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THE EVOLUTION OF SYNOPTIC OZONE ANOMALIES DURING THE EUROPEAN ARCTIC STRATOSPHERIC OZONE EXPERIMENT IN WINTER 1991/92

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ABSTRACT

The evolution of ozone anomalies over the middle and high latitudes of the Northern Hemisphere during the winter 1991-1992 is studied in this work. The largest monthly mean negative deviations in the middle latitudes of the Northern Hemisphere were about 10% in November and December, and up to 20% in January, February and March over Eurasian territories, and much smaller over the Canadian sector. At the end of January, on individual days, total ozone values of 190-210 D.U. were observed over Eastern Europe and European part of Russia, that is 40-45% below normal. On the whole, the 1991-1992 winter was one of the most anomalous over all the period of ozone observations. Finally, an attempt is made to quantify the contribution of transport in the ozone layer changes over Europe during this period.

1. DATA SET

In support of the European Arctic Stratospheric Ozone Experiment (EASOE) the Laboratory of Atmospheric Physics (LAP) in Thessaloniki, in collaboration with the Central Aerological Observatory (CAO) in Moscow, served as a WMO provisional ozone data collection Center to prepare and distribute daily maps of the total ozone field based on all Global Ozone Observing System (GO3OS) ground based observations.

2. TOTAL OZONE FIELD ANALYSIS

Ozone distribution in the Earth's atmosphere varies according to the season, latitude and longitude. Therefore, any ozone anomalies can be detected by comparison of total ozone values with the climatic norms, established for a given time of the year and location. For the total ozone field, such norms are provided by the empirical model of the total ozone field developed in CAO (Fioletov, 1987).

This model is based on data from the ground based network for the period 1974-1984, and allows the estimation of the long-term mean value for any day of the year at any point of the Northern Hemisphere, as well as the standard deviations from the means. The model uncertainty over the regions covered by total ozone stations is not higher than 3-4%. Thus, allowing also for the instrumental errors, the overall uncertainty of total ozone deviations from the climatic norms cannot be higher than 5%.

Finally, only the stations with at least 12 days of observations within a month were used for the analysis of the monthly mean ozone fields.

3. GENERAL CHARACTERISTICS OF TOTAL OZONE FIELD

Generally, in the period from November 1991 through March 1992 low total ozone values predominated over Eurasia. During the whole period total ozone monthly mean values to the north of 45°N were lower than the climatic norm with the exception of the Far East and Canadian sectors. However, since February 1992 total ozone values at these regions were also below normal. The largest ozone anomalies were observed between 50°N and 60°N, though they appeared at various longitudes in different months. As a representative example, in Figure 1 the maps of the total ozone deviations (in percent) from the climatic

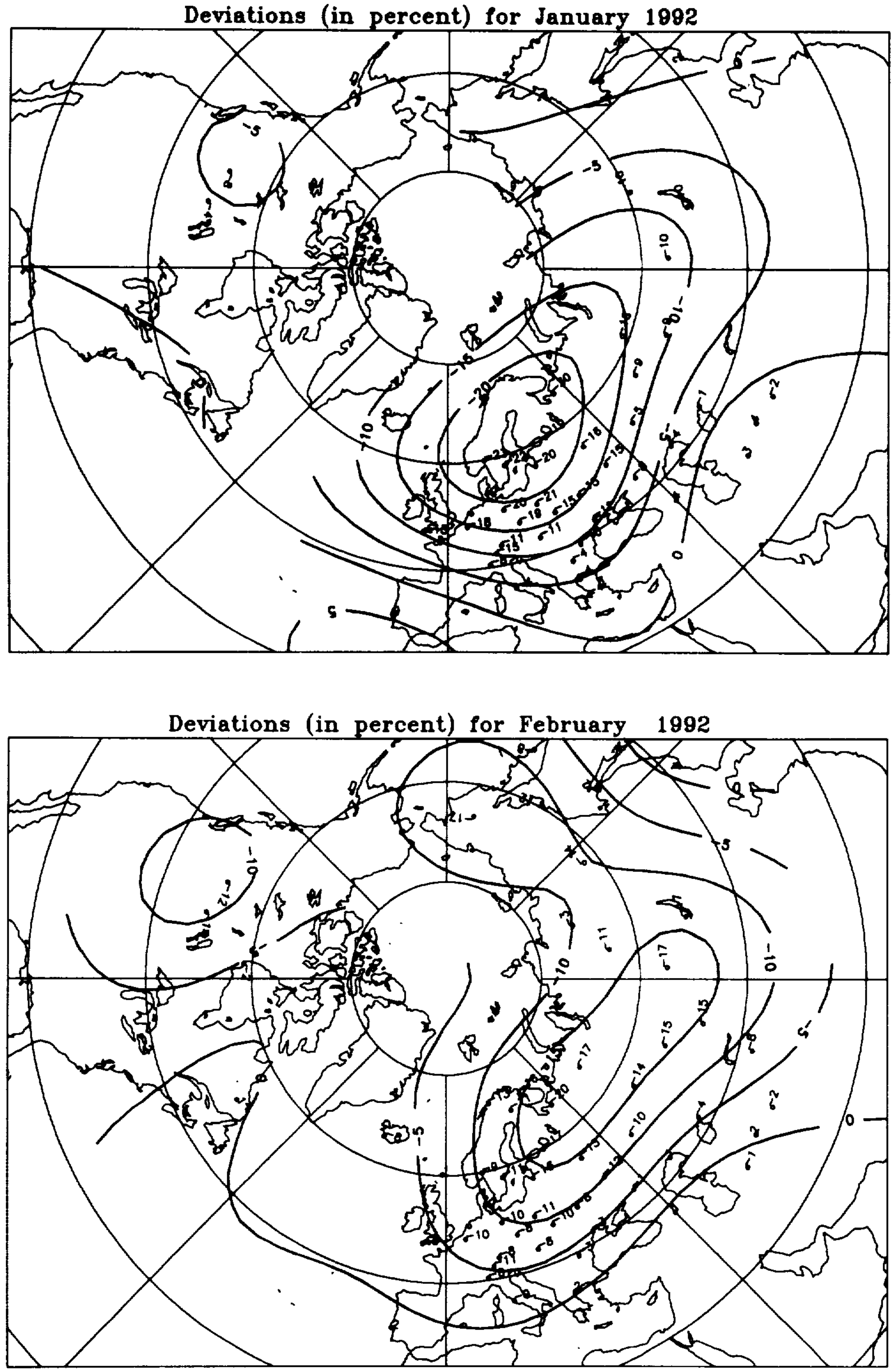

Fig. 1. Maps of total ozone deviation from the climatic norms in percent for January (upper) 1992 and February 1992 (lower part).

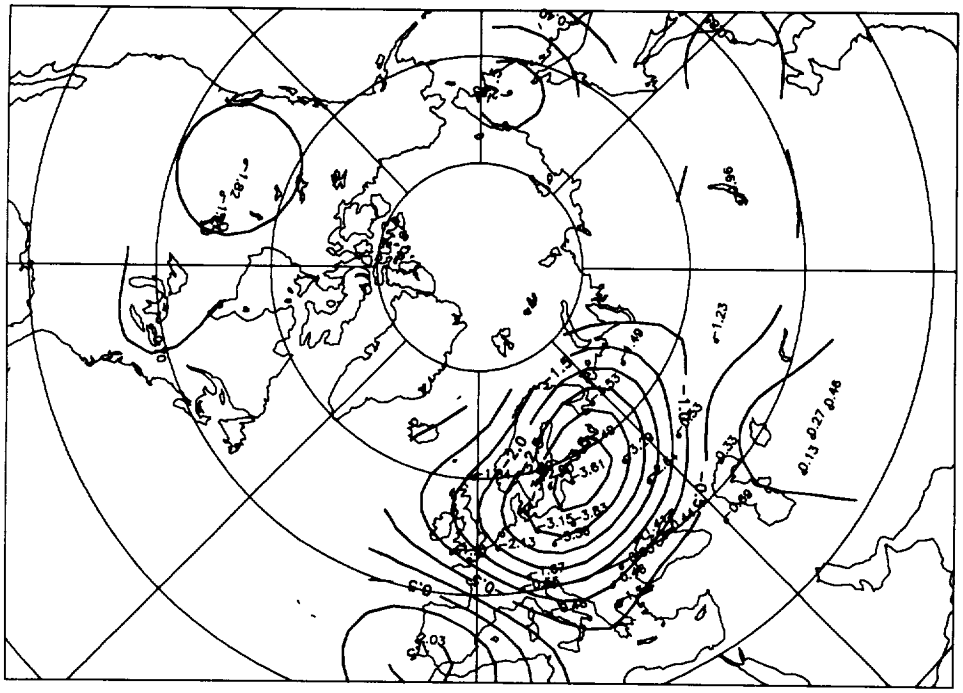

Fig. 2. Map of total ozone deviation from the climatic norms in units of standard deviation for January 28, 1992.

norms for January (upper) and February (lower) 1992 are shown.

In November 1991 the deviations over Canada, Northern Europe and Western Siberia were below normal (5-10%), while over Central Europe the total ozone field was close to the climatic norm. Since December 1991 the deviations from the climatic norms over the Northern, Central and Eastern Europe have become stronger, reaching -20% in January. The total ozone decrease was apparently continuing up to the end of January, and only in February a tendency for recovery was observed. However, both in February and March the total ozone values were still below normal, 5-10% over Northern and Central Europe and 10-15% over Western Canada. In February and March the region of the largest total ozone anomalies appeared eastward. As a result, in 1992 the Far East ozone maximum was significantly weaker than usual, and the highest total ozone values in this region were observed in January, rather than in March. Finally, over Middle Asia the total ozone field was near to the climatic norms throughout the whole period (November 1991- March 1992).

It is much more difficult to judge the state of the ozone layer over the Arctic, because of both the sparse network in this region and the complicated conditions of observations. The data analysis of the Heiss Island, Dixon and Spitsbergen stations shows that the decrease in this region was not as strong as in the 50°N to 60°N region. The total ozone values in January were close to the values estimated by the empirical model and similar to the observations obtained in this region during the previous years.

Periods of low total ozone values at the middle and high Northern Hemisphere latitudes in the winter time were observed in the 1960's, 1983, 1985, 1989 and 1990, but the 1992 winter is one of the most unusual because of the duration of the period with low ozone and the magnitude of the deviations.

4. ANOMALIES IN THE TOTAL OZONE FIELD

Against the background of the general total ozone decrease, several cases of particularly low values were observed in the 1991-1992 winter. On January 28 the absolute total ozone minimum of the whole, more than 20 years long, period of observations occurred at a number of European stations (Riga, Hradec Kralove, Belsk, St. Petersburg). Total ozone reached the value of 200 D.U., that is 40-45% below the climatic norms, and for this day the ozone departures exceeded 3.5 standard deviations. Fig-

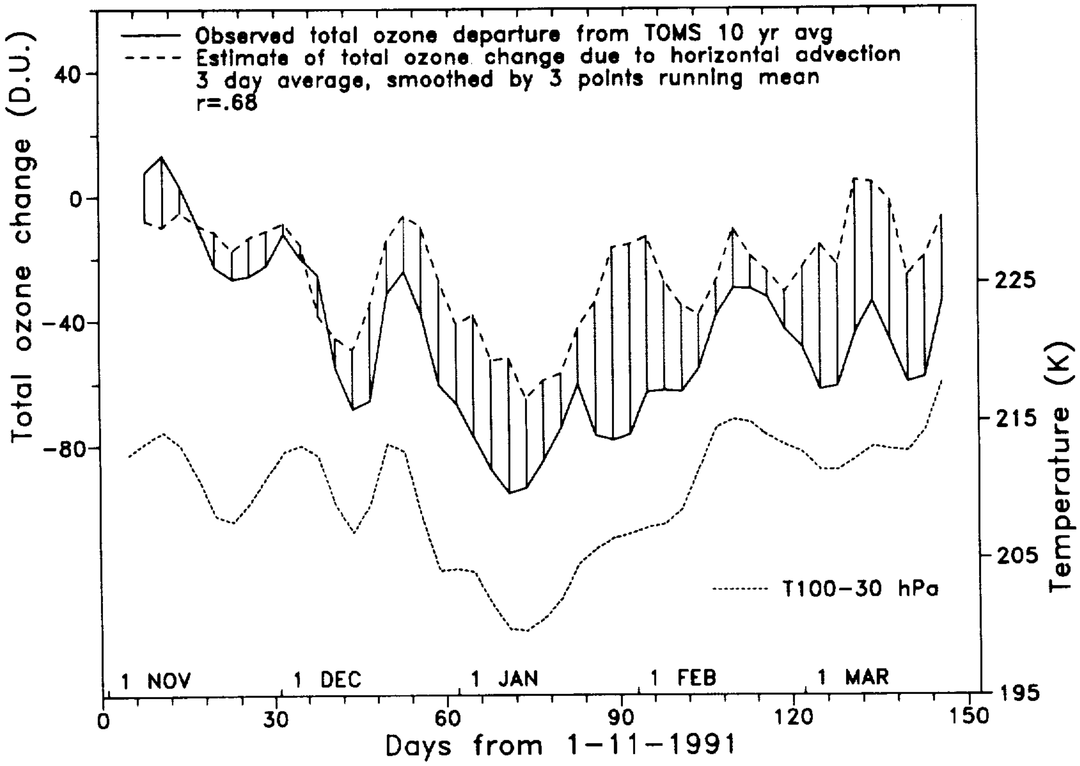

Fig. 3. Total ozone departures from TOMS (solid line) and day-to-day change of the horizontal advection component (dashed line). Dotted line represents the mean temperature of 100-30 hPa layer.

ure 2 shows the map of total ozone departures from the climatic norms in units of standard deviation for January 28, 1992 over the Northern hemisphere. Such high deviations were observed only for this single day during the EASOE period. A similar anomaly was also observed in December 17-19, 1991, but the departures were within 2.5 to 3 standard deviations. Finally, in the past, significant anomalies in this region were observed in January 1989 and at the beginning of February 1990.

5. CIRCULATION EFFECTS

A large part of the day-to-day ozone variability was caused by circulation effects, as shown by the high correlation between deseasonalized ozone departures and the mean temperature of the 100-30 hPa layer for the European region 50°N-60°N (Figure 3). In the present work an attempt is made to quantify the contribution of transport changes in the ozone layer over Europe during the EASOE. It is well documented that ozone advection, vertical motion and chemistry can explain the largest part of the ozone variance (WMO, 1991). An estimate of the daily change in ozone due to horizontal advection in the region bounded by the latitude circles 50°N-60°N and by the meridians 10°W-40°E was obtained by the equation:

$$\Delta[O_3] = <u[O_3]>\Delta y_{10W} - <u[O_3]>\Delta y_{40E} + <v[O_3]>\Delta x_{50N} - <v[O_3]>\Delta x_{60N}$$

where:

[O3] : total ozone at a grid point
u, v : west, south wind component at the same grid point averaged over the vertical layer (from 100 hPa to 30 hPa)
< > : this symbol means averaging over the whole number of grid points of the boundary
x, y : the lengths of the boundaries

In this equation, we first calculate the estimated transport through the boundaries as [O3]y for the west-east boundaries along latitude 50°N to 60°N and [O3]x for the north-south boundaries along longitude 10°W to 40°E. Then, the daily change in ozone due to horizontal advection is given by the net transport through the boundaries, divided by the surface area enclosed and multiplied by the time interval of the calculations (86400 sec). This index is next compared with ozone changes so as to set some limits on the observed ozone change due to horizontal advection. This is seen in Figure 3, which shows the observed total ozone departures from TOMS data along with the day-to-day change of the horizontal advection component. It is obvious that the difference between the two curves is an estimate of the changes due to vertical motion and chemistry. From that Figure it can be seen that the most chemically disturbed period and the coldest of the season coincides with the largest ozone decrease in late January 1992. The difference between the two curves (Figure 3, shaded area) has also maximum which extends from late January through early February. It is concluded, therefore, that during the complicated and active ozone structure over the European Arctic, one needs a careful calculation of the circulational effects (Bojkov, 1987) in addition to the chemical ozone destructive processes.

ACKNOWLEDGMENTS

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