RESULTS OF OZONE MEASUREMENTS IN NORTHERN GERMANY – A CASE STUDY –

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ABSTRACT

At most of the German ozone recording stations which have records over a sufficiently long period, the results of the summer months 1989 showed the highest values since the beginning of the measurements. One of the reasons for this phenomenon was the high duration of sunshine in that summer; for example, in Potsdam near Berlin in May 1989 the sunshine duration was the highest in May since the beginning of the records in 1893. For that reason we selected this summer for a case study.

The basis for the study was mainly the ozone measuring stations of the network of Lower Saxony and the Federal Office of Environment (Umweltbundesamt). The results of these summer measurements point to intense sources of ozone, probably in form of gaseous precursors, in the Middle German industrial areas near Leipzig and Halle and in Northwestern Czechoslovakia, with coal-mining, chemical and petrochemical industries, coking plants and others. The maps of average ozone concentrations, number of days with high ozone maxima, ozone-windroses of the stations etc., suggest that these areas could be a main source of precursors and of photochemical ozone production in summer smog episodes in Central Europe.

Stations on the North Sea coast, at which early ozone measurements were made by our institute in 1973/74 are compared with similarly located stations of the Lower Saxon network in 1989 and the results show a reversal of the ozone-windroses. In 1973/74, the highest ozone concentrations were correlated with wind directions from the sea while in 1989 these concentrations were correlated with directions from the continent. In the recent years, photochemical ozone production on the continent is probably predominant, while in former years the higher ozone content of the maritime subpolar air masses has been explained by stratospheric-tropospheric exchange.

1. INTRODUCTION

Figure 1 shows the summer ozone concentration averages (May–August) of some stations in Germany with

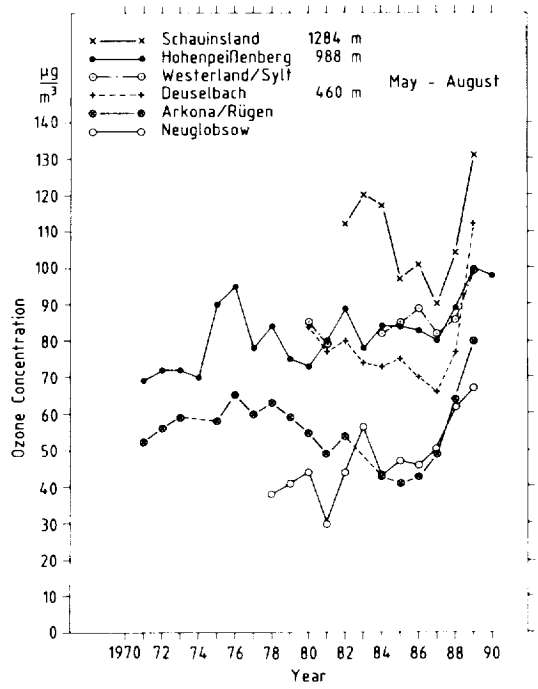

Fig. 1 Average ozone concentrations in the summer months May–August of 6 German stations, 1971–1989

longest duration of records; the longest series are at Arkona on the coast of the Baltic Sea (since 1956) and at Hohenpeißenberg in southern Germany (since 1971) [e.g. Low et al., 1990]. The geographical positions of these stations, and others considered in this paper, are plotted in Fig. 2. The most striking features in Fig. 1 are the very high O_3 values in the summer of 1989, at all stations without exception. These are the highest average concentrations since beginning of the records. The 1989 summer in Germany was dry and the recorded sunshine durations and global radiations were far above normal (up to 120–140% sunshine duration). If we consider sufficient concentrations of gaseous precursors, NO_x, CO, CH_4 and non-methane hydrocarbons (NMHC), an increased photochemical produc-

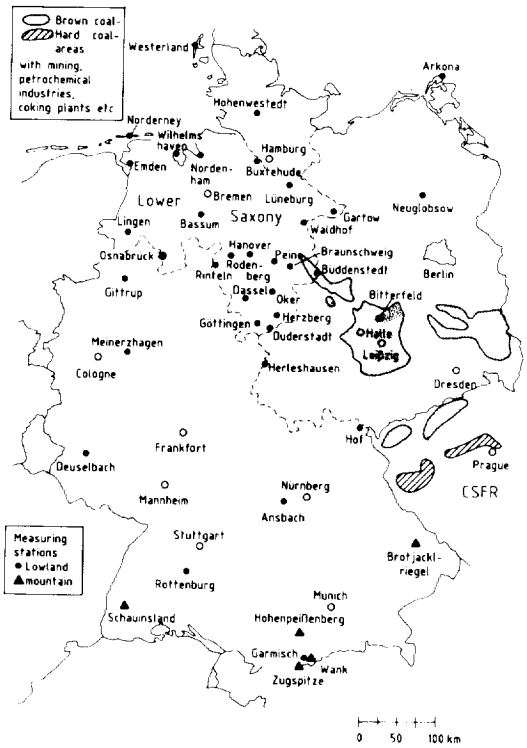

Fig. 2 Map of Germany with relevant ozone measuring stations, and the location of important industrial areas. Stations in Lower Saxony are considered especially

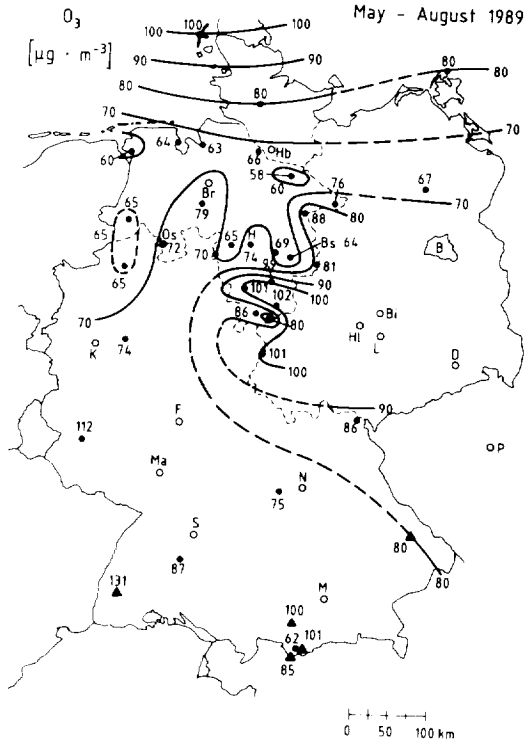

Fig. 3 Average ozone concentrations May–August 1989 of the stations in Fig. 2

tion of ozone during these enhanced radiation conditions with simultaneously increased UV radiation is to be expected [Schmidt, 1989]. A further reason for choosing the 1989 summer months for a case study was the unusually high ozone concentration at all stations in the southern part of Lower Saxony, the district which contains the city of Göttingen and the location of our institute. This is the main point of discussion in this paper.

We have, therefore, concentrated on air quality measurement data from the 17 stations in the Federal State Lower Saxony, in addition to the 15 stations of the Federal Office of Environment, and the two WMO Background Air Pollution Monitoring stations of the former GDR (names and positions in Fig. 2). Wind direction measurements have been taken from suitable stations of the German Weather Service.

2. RESULTS

In Fig. 3, we have plotted the average ozone concentrations for May–August 1989 from all stations mentioned and indicated in Fig. 2. To a careful first approximation, we have also included isolines. Unexpectedly, "a priori", the highest ozone concentrations > 100 $\mu g/m^3$ appeared in districts north and southeast of Göttingen, > 90 and > 80 $\mu g/m^3$ in the adjacent regions, all situated near the border to the former GDR. Similar high concentrations were

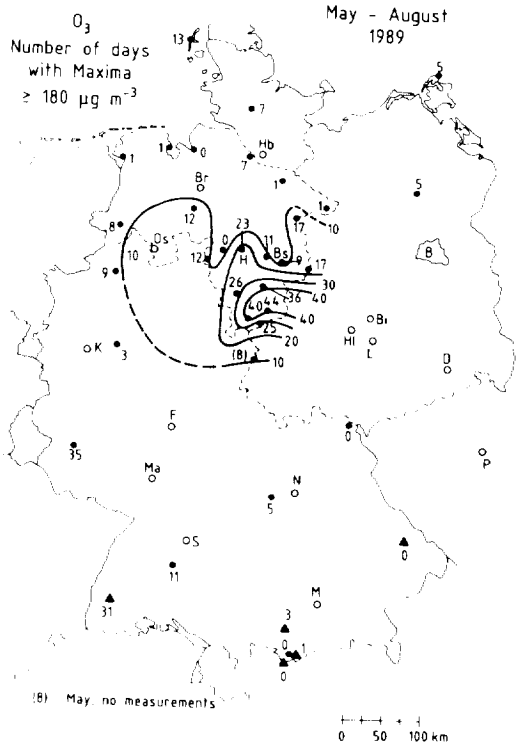

Fig. 4 Number of days with ozone maxima ≥ 180 $\mu g/m^3$ in May–August 1989. Ozone stations of Fig. 2

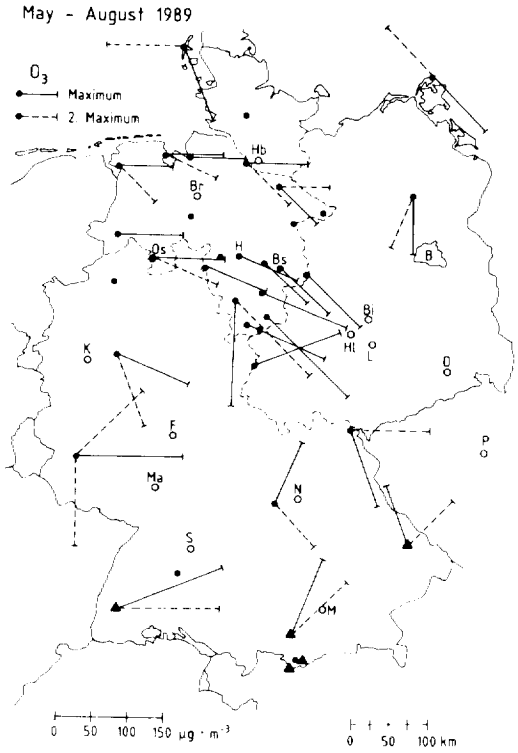

Fig. 5 Direction and amount of maximum and 2nd maximum of the ozone-windroses, epoch May–August 1989

found in the northernmost parts of Germany, at and near the North Sea and the Baltic Sea coasts, and again at elevated places in Southern Germany. The highest average concentration of 130 $\mu g/m^3$ was measured at the peak of Schauinsland in the Black Forest, 1284 m a.s.l. At this mountain station, the O_3 concentrations are normally the highest of all stations, also during other periods – months and seasons –, a fact, which should be investigated further on. Very surprising and impressive are supporting results, shown in Fig. 4, the number of days with O_3 maxima > 180 $\mu g/m^3$ at the stations considered. This value is an upper limit during summer smog episodes, from which the authorities disseminate warnings to patients and persons with diseases affected by high ozone concentrations and other poisonous substances in the photochemical smog. In the southeastern part of Lower Saxony and probably to the east we find the highest number of such days, more than 20 to 40, in the summer of 1989. Similar high values, 31 and 35 days, appeared at two further stations, Schauinsland (1284 m) and Deuselbach (460 m a.s.l.), the latter probably influenced by two other industrial centers (Fig. 5 and section 3).

In Fig. 5, we have plotted the directions and amounts of the maximum and 2nd maximum of the ozone windroses of nearly all of the stations. These ozone-wind vectors are the key to an explanation of the results in Figs. 3 and 4.

3. DISCUSSIONS

The results given in Figs. 3, 4 and 5, notably in Fig. 4, suggest that the sources of these unusually high ozone concentrations may be in the strongly polluted industrial areas of the former GDR, in the district Halle–Leipzig–Bitterfeld (at the time of these measurements, 1989, HL, L, Bi in Figs. 3–5). Nearly all maximum ozone-wind vectors of nearby stations in Fig. 5 point in this direction. Similar strongly polluted industrial areas are also located in the northwestern part of CSFR (Fig. 2), indicated by an extension of the vectors above. Even the vectors of the station Brotjacklriegel in the Bavarian Forest and one vector of the station Hof point in this direction.

The industrial areas just mentioned are, admittedly, the highest polluted areas in Central Europe, particularly with regard to the SO_2 emission. One of the reasons for this is the almost exclusive use of the pit-browncoal for energy production, raw material for chemical and petrochemical industries and for coke production. The most important chemical factories of the former GDR are located in the district Halle–Bitterfeld. One of these factories was the largest factory of all kinds in the GDR. These factories mainly produced fuels of all kinds, acids, nitrogen fertilizers, technical gases, chemicals, medicaments and plastics. One of these factories was the greatest producer of calcium carbide CaC_2 in Europe, made from brown coal and lime, with water transformed into acetylene C_2H_2, and finally used as a basic substance via other NMHC's for the production of plastics. From extended artificial mud pools containing the remaining $Ca(OH)_2$, large amounts of residual C_2H_2 must surely have escaped into the atmosphere, to be converted there into further NMHC's. Sources of precursors are to be expected from parts of the gas, escaping from coking plants operated there. Coke-oven gas mainly contains tar vapour, H_2, CH_4, NMHC's, N_2, CO, CO_2 and others, most of them being precursors for photochemical O_3 production. Unfortunately, no direct measurements of trace gases including ozone are available from these areas before the time of unification of the German states. Our results are supported by some other observations. Kourtidis [1991] published results of PAN measurements, made in the spring of 1989 at our institute in Katlenburg-Lindau near Göttingen. His PAN windroses point with the maxima in the same directions, East to South, like our windrose vectors in Fig. 5. In the 3 summers prior to 1989, 1986 – 1988, the numbers of half-hour averages of O_3 concentrations > 120 $\mu g/m^3$ and > 180 $\mu g/m^3$ were highest at the two Lower Saxon stations Dassel and Oker, compared with 4 further stations in the North, Hanover, Braunschweig, Wilhelmshaven and Emden. All stations attained maxima in 1989. Even the annual O_3 means of Dassel and Oker in the years 1986–1988 show higher values than those of Hanover and Emden. In these years, the number of stations was still reduced.

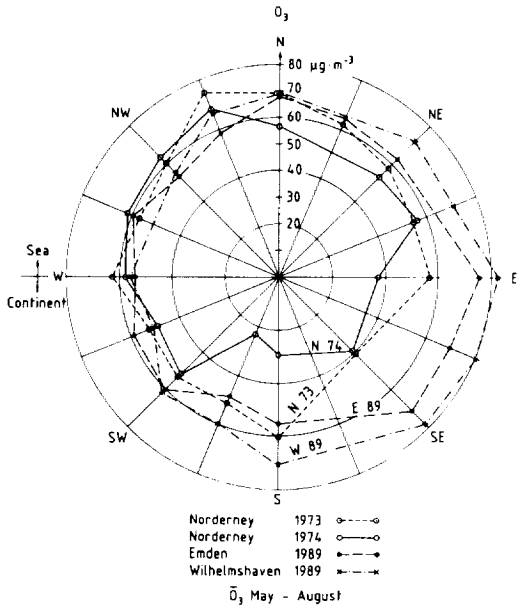

Fig. 6 Ozone-windroses May–August of 3 nearby located stations at the German coast of North Sea; Norderney 1973 and 1974, (N73, N74), Emden (E89) and Wilhelmshaven 1989 (W89). Locations see Fig. 2. Sunshine duration: 942 (N73), 973 (N74), 949 (E89) and 951 (W89) hours

The maximum ozone vectors in Fig. 5 of station Deuselbach, with similar high values in Figs. 3 and 4, point in directions where the chemical industries in the area Mannheim–Ludwigshafen–Frankfort are located and, furthermore to the South, in the direction of the coal mining and coal manufacturing districts in the Federal State of Saar. The vector of Schauinsland, mentioned in section 2, point to the densely populated area of Stuttgart, the vectors of Hohenpeißenberg to the similarly populated district of Munich [like Wege and Vandersee, 1991]. In the northermost part of Germany, the ozone concentrations in Fig. 3 increase towards the North, up to 100 $\mu g/m^3$ at station Westerland. The vectors of the 2nd ozone maximum in Fig. 5 point to the West in Westerland and to the Northwest in Arkona. These facts suggest that the ozone concentrations at such rural stations near the Middle European sea shores are, at least partially, composed of ozone, transported by subpolar air masses and coming from stratospheric-tropospheric exchange processes, if the wind is blowing from the North towards the stations. This also should be the subject of further investigation.

An interesting result, regarding this question, is plotted in Fig. 6. During project "Tropospheric Ozone" in the seventies [e.g. Schmidt, 1981], our institute operated an ozone measuring station at Norderney, in the same coastal area as the stations Emden and Wilhelmshaven of the recent Lower Saxon network (Fig. 2). At station Norderney increased ozone concentrations were found in all seasons during wind directions from the Southwest via North to the Northeast, i.e. from the North Sea and Baltic Sea, and decreased concentrations from all other directions, i.e. from the European continent. Fig. 6 shows two examples in the summers of 1973 and 1974 (N73,74). On the other hand, the nearby located stations Emden (E89) and Wilhelmshaven (W89) show the highest O_3 concentrations 15 years later in the summer of 1989 during wind directions from the continent, with slightly lower concentrations when the wind was from the North Sea, W to NNW. The total sunshine durations during each of these 3 summers were nearly the same, as indicated in Fig. 6 below. An explanation of these contrary results could be that, in recent years, the photochemical ozone production on the European continent was predominant, especially in the summer months, and caused by a distinct increase of anthropogenic gaseous precursors; this is also suggested by measurements. In former years, the higher ozone content of the subpolar air masses correlated with wind directions from the northern sector; this was explained by stratospheric-tropospheric exchange and demonstrated in a series of papers [e.g. Fabian and Pruchniewicz, 1977; Schmidt and Fabian, 1980].

4. CONCLUSIONS

The assumption is justified, the industrial areas in Eastern Germany and CSFR have been important sources of precursor gases for the ozone production in summers such as 1989 with its relatively strong UV radiation. Since some of these factories are now obsolete and have since been closed (for renewal), further investigations of ozone during sunny summers in the future should consider, whether or not the ozone concentrations will now decrease in these locations.

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