion duration and intensity estimations are not possible without more specific data.

7. Conclusions and Recommendations

A number of probable reasons for the decreasing trend in "heavy" pollution amount were noted. Whether there had actually been a decrease in source output, or that only the dilution through meteorological factors had been better, cannot be concluded. It is indicated that the horizontal ventilation was, in general, increasing during the period, with the noted exceptions, but, without proper instrumentation, no estimation of the variation in vertical dilution is possible.

No clear-cut correlation with other meteorological parameters was evident, indicating that the Pollution Control Officer would not obtain fruitful results b y including these in his studies.

To obtain the complete answer would require a large scale instrumented study, including a detailed source inventory, such as has been conducted at Louisville (10), Chicago or Los Angeles. These are extremely expensive projects, both in funds for instrumentation, and for technical manpower. However, at Vancouver, a reasonable estimate may be obtained through the continuation and expansion of the present sampling and analysis program. A more dense network of samplers, particularly in those areas where pollution is excessive, will indicate the location of major sources of pollution, and will provide mean background values under varying wind flow patterns. The additional surface wind data, to be made available shortly, will provide a well documented picture of the wind flow within the city, and assure reliable estimations of the horizontal dilution of pollution.

Measurement of parameters to provide the vertical dilution is equally important, however, if an estimation of tolerable emission rates is to be made. This will require installation of a tower to measure vertical temperature gradients as was mentioned, is done at a number of other Canadian cities.

The study must be coupled to a vigorous program of pollution abatement, backed by realistic legislation, if progress is to be made in this extremely complex urban problem.

Authors Note - Since presentation of this paper, two additional seasons of Vancouver air pollution data have been tabulated. Mention of them is worthwhile here since the trend of wind flow and "heavy" pollution amount exhibited in the paper appears to have reversed. A further striking interdependence of these two measurements is noted when the values in the following Table (same notation) are compared with those in Figures 2 and 3E.

	A	B	C	D	Light Wind	Strong Wind
Fall /64	20.0	6.1	37.0	1.5	127	73
Winter 64/65	23.3	5.8	51.8	1.8	109	97

Comparison of the fall /64 data with that of a previous fall of nearly identical wind flow, as in the following Table, leads one to the conclusion that the decreasing trend in "heavy" pollution measurement noted in the paper, is the result of increased ventilation rather than in the reduction of the volume of emission.

	Light Wind	Strong Wind	A	B	C	D
Fall /60	127	87	15.0	7.3	40.2	0.0
Fall /64	127	73	20.0	6.1	37.0	1.8

APPROVED,

J. R. H. Noble,
Director,
Meteorological Branch.

8. References

(1) Emslie, J. H., 1964: The Analysis of National Air Pollution Program Data. Canada, Department of Transport, Meteorological Branch, Technical Circular Series, CIR-4021, TEC-512.

(2) Hemeon, W. C. L., G. F. Haines Jr., and H. H. Ide, 1953: Determination of Haze and Smoke Concentrations by Filter Paper Samplers. Journal, Air Pollution Control Assn., Vol. 3, No. 1, pp. 22, August 1953.

(3) American Society for Testing Materials - Tentative Method of Test for Particulate Matter in the Atmosphere. ASTM designation D1704 - 59T, 1959.

(4) Climate of British Columbia. Canada, Department of Transport, Meteorological Branch.

(5) New Jersey State Department of Health, 1958: State Wide Air Pollution Survey -- Smoke Index.

(6) Wright, J. B., 1965: Some Aspects of Vancouver City Weather. 1965 National Meteorological Congress, Royal Meteorological Society.

(7) Munn, R. E., 1961: The Interpretation of Air Pollution Data, with Examples from Vancouver. 13th British Columbia Natural Resources Conference, March, 1961.

(8) Munn, R. E., J. H. Emslie, and H. J. Wilson, 1963: A Preliminary Analysis of the Inversion Climatology of Southern Ontario. Canada, Department of Transport, Meteorological Branch, Technical Circular Series, CIR-3834, TEC-466.

(9) Meteorology and Atomic Energy, 1955. AECU 3066, Weather Bureau, United States Department of Commerce.

(10) Rossano, A. T. Jr., The Joint City, County, State and Federal Study of Air Pollution in Louisville, Kentucky. Journal, Air Pollution Control Association, 6, 176, 1956.

CIR-4396 UDC: 551.508.91
TEC-605 551.510.42
7 Mar. 66.

CANADA
Department of Transport - Meteorological Branch
315 Bloor St., W., - Toronto 5, Ontario

Air Pollution - Meteorological Relationships
at Vancouver, British Columbia
by J. H. Emslie and J. Satterthwaite

9 pps. 4 figs. 10 refs.

Subject reference: 1. Air Pollution.
2. Vancouver, British Columbia.
3. Hemeon A.I.S.I. Smoke Samples.

CIR-4396 UDC: 551.508.91
TEC-605 551.510.42
7 Mar. 66.

CANADA
Department of Transport - Meteorological Branch
315 Bloor St., W., - Toronto 5, Ontario

Air Pollution - Meteorological Relationships
at Vancouver, British Columbia
by J. H. Emslie and J. Satterthwaite

9 pps. 4 figs. 10 refs.

Subject reference: 1. Air Pollution.
2. Vancouver, British Columbia.
3. Hemeon A.I.S.I. Smoke Samples.

CIR-4396 UDC: 551.508.91
TEC-605 551.510.42
7 Mar. 66.

CANADA
Department of Transport - Meteorological Branch
315 Bloor St., W., - Toronto 5, Ontario

Air Pollution - Meteorological Relationships
at Vancouver, British Columbia
by J. H. Emslie and J. Satterthwaite

9 pps. 4 figs. 10 refs.

Subject reference: 1. Air Pollution.
2. Vancouver, British Columbia.
3. Hemeon A.I.S.I. Smoke Samples.

CIR-4396 UDC: 551.508.91
TEC-605 551.510.42
7 Mar. 66.

CANADA
Department of Transport - Meteorological Branch
315 Bloor St., W., - Toronto 5, Ontario

Air Pollution - Meteorological Relationships
at Vancouver, British Columbia
by J. H. Emslie and J. Satterthwaite

9 pps. 4 figs. 10 refs.

Subject reference: 1. Air Pollution.
2. Vancouver, British Columbia.
3. Hemeon A.I.S. Smoke Samples.

ABSTRACT: The Vancouver air pollution measurement network and instrumentation are described.

Seasonal "heavy" air pollution measurements are related to seasonal values of a number of meteorological variables to obtain the gross picture of correlation. Wind speed appears to bear the only consistent relationship to "heavy" pollution values, for the time-scale considered.

A number of recommendations are presented regarding future requirements of the Vancouver measurement and abatement program.

ABSTRACT: The Vancouver air pollution measurement network and instrumentation are described.

Seasonal "heavy" air pollution measurements are related to seasonal values of a number of meteorological variables to obtain the gross picture of correlation. Wind Speed appears to bear the only consistent relationship to "heavy" pollution values, for the time-scale considered.

A number of recommendations are presented regarding future requirements of the Vancouver measurement and abatement program.

ABSTRACT: The Vancouver air pollution measurement network and instrumentation are described.

Seasonal "heavy" air pollution measurements are related to seasonal values of a number of meteorological variables to obtain the gross picture of correlation. Wind speed appears to bear the only consistent relationship to "heavy" pollution values, for the time-scale considered.

A number of recommendations are presented regarding future requirements of the Vancouver measurement and abatement program.

ABSTRACT: The Vancouver air pollution measurement network and instrumentation are described.

Seasonal "heavy" air pollution measurements are related to seasonal values of a number of meteorological variables to obtain the gross picture of correlation. Wind speed appears to bear the only consistent relationship to "heavy" pollution values, for the time-scale considered.

A number of recommendations are presented regarding future requirements of the Vancouver measurement and abatement program.