Atmospheric Environment Pergamon Press 1969. Vol. 3, pp. 455–460. Printed in Great Britain.

ON THE RELATION BETWEEN CHANGING METEOROLOGICAL CIRCUMSTANCES AND THE DECREASE OF THE SULPHUR DIOXIDE CONCENTRATION AROUND ROTTERDAM

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(*First received* 11 *November* 1968 *and in final form* 12 *December* 1968)

Abstract—Due to the ever growing anxiety about the effects of air pollution on the health of the inhabitants of industrialized regions, every decrease of the average concentration of a pollutant such as SO_2 is welcomed, by the authorities as well as by the public. In various cases such a decrease may be attributed to improved methods to reduce the escape of noxious gases but sometimes meteorological circumstances play an important role. During the last six winters there was an almost continuous decrease of the SO_2 content of the air in the region of Rotterdam. Although an improvement of some industrial processes may have helped to bring about this decrease, it can be shown that meteorological circumstances contributed significantly.

1. THE SO_2 CONTENT IN THE REGION WEST OF ROTTERDAM DURING THE LAST SIX WINTERS

THE SO_2 content of the air has been measured daily at a number of stations in the industrial area along the Waterway connecting Rotterdam with the North Sea. Measurements made at seven of these stations were available during the period 1962 to 1968 and the contamination of the atmosphere as determined from the observations made at these stations has been considered for the six winter periods 1962–63, . . . 1967–68. A winter is defined as the period October–March inclusive. A comparison of the six winters shows that the average concentration of SO_2 decreased monotonically during the 6 years that have been considered.

TABLE 1 shows this result as well as the number of days on which the average value of the SO_2 concentration in the seven stations surpassed specified values.

TABLE 1. MEAN SO_2 CONCENTRATION AND NO. OF DAYS WITH CONCENTRATION ABOVE SPECIFIED LEVELS IN THE SIX WINTERS 1962–63 TO 1967–68

Winter	Mean value (S) (μg/m^3)	>200 μg/m^3	>300	>400	>500
1962–63	261	120	49	19	8
1963–64	258	128	53	14	4
1964–65	229	103	27	6	2
1965–66	216	102	25	4	0
1966–67	203	88	14	4	0
1967–68	183	65	8	2	0

2. METEOROLOGICAL CIRCUMSTANCES DURING THE LAST SIX WINTERS

It has been shown in a number of publications that in large areas with many sources atmospheric stability and low windspeeds as a rule tend to increase the concentration of pollutants (e.g. SCHMIDT, 1964; VELDS, 1969). The effect of precipitation is to diminish the concentrations, primarily when the pollutants are particulate but to a lesser extent also in the case of gaseous pollution. If we want to judge the decrease of the SO_2 concentrations, observed in the Waterway region and especially if we want to answer the question whether measures of the industry are the cause of the decrease we will have to look into the effect of weather conditions first.

In order to do so we have chosen the windspeed, the circulation type considered to give an indication of the stability conditions, and the amount of precipitation as the most important meteorological parameters. For windspeed the average value at Flushing* has been taken. Although this station is situated at about 75 km to the SW, it is thought that windspeeds at this station are reasonably representative for the

TABLE 2. MEAN VALUES OF PRECIPITATION WINDSPEED AND TEMPERATURE AND FREQUENCY OF ADVERSE CIRCULATION TYPES IN THE SIX WINTERS 1962–63 TO 1967–68

Winter	Number of days with HM	HNa	Sz	Total C	Mean six-monthly precipitation (mm) R	Mean wind speed (m/s) F	Mean temp. (°C) T
1962–63	32	10	13	55	304	4·95	2·18
1963–64	35	13	3	51	269	5·10	4·48
1964–65	13	7	2	22	472	5·57	4·86
1965–66	26	3	0	29	492	6·47	4·91
1966–67	9	0	2	11	498	6·73	6·65
1967–68	8	0	0	8	468	6·80	5·75

Waterway region. With respect to the circulation type the number of days during which a high pressure over Central Europe (HM), a high pressure over the northern part of the Atlantic (HNa) or a cyclonic southerly current over Western Europe (Sz) occurred have been taken as the relevant parameter. The choice was based on the results of an investigation by VELDS (1969), who showed that the above mentioned circulation types are associated with high SO_2 concentrations.

Precipitation tends to show rather big variations from one station to the other. Therefore, the mean of four stations situated in or near the region, Poortugaal, Keilehaven, Bergse Hoek, Rotterdam filiaal has been used.

There is still another meteorological parameter that could be used, notably air temperature as high winter temperatures may lead to a reduction of heating activities. The temperatures of Rotterdam Airport have been used.

TABLE 2 shows the values of the various meteorological parameters for the six winter seasons.

FIGURE 1 shows the values of the mean SO_2 concentration (S), the number of days

* Vlissingen.

in which the average SO_2 concentration surpassed 300 $\mu g/m^3$ (N_{300}), the number of days with HM, HNa or Sz (C), the precipitation (R), the temperature (T) and the wind speed (F).

The decrease of the unfavourable circulation types in the course of the six winters is striking. According to CAPPEL (1957) the occurrence of the various circulation types

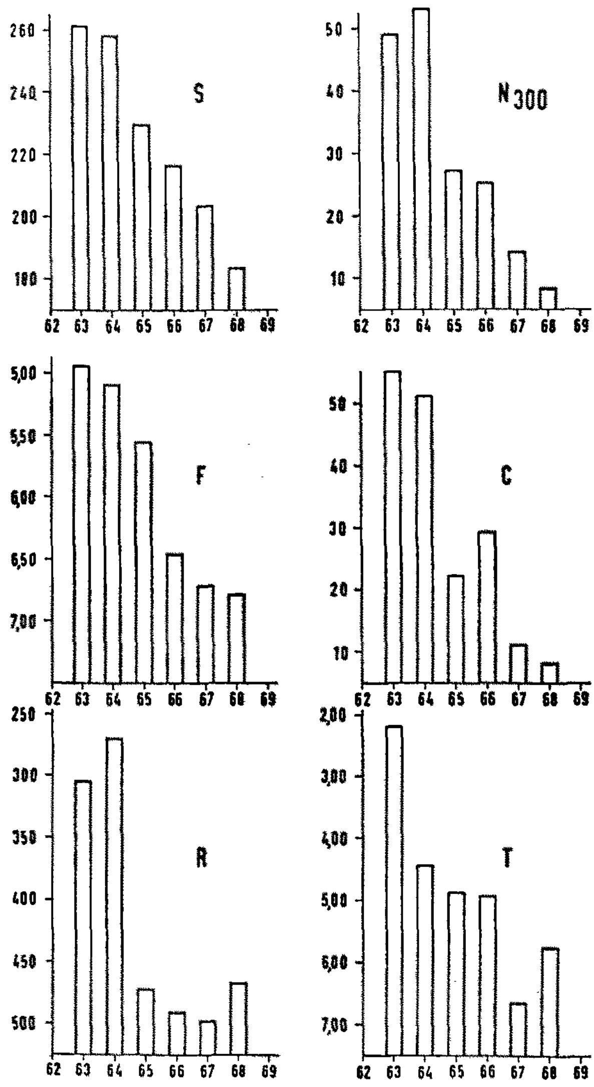

FIG. 1

is related to the phase of the sunspot cycle. LAWRENCE (1966) found that smoke pollution peaks in London occur on average about two years before a minimum in the sunspot cycle, due to the fact that there is at that time a tendency for a relative increase in the development of cold anticyclones. As an average Cappel found e.g. that situations with high pressure over Central Europe (HM) show a maximum frequency two years before a sunspot minimum and during the maximum and the year thereafter. The minimum frequency occurs during the sunspot minimum and 3 to 4 years after the maximum. The other two circulation types that are of importance for this study do not behave in the same way so that it is not possible to relate the decrease of the relevant circulation types given in TABLE 2 in a simple way with Cappel's results. It is almost certain, however, that the decrease since 1962 of the frequency of the unfavourable circulation types will come to an end and high frequencies may occur again in the near future.

The same holds true for the change observed in the other meteorological parameters. Besides these are correlated with the total occurrence of the three circulation types. The correlation coefficient (r) for C with R is designated r (CR), etc. The values obtained were:

$r(CR) = -0{\cdot}748$; $r(CF) = -0{\cdot}753$; $r(CT) = -0{\cdot}719$. The other correlations are: $r(RF) = 0{\cdot}862$; $r(RT) = 0{\cdot}718$; $r(FT) = 0{\cdot}835$. The 5 per cent level of significance lies at 0·729, so that only precipitation and windspeed are significantly correlated with C.

3. THE RELATION BETWEEN THE AVERAGE SO_2 CONCENTRATION (S) AND THE METEOROLOGICAL PARAMETERS C, R, F AND T

From the fact that at least three of the meteorological parameters are correlated it follows that partial regression coefficients must be determined between S and these meteorological parameters. In order to avoid the regression becoming too complicated we first try to compare the influence of the four meteorological parameters separately by applying Kendall's rank correlation method (KENDALL, 1948). The result of the calculation of his correlation coefficient τ, for the two rankings S and C given as τ (SC) etc. is:

$\tau(SC) = 0{\cdot}867$; $\tau(SR) = -0{\cdot}467$; $\tau(SF) = -1{\cdot}000$; $\tau(ST) = -0{\cdot}867$

As the 5 per cent level of significance for six pairs is 0·733 it appears that the SO_2 content of the air is significantly correlated with circulation type, temperature and wind speed.

In deriving a regression equation which is to describe the combined effect of various meteorological factors we will omit the circulation type directly as it seems to be preferable to consider only parameters of which average values are available. We will therefore only consider as relevant meteorological parameters R, being a measure for the amount of precipitation, F, a measure for the intensity of dynamic turbulence and finally T, which may be related to a certain extent with the SO_2 production. TABLE 3 gives the correlation coefficients that determine the regression between S and R, T and F. The total correlation coefficient between S and R is denoted by $r(SR)$, the partial correlation coefficient between S and R when the temperature effect has been removed is given by $r(SR, T)$ and the partial correlation coefficient between S and R when temperature and wind speed effects are eliminated is given by $r\,(SR, TF)$.

Obviously the effect of temperature as well as that of precipitation is very small. Wind force is the most important factor determining the concentration of SO_2. The regression equation becomes:

$S_c = 440{\cdot}84 - 0{\cdot}352\,T - 0{\cdot}0106\,R - 35{\cdot}61\,F$. It results in computed values S_c for the six winter seasons of respectively:

262; 258; 239; 207; 197 and 196 $\mu g/m^3$.

The multiple correlation coefficient $R(S,FRT)$ is 0·96, this means that 92 per cent of the

TABLE 3. TOTAL AND PARTIAL CORRELATION COEFFICIENTS BETWEEN SO_2 CONC., RAINFALL, WINDSPEED AND TEMPERATURE

$r(SR) = -0.846$	$r(ST,R) = -0.534$
$r(ST) = -0.805$	$r(SF,R) = -0.896$
$r(SF) = -0.971$	$r(TF,R) = +0.612$
$r(RT) = +0.718$	$r(SF,T) = -0.916$
$r(RF) = +0.862$	$r(SR,T) = -0.649$
$r(TF) = +0.835$	$r(FR,T) = +0.685$
5% sign. level 0·811	5% sign. level 0·878
$r(SR,TF) = -0.075$	
$r(ST,FR) = -0.040$	
$r(SF,RT) = -0.848$	
5% sign. level 0·950	

total variance in the SO_2 concentrations might be attributed to meteorological factors.

4. THE OCCURRENCE OF HIGH CONCENTRATIONS

The number of days with SO_2 concentrations above certain specified values, given in TABLE 1, is thought to be connected with the number of unfavourable situations and not with mean values of precipitation, windspeed or temperature. The number of days with mean SO_2 concentrations above 200, 300, 400 and 500 $\mu g/m^3$ (N_{200}, N_{300}, N_{400} and N_{500}) have for that reason been correlated directly with C.

The result is given in TABLE 4.

TABLE 4. CORRELATION COEFFICIENTS BETWEEN CIRCULATION TYPE AND NO. OF DAYS A GIVEN CONC. WAS EXCEEDED

$r(N_{200},C) = 0.765$
$r(N_{300},C) = 0.816$
$r(N_{400},C) = 0.782$
$r(N_{500},C) = 0.770$
5% sign. level is 0·729

All four correlations are significant to the 5 per cent level, but as a matter of fact the four correlation coefficients are not mutually independant, as e.g. N_{500} is included in N_{400}, N_{300} and N_{200}. It appears sufficient, therefore, to state that N_{300} is significantly correlated with the number of days on which one of the unfavourable circulation types occur.

5. CONCLUSIONS

The foregoing analysis makes it clear that the gradual decrease of the SO_2 concentration in the industrial area in Rotterdam can almost completely be explained as a consequence of meteorological circumstances. Obviously, these circumstances improved during the successive winter seasons from October 1962 to March 1968.

The frequency of unfavourable circulation types decreased, whereas the average windspeed, the amount of precipitation, as well as the average temperature increased.

The number of days with high SO_2 concentrations is clearly related with the number of days with unfavourable circulation types. The present result does not prove, however, that the production of SO_2 has not been reduced in some cases. Industrialisation having been intensified during the considered period it is not improbable that, relatively speaking, the SO_2 production decreased in fact. A further relative decrease may be expected from the increasing use of gas instead of other fuels containing sulphur.

Account must be taken, however, of the fact that meteorological circumstances may become more unfavourable again in the next years. Such a meteorological deterioration will inevitably result in an increase of the concentration of pollution.

Acknowledgements—The authors would like to thank the Director in Chief of the Royal Netherlands Meteorological Institute, Dr. M. W. F. Schregardus, for his permission to undertake this study; Drs. J. Wieringa for his critical reading of the manuscript and Dr. P. J. Rijkoort for his statistical advice.

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