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RELATIONSHIPS BETWEEN SULPHUR DIOXIDE POLLUTION AND METEOROLOGICAL FACTORS IN MONTREAL*

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ABSTRACT

In this paper the effects of some meteorological variables on the SO2 pollution level is determined for the Montreal region. We have considered the SO2 concentrations measured at six sampling stations in the region of Montreal during the year 1975 together with some meteorological variables measured at one site for the same year. A descriptive analysis of these data indicates which of the available meteorological variables are most related to the SO2 level: wind speed, wind direction and temperature, mainly in winter. Some winds have a cleaning effect whereas others favor pollution. Increasing temperature results in a decreasing SO2 level in the urban area. Then some regression models are built for each station and a more detailed analysis is made of the meteorological variables effects on the SO2 level. These effects can be evaluated locally at each station. Finally a principal component analysis of the stations is made in order to evaluate the same effects globally in the region of Montreal.

SECTION 1: INTRODUCTION

This paper is concerned with air pollution in the Montreal region. In the early sixties, the various levels of governments initiated a network of stations monitoring pollutant concentration data. Actually this network is rather dense and the concentration of the following pollutants is systematically recorded at different stations: sulfur dioxide (SO2), soiling (COH), sulphation (SO3), dustfall, suspended particulates, sulfured hydrogen (H2S), nitrogen oxides (NOX), carbon monoxide (CO) and ozone (O3).

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Montreal is one of the most polluted cities in Canada with respect to SO2 emissions [1]. The present study is limited to SO2 and the objectives are:
1. to find the meteorological variables most related to the pollution level; and
2. to evaluate their effects locally at different stations and globally in the region of Montreal. Knowing what variables affect significantly the SO2 pollution level and knowing also their effects can certainly be useful in air pollution prediction.

The air pollution levels that are measured at a given station also depend on the source of pollution, on the distance between the source and the station and on the height of the station and of the source of pollution.

According to a report of Environment Canada [2], the main sources of SO2 emission are: 700,000 motor vehicles, six refineries dealing with 17,000,000 gallons of crude oil daily (30% of the Canadian consumption), two concrete industries producing more than one million tons of concrete annually, fourteen petrochemical factories and allied industries, and finally the heating of houses and buildings in winter.

The pollution data we consider in this paper are the concentration of SO2 in parts per hundred millions (pphm), measured every hour or every other hour at six stations during 1975. They were obtained from the Services de protection de l'environnement, Gouvernement du Québec [3]. These stations are geographically spread out in the region of Montreal and their choice follows the classification of stations made in Cléroux, Roy and Fortin [4]. The presence of SO2 in the air is determined in different ways: some stations are equipped with automatic devices which continuously register the concentration level; others are equipped with sequential devices which sample the air which, in turn, is analyzed in a laboratory. The six stations are listed below: we give, for each station, its official number, its address, its height in meters above sea level and ground level (when available) and the type of device used to measure the SO2 concentration.

		Height (m) above		*Type of device*	
No.	*Station Address*	*sea l.*	*ground l.*	*continuous*	*sequential*
3	1050 St-Jean Baptiste Pointe-aux-Trembles	–	3	Phillips	
13	1212 Drummond Montreal	35	12		Sequential
16	7450 Champagneur Montreal	55	13		Sequential
20	525-9th Avenue Pointe-aux-Trembles	9	6	Beckman 906	
23	433 Sherbrooke W. Westmount	55	9	Beckman 906	
29	Pilon Park Montreal-North	–	3	Philips	

Figure 1 shows the locations of these six stations in the Montreal region. Let us note that stations 3 and 20 are located to the east of and near the oil-refineries, that station 13 is located in the heart of downtown Montreal, that stations 16 and 29 are located in an average population and industry density area, and finally, that station 23 is located in a weak population and industry density area. The missing data have been treated as such, that is, they were not estimated from the existing data, and no computation is made for those periods where data is missing.

The meteorological data used in this study are the wind direction and speed, the temperature, the relative humidity, the ceiling height and the station pressure. They were also measured for the year 1975 at Dorval meteorological station situated in the north-west area of the island of Montreal. They are measured at one hour intervals and there are no missing data.

In Section 2, some descriptive statistics are made on the data in order to find, for each station, the meteorological variables most related to the SO2 pollution level. And this is done separately for winter and for summer. In Section 3 some regression models are built for each station in order to evaluate locally the effects of the meteorological variables on the SO2 level. In Section 4 a principal component analysis is made on the stations and some more regression models are built in order to evaluate globally the effects of the meteorological variables on the pollution level. Finally, in Section 5 we draw a conclusion of this study and indicate briefly some subjects for further research.

SECTION 2: SOME DESCRIPTIVE STATISTICS

In this section some elementary computations are made on the data and the descriptive statistics obtained give a good indication of the overall importance of some meteorological variables on the SO2 pollution level.

Methodology

Fuel oil combustion is an important source of pollution by SO2 and this occurs mainly in winter. Therefore the effect of meteorological variables on the pollution level have been found separately for winter (December to March) and for summer (June to September). The meteorological variables are either quantitative (like the wind speed) or qualitative (like the wind direction). For the quantitative variables, some classes are constructed and, for each class, the average SO2 level is computed separately for winter and summer. If a given class has less than thirty observations, it is grouped with its immediate neighbor having the smallest number of observations, and that is done until each class has at least thirty observations. Then the means are computed and the results are presented as graphs where the abcissa is the mid-interval point and the ordinate is the class average pollution level. For the qualitative variables, the average SO2 level is computed for every possibility.

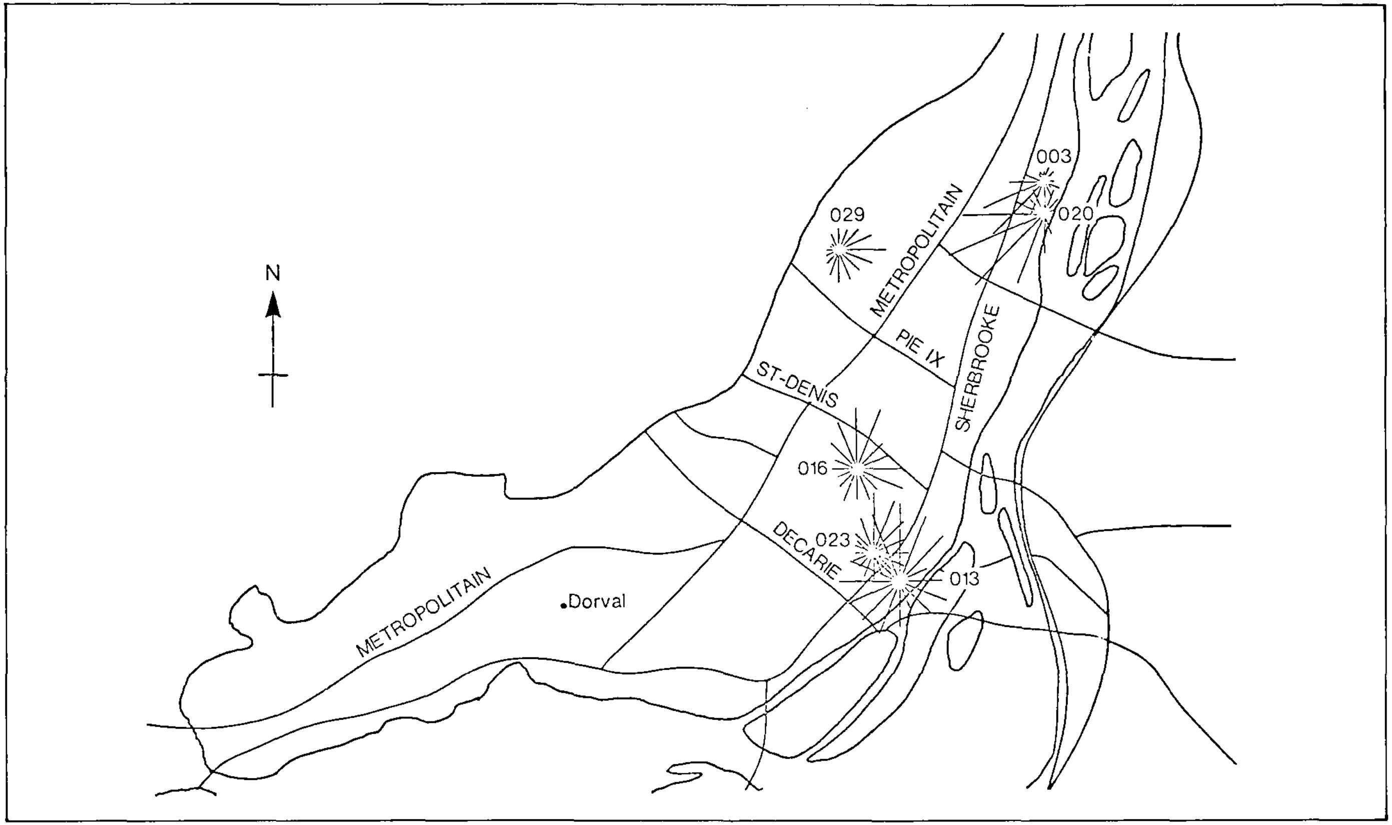

Figure 1. Location of the six pollution stations with pollution roses for winter (scale - 5.5 PPHM/cm.)

Wind Direction

There are sixteen wind directions: N, NNE, NE, ENE, E, ESE, SE, SSE, S, SSW, SW, WSW, W, WNW, NW and NNW, where N stands for North, E for East, S for South and W for West. For each direction, and separately for winter and summer, the average SO2 level has been computed when a wind direction could be clearly identified (wind speed greater than or equal to 1 mi/h.).

Winter—Table 1 shows the wind directions with relative frequencies together with the average SO2 pollution levels. The latter are also represented as pollution roses in Figure 1. A line segment is associated to each wind direction, its length being proportional to the average SO2 level. One end of the line segment is located at the pollution station and the other is in the direction where the wind comes from. The scale is 5.5 pphm per cm. From Figure 1, it is seen that when the winds come from the oil refineries, the pollution level is higher at every station and mainly at stations 3 and 20. The fact is that the refineries are an important source of pollution by SO2 and that their influence extends to the urban area. Station 13 is particular in the sense that almost every wind direction brings a high pollution level. From Table 1 it is seen that the wind directions, SW, WSW and W are very frequent winds and they are those which

Table 1. Wind Directions with Relative Frequencies and Average SO2 Pollution Level for the Winter Period

	Average SO2 Pollution Level						
	Station						
Wind	*3*	*13*	*16*	*20*	*23*	*29*	*Relative Frequency*
N	1.65	9.25	7.06	3.19	7.11	2.79	4.65
NNE	2.05	7.90	7.70	3.39	6.45	2.65	11.78
NE	1.93	7.56	5.44	2.83	5.52	3.40	6.89
ENE	0.97	5.80	4.44	2.19	4.00	4.24	1.76
E	1.35	5.40	5.19	2.05	4.29	5.00	2.07
ESE	1.99	6.19	5.75	2.37	4.00	4.43	3.20
SE	1.19	5.40	3.67	2.18	2.81	3.56	5.06
SSE	2.07	5.24	3.74	2.55	2.87	3.53	3.31
S	4.04	5.52	3.79	4.07	3.00	3.36	1.72
SSW	5.35	6.70	4.21	8.44	3.18	3.13	5.37
SW	8.25	6.42	3.12	11.52	2.68	2.19	12.98
WSW	7.79	6.93	3.20	12.36	2.41	1.72	14.22
W	4.16	7.15	3.17	8.99	2.45	1.55	10.67
WNW	2.27	6.17	3.09	4.00	2.58	1.21	5.10
NW	0.90	6.87	4.40	2.59	3.23	1.40	3.31
NNW	1.52	8.00	5.71	3.38	4.44	2.15	2.75
No Wind	–	–	–	–	–	–	5.17

bring a high pollution level at stations 3 and 20. The wind directions NNE and NE are also frequent and they are those which bring a high pollution level at stations 13, 16 and 23. Only station 29 seems relatively pollution-free since the wind directions ENE, E and ESE do not occur often.

Summer—Table 2 shows the wind directions with relative frequencies together with the average SO2 pollution levels. The SO2 levels are low for every station except station 20. It is seen, although not significantly, that the polluting winds in summer are among the polluting winds in winter. Since there is no heating in summer, the pollution levels in the urban areas are mainly due to the refineries. For station 20, the pollution level is high all year long.

Wind Speed

The data are in miles per hour and are rounded off at the nearest integer. For every station a graph is obtained of the SO2 level as a function of wind speed. Figure 2 shows these graphs for stations 3 and 13 for the winter period.

Winter—It is seen that for stations 13, 16, 23 and 29, the SO2 levels decrease with increasing wind speed and that the converse holds for stations 3 and 20.

Table 2. Wind Direction with Relative Frequencies and Average SO2 Pollution Level for the Summer Period.

	Average SO2 Pollution Level						
	Station						*Relative*
Wind	*3*	*13*	*16*	*20*	*23*	*29*	*Frequency*
N	0.14	0.74	0.07	1.92	0.09	0.02	3.79
NNE	0.16	0.70	0.03	1.64	0.08	0.10	5.70
NE	0.13	0.52	0.11	1.38	0.07	0.47	4.27
ENE	0.10	0.48	0.10	1.05	0.07	0.17	2.63
E	0.18	0.50	0.03	1.44	0.00	0.38	1.02
ESE	0.30	0.33	0.01	1.25	0.02	0.16	2.87
SE	0.16	0.40	0.00	1.53	0.02	0.03	5.87
SSE	0.15	0.47	0.01	1.73	0.01	0.05	6.90
S	1.10	0.45	0.00	3.88	0.03	0.03	2.94
SSW	1.13	0.55	0.02	6.45	0.02	0.04	8.37
SW	1.42	0.42	0.02	7.67	0.01	0.04	16.12
WSW	1.65	0.44	0.02	7.01	0.03	0.04	13.73
W	0.81	0.48	0.01	4.46	0.06	0.04	10.38
WNW	0.59	0.51	0.02	2.85	0.07	0.05	5.70
NW	0.23	0.50	0.04	1.74	0.02	0.04	3.28
NNW	0.11	0.56	0.08	2.25	0.05	0.00	2.80
No Wind	–	–	–	–	–	–	3.62

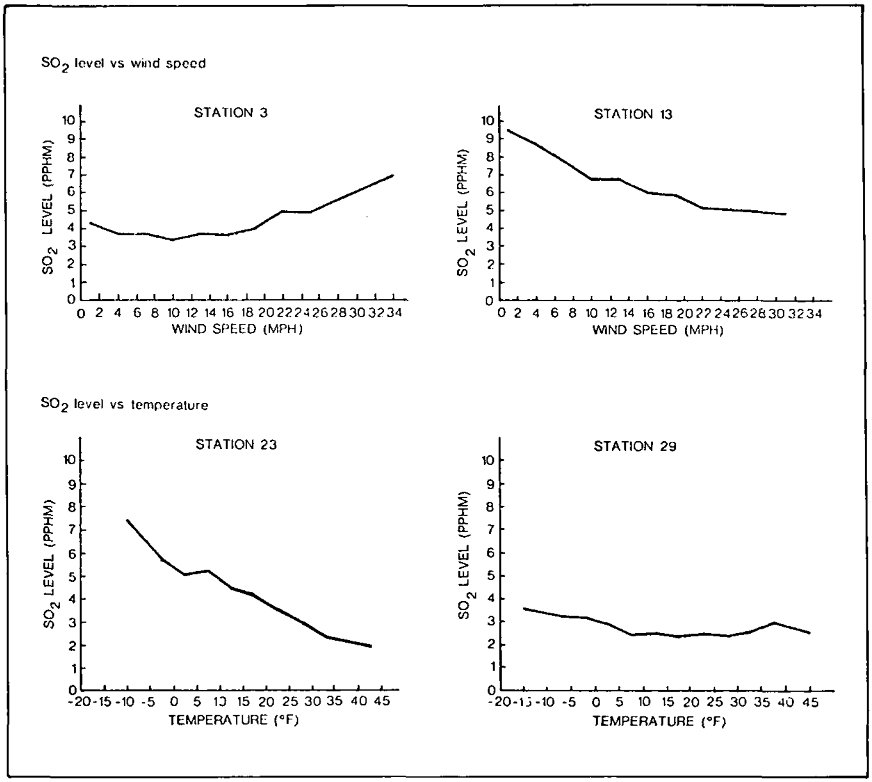

Figure 2. Some meteorological variables and average SO_2 level in winter.

Since, as was seen previously, the wind direction have more influence at stations 3 and 20 than at the others, we have obtained for these two stations similar graphs separately for polluting wind directions (SW, WSW, W) and for non-polluting wind directions (others). For the non-polluting winds the pollution level decreases with increasing wind speed and the converse still holds for polluting winds. We can therefore say that the wind has a dispersion effect proportional to its speed. However, when it blows from a near and important pollution source, it contributes to accumulate the pollution, probably by bringing it to the ground rapidly. At station 3 the pollution is measured at 3 meters above ground level and at 6 meters above ground level at station 20.

Summer—Wind speed has no effect on the SO2 level except at station 20 where its effect is similar to that in winter. This is not surprising since that station has high pollution level in summer and frequent polluting winds. Zanetti, Melli and Runca obtained similar results in Venice where there are an urban and an industrial area, like in Montreal [5].

Temperature

The temperature is measured in degrees Fahrenheit and rounded off at the nearest integer. For every station, graphs of the average SO2 level were obtained as functions of the temperature. Figure 2 shows these graphs for stations 23 and 29 in winter.

Winter—It is seen that for stations 13, 16 and 23, the SO2 level decreases with increasing temperature and that at stations 3, 20 and 29 it does not show any tendency. This clearly corresponds to intuition. When the temperature increases, there is less heating and the SO2 level decreases when no other pollution source is more important than heating.

Summer—Temperature has not effect on SO2 level at stations 13, 16, 23 and 29. At station 3 it decreases with increasing temperature and the converse holds for station 20. This fact cannot be explained, as in Zanetti et al. by correlations between wind directions and temperature since the pollution roses for stations 3 and 20 are similar. No explanation was found here [5].

Relative Humidity

The relative humidity is measured in per cent, from 0 to 100. No effect of relative humidity on SO2 level was found except at stations 3 and 20 in winter where the SO2 pollution level is lower when the relative humidity is below 45 per cent.

Ceiling Height

The ceiling height is the smallest height from the ground where the total opacity is greater than or equal to 0.6, or it is the vertical visibility under gloomy conditions. It is measured in feet on a scale varying from 0 to 99000 feet and can be unlimited. No effect of ceiling height was found either in winter or in summer.

Station Pressure

It is given in millibars and is situated around 1000. No effect of station pressure on SO2 level was found either in winter or in summer.

SECTION 3: SOME MULTIPLE LINEAR REGRESSION MODELS

In the preceeding section we have found the meteorological variables mostly related to SO2 pollution level among those considered in this study. Their general effects have been briefly indicated. In this section, the interaction between the meteorological variables will be taken into account and for each station we shall try to explain the SO2 level from the smallest possible number of meteorological variables. The contribution of each of them will be evaluated in order to understand its importance in the explanation of SO2 level. If the model so obtained is satisfactory, then it could be used to predict the pollution level from the explaining variables, with an acceptable error.

Methodology

Since the SO2 levels are low during summer, only the winter period is considered in this section. For each station, two regression models have been obtained relating SO2 level with the meteorological variables. Model I is based on the hourly or bi-hourly data whereas Model II is based on daily averages. More data are available for building Model I but on the other hand Model II takes into account a delay in the effect of a meteorological variable. For example, if the wind blows from a pollution source at a given time, its effect on a pollution station may be noticeable only a few hours later. Model II will show the total effects of the meteorological variables during the day. Finally in Model II the dependent variable (SO2 level) can be considered as a continuous variable since it is an average whereas in Model I it takes discrete values. However it will be interesting to discuss both models for each station.

The Regression Models

Following the discussion of section 2, we are looking for a relation of the form

$$Y_i = \alpha_0 + \alpha_1 N_i + \alpha_2 NNE_i + \ldots\ldots + \alpha_{16} NNW_i + \alpha_{17} WIND_i + \alpha_{18} TEMP_i + \alpha_{19} Y_{i-1} + \epsilon_i$$

where

(i) Y_i is the i^{th} measured SO2 level in pphm (for Model I) and the i^{th} daily average (for Model II), and Y_{i-1} is defined similarly.

(ii) $N_i, NNE_i, \ldots, NNW_i$ are the 16 variables associated to the wind directions. In Model I those variables are binary variables and take the value 1 if the wind comes from this direction at that time and 0 otherwise. In Model II they can take the values 1/12, 2/12, . . . , 12/12 for bi-hourly data and the values 1/24, 2/24, . . . , 24/24 for hourly data. For example, the value $N_i = 5/24$ means that for the i^{th} day, the wind was blowing from the North during 5 hours out of 24.

(iii) $WIND_i$ is the wind speed in mph for the i^{th} measure (Model I) and the average wind speed for the i^{th} day (Model II).

(iv) $TEMP_i$ is the temperature in °F for the i^{th} measure (Model I) and the average temperature for the i^{th} day (Model II).

(v) $\alpha_0, \alpha_1, \ldots\ldots, \alpha_{19}$ are unknown parameters to be estimated.

(vi) ϵ_i is a random error associated to Y_i.

The ϵ_i's are assumed to be identically and independently distributed according to a $N(0, \sigma^2)$ distribution and the α_i's are estimated by minimising the sum of squares of the errors. At first step, we used the stepwise multiple regression algorithm with test level 1 per cent (see reference [6] for example) and an analysis of the residuals was made. For every station and for the two models it was found that the variances were unequal and increasing with increasing SO2 levels. It was then decided to proceed as in March and Foster [7] and take the logarithms of the variables, thus supposing that the meteorological variables have a multiplicative effect on the SO2 level. The variables were therefore transformed in the following way: Y_i was replaced by $\ln(Y_i + 1)$. $WIND_i$ by $\ln(WIND_i)$, $TEMP_i$ by $\ln(TEMP_i + 20)$ and Y_{i-1} by $\ln(Y_{i-1})$. Some constants were added to the variables before taking the logarithms to avoid negative or zero values. The algorithm was run again and this time the hypothesis of equal variances was acceptable. However some residuals were at more than three standard deviations away from zero. These residuals clearly correspond to outliers since, if the ϵ_i's are $N(0, \sigma^2)$, this probability is .003 of having an observed residual that far away from its mean. Therefore the data corresponding to these residuals were removed and the algorithm was run until all the residuals where inside three standard deviations from zero. For Model II, the hypothesis of independence was accepted for every station except station 3. For Model I, as expected, it was rejected for every station. Now as stated in Scheffé [8], the inference on the α_i's is sensible to this hypothesis. Therefore the levels of the tests which determine the presence or the absence of a variable in the model are no more 1 per cent but are unknown. Since in this case the stepwise procedure gives the same results as a forward procedure, and since the variables entered in the models have been supported by the empirical study of Section 2, it is felt that those variables which entered the models are really the most important ones, and that there is no redundancy among them. These models, however, cannot take into account a possible redundancy among one variable with a group of wind directions for example. The results are given in Table 3. The order of entry of each variable is given with its coefficient in the model together with the R^2 value obtained after the entry of this variable in the model.

Discussion of Results

Model I—It is seen that for every station the first variable to enter the model is Y_{i-1}. It explains alone almost all of the variability of Y_i since its R^2 value differs from the total R^2 by at most 4 per cent. It is of course not surprising to realize that the SO2 level measured one or two hours ago is strongly related to the present SO2 level.

The wind directions included in the models are, except for station 13, among the most polluting directions and they all have positive coefficients. For

Table 3. Multiple Linear Regression Models I and II for All Stations, Winter.

Station		*Constant*	*Wind*	*Temp*	Y_{i-1}	*Wind Direction*	R^2 *(%)*
3	Model I	0.18			0.82		79
						SW: 0.25	80
						WSW: 0.19	80
						SSW: 0.18	80
	Model II	1.47				WSW: 1.40	35
						SW: 1.60	48
			-0.22				52
						NNW: -2.30	57
						ENE: -1.50	60
					0.17		63
13	Model I	0.62			0.82		74
			-0.04				74
				-0.05			74
						SE: -0.10	74
	Model II	1.78			0.43		34
			-0.28				45
						E: -1.70	50
						NNE: 0.34	54
16	Model I	0.94			0.75		76
			-0.09				76
				-0.11			77
						NNE: 0.16	78
						NE: 0.10	78
						N: 0.11	78
	Model II	2.80			0.34		33
			-0.40				52
						NNE: 0.91	68
				-0.26			74
20	Model I	0.64			0.69		73
						WSW: 0.40	74
						SW: 0.42	75
						W: 0.24	76
						SSW: 0.25	76
				-0.07			77

Table 3. (Cont'd.)

Station		*Constant*	*Wind*	*Temp*	Y_{i-1}	*Wind Direction*	R^2 *(%)*
20		1.74				WSW: 1.38	49
	Model II					SW: 1.71	61
						W: 1.05	72
			-0.17				75
23	Model I	1.00			0.76		77
			-0.10				78
				-0.13			79
						NE: 0.15	79
						NNE: 0.13	79
						N: 0.09	79
	Model II	3.01	-0.43				36
					0.35		62
						NNE: 0.69	71
				- 0.52			75
						WNW:-0.52	77
29	Model I	0.28			0.86		85
			-0.06				85
						ESE: 0.08	85
	Model II	1.96	-0.48				41
						WNW:-0.76	53
						NE: 0.49	59
					0.23		62
						SSE: 0.69	65
						ENE: 0.86	67

station 13 the SE wind direction has a negative coefficient. It is a wind direction for which low SO2 levels were observed during winter. Because of the wide spread of the pollution rose at station 13, one did not expect wind directions with positive coefficients in the model. At stations 13, 16 and 23 we note the presence of temperature and wind speed as explanatory variables. They have negative coefficients meaning that the SO2 level decreases with increasing temperature or increasing wind speed. This was also seen in Section 2. For station 29 the temperature is excluded from the model. We have also observed that fact in Section 2. At station 20, the temperature has a negative coefficient but contributes very little in explaining the SO2 level. This does not contradict the results of Section 2.

Model II–The R^2 values are smaller here than for Model I. This is mainly due to the fact that Y_{i-1} is less explanatory here than in Model I since it corresponds to the average SO2 level of the precedingday. The pollution winds of Model II, those with a positive coefficient, are in general among the polluting winds of Model I or those found in Section 2. However, we find in Model II more wind directions with negative coefficient than in Model I. This probably means that the cleaning effect of some winds takes some time (more than an hour or two but less than a day) before being significant. For stations 3 and 20 the wind speed has a negative coefficient. We observed previously that, in winter, the SO2 level was increasing for polluting winds and decreasing for the non-polluting winds, when the wind speed increased. This could mean that for a whole day the cleaning winds may have a high speed and be frequent enough to have a significant effect in a regression model. This is supported by the frequencies of N, NNE and NE winds in Table 1. For stations 16, 23 and 29, the other explanatory variables are the same as those of Model I.

SECTION 4: PRINCIPAL COMPONENT ANALYSIS: A GLOBAL APPROACH

In the preceding section the relations between the SO2 level and some meteorological variables have been studied separately for every station. In this section a similar study is made globally for the region of Montreal. In order to achieve this, a principal component, analysis is made on the six stations and two components are retained. For each of these two components, which are interpreted as two new stations, a regression model is obtained as previously.

The Principal Component Analysis

We consider vectors of size 6, the components being the daily average SO2 level for the six stations. Excluding those vectors with missing values, 101 such vectors remains for the winter season. Principal component analysis consists in finding a first linear function of the vector components that extracts as much variation as possible from the original data, then finding a second linear function, uncorrelated with the first one, that extracts as much residual variation as possible, and so on; the process is repeated until a reasonable proportion of variation has been extracted from the data, or until the number of linear functions established equals the dimension of the originally-measured vector (in this case, six). The linear functions so obtained are called principal components and must be interpreted in order to make the analysis interesting. The principal component analysis is described in details in Anderson [9].

A principal component analysis has been made using the covariance matrix S and using the correlation matrix R and the interpretation of the results is the same for both cases. We work with S in the sequel. Two principal components are retained which explain 84.5 per cent of the total variation of the system.

These two linear functions will be called respectively station (a) and station (b). Table 4 gives the results of the analysis: the covariance matrix S, the variance of each linear function (the eigenvalues of S), their relative contribution (in %) to the total variation and finally, the coefficients defining the first two principal components. We can consider that these two principal components define conceptual stations which we shall refer to as station (a) and station (b). These two stations are defined by the following equations:

$$ST(a) = 0.51ST^*(3) - 0.16ST^*(13) - 0.31ST^*(16) + 0.70ST^*(20) - 0.32ST^*(23) - 0.14ST^*(29)$$

$$ST(b) = 0.34ST^*(3) + 0.57ST^*(13) + 0.42ST^*(16) + 0.32ST^*(20) + 0.50ST^*(23) + 0.16ST^*(29)$$

where $ST^*(3)$ is the SO2 pollution level at station 3 minus the mean of all these levels at station 3, and similarly for $ST^*(13)$, $ST^*(16)$, $ST^*(20)$, $ST^*(23)$ and $ST^*(29)$. It is seen that station (a) can be interpreted as a conceptual station which opposes the stations with positive coefficients (stations 3 and 20 near the oil-refineries) to those with negative coefficients (stations 13, 16, 23 and 29 in urban areas). Station (b) can be interpreted as a conceptual station which is a weighted average of the six stations.

Regression Models for Stations (a) and (b)

The values associated to station (a) and to station (b) were obtained and as in Section 3, a regression model was built to explain the SO2 pollution level of stations (a) and (b) from the same meteorological variables which were transformed as before. The SO2 level for stations (a) and (b) were transformed as $\ln (Y + 10)$. The stepwise multiple regression algorithm was used with test level of 1 per cent and the results are also shown in Table 4. An analysis of the residuals indicated that their variances can be considered as equal for both stations, that they are independent for station (b) but not for station (a). Therefore the test levels which determine the presence or the absence of a variable in the model for station (a) will no more be 1 per cent but are unknown.

Discussion of the Results

Station (a)—The wind directions are important. The directions WSW, SW and W have positive coefficients and are those which favor pollution at stations 3 and 20. The directions N and NNE have negative coefficients and are those which favor pollution in the urban area. The temperature also has a positive coefficient. Thus, for station (a), a high temperature is associated with a high pollution level, and in relation with the results of Section 2, this is explained as follows: When the temperature is high, pollution is low in the urban area and therefore high at station (a). The temperature has no effect on the pollution

Table 4. Principal Component Analysis on the Six Stations and Regression Models for Stations (a) and (b)

Station	*Covariance Matrix S*					
3	9.12					
13	1.43	8.46				
16	-0.44	4.84	6.36			
20	8.53	1.04	-1.91	12.93		
23	-0.16	5.30	5.65	-1.48	7.98	
29	-0.09	1.58	2.17	-1.09	2.50	2.15
Station	3	13	16	20	23	29

Principal Component	*1*	*2*	*3*	*4*	*5*	*6*
Variance	20.7	18.6	3.1	2.1	1.4	1.1
Contribution (%)	44.0	39.5	6.7	4.5	2.9	2.3

Station	*First Component Station (A)*	*Second Component Station (B)*
3	0.51	0.34
13	-0.16	0.57
16	-0.31	0.42
20	0.70	0.32
23	-0.32	0.50
29	-0.14	0.16

Regression Models	*Constant*	*Wind*	*Temp*	Y_{i-1}	*Wind Direction*	R^2 *(%)*
Station (a)	1.18		0.22		WSW: 1.07 N: -1.40 SW: 1.09 W: 0.67 NNE: -0.39	80
Station (b)	2.25	-0.28		0.36	NW: -1.74 SE: -1.68 ENE: -1.07	58

level at stations 3 and 20. In summary, the regression model of station (a) points out two sources of pollution in the region of Montreal: the oil-refineries for all stations and heating for the urban area.

Station (b)–Here the R^2 value is only 58 per cent. Station (b) is a weighted average of the six stations and can be considered as a global representation of the pollution situation in the region. The meteorological variables which enter the model for station (b) can be considered as having a global effect on the SO2 level. The model includes the average level of the preceding day; the wind directions which are present in the model are those which have a cleaning effect for almost all stations and the wind speed has a negative coefficient emphasizing the cleaning effect of wind of those directions selected. That is the global effect of the selected meteorological variables in the region of Montreal for a daily period.

SECTION 5: CONCLUSION

It was found that the wind direction, the wind speed, the temperature and the SO2 level at the preceding period are important in explaining the actual SO2 level. In comparing the two regression models obtained at a given station we found that some meteorological factors may have a delayed effect on the SO2 level. This raises the problem of choosing the period with respect to which such regression models should be built. It is not clear whether the hourly or bi-hourly data or the daily averages are the optimal SO2 levels to use in such models.

In a more global analysis it was found that some meteorological variables have an important effect on the region of Montreal as a whole. The wind directions WSW, SW and W will increase the SO2 level near the refineries whereas the directions N and NNE will do the same for the urban area (excluding station 29). A decrease in the temperature will increase the SO2 level in the urban area. More generally and less significantly we can say that an increase in wind speed in the directions NW, SE and ENE will reduce the SO2 pollution level in the area.

Some important factors were neglected in this paper and should be considered in future studies. Turner [10], Marsh and Foster [7] and Zanetti, Melli and Runca [5], all found that the stability of the atmosphere is favorable to high pollution levels. No data were available here on the stability of the atmosphere. Marsh and Foster claimed that the heights of pollution sources is an important factor [7]. We did not consider it here. Some questions may also be raised about the fact that the meteorological variables were measured at Dorval, located 10 kilometers away from downtown Montreal. Finally, it should be interesting in future studies, to group some wind directions together and look for possible correlations between other meteorological factors and such groups.

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