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STABLE OZONE LAYER IN NORWAY AND USSR

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ABSTRACT

Long-term column ozone density measurements have been carried out in Norway and USSR. Data from Tromsø and two meridional chains in USSR are analysed, and most of the stations show that no significant decreasing trend in ozone has occurred during the last two decades.

1. INTRODUCTION

In a recent statistical study of ground-based ozone data from 19° N to 64° N (Bojkov et al., 1990) results similar to those in the NASA/WMO report (1988) were obtained, but this study also reveals essential regional differences with no negative trend in Iceland and Mexico. The biggest negative trend, 3.5% per decade, was found at Ucclé, Belgium. Subsequently the Belgian data were reanalysed by the scientists responsible for the data collection, and no negative trend was found. The reason for this change was the decreasing load of SO_2 content over Belgium during the two last decades. The results of this reanalysis were presented at a scientific meeting in Tromsø, Norway in June 1991 (De Backer and De Muer, 1991).

In accordance with the Belgian results it has been documented that there is no long term decrease of the ozone layer in the Scandinavian sector of the Arctic (Larsen and Henriksen, 1990; Henriksen et al., 1991, 1992). However, the Oslo data have been reanalysed using new charts for the zenith sky observations and correcting the data according to the results of the intercomparison workshop in Arosa, Switzerland in 1986. These two factors result in a decrease of 7% during the period of the observation in Oslo from 1978 throughout 1991. It must be added that no correction for possible changes in SO_2 content over Oslo has been considered.

2. NORWEGIAN DATA

Ozone data from Tromsø and two meridional chains in USSR, comprising the period from 1973 to 1988, are used in this study. The Norwegian and Soviet stations are shown on the map shown in Fig. 1.

The ozone measurements in Tromsø started in 1935 but were interrupted from 1969 to 1984. The average ozone values for each year, having a complete record, are shown in Fig. 2. The average ozone value for the period 1935–1969 is 337 DU. In this period the release of CFC gases was negligible and similarly the ozone destruction due to anthropogenic sources is believed to be negligible. Fig. 2 also shows that the yearly average ozone values of the years 1985 through 1989 all lie above the average for the period 1936 to 1969. Statistical analysis of the data identify that ozone increase has occurred through July, August, and September months (Henriksen et al., 1991).

The Tromsø data were obtained with a Féry spectrograph from 1935 to 1939 and since 1939 with

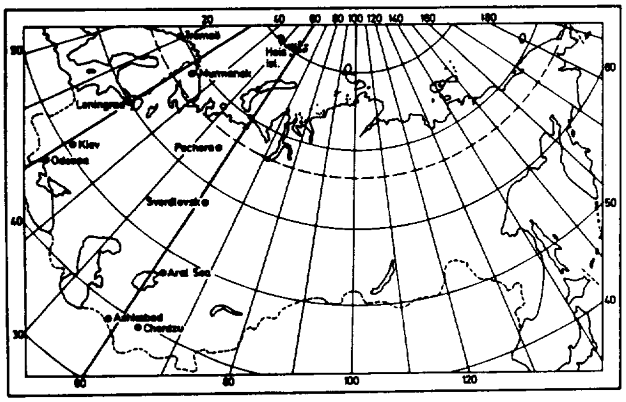

Fig. 1. Map of Europe and USSR pointing out the ozone observing stations used in this review.

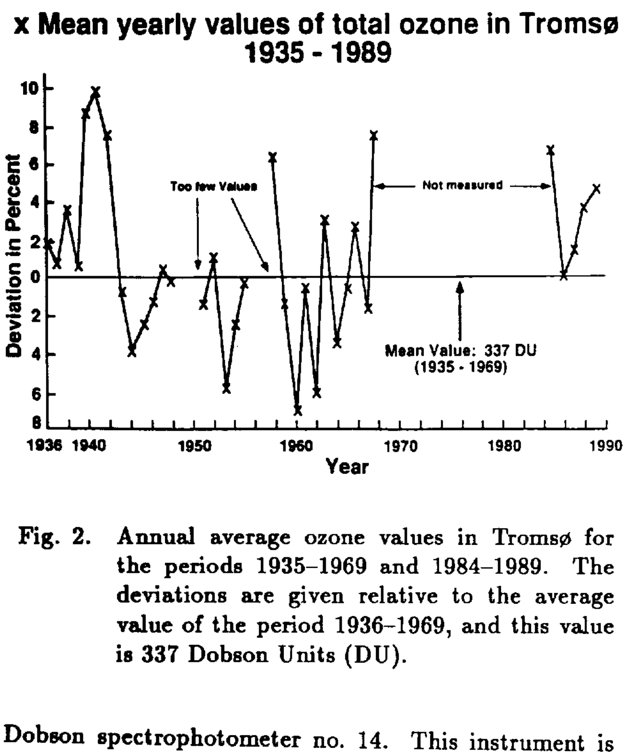

Fig. 2. Annual average ozone values in Tromsø for the periods 1935–1969 and 1984–1989. The deviations are given relative to the average value of the period 1936–1969, and this value is 337 Dobson Units (DU).

Dobson spectrophotometer no. 14. This instrument is a highly stable instrument calibrated three times in 1939, 1950, and 1954 against G.M.B. Dobson's calibration standard, in 1977 against Dobson spectrophotometer no. 83 in Boulder, USA, and in 1990 against Dobson spectrophotometer no. 65 in Arosa, Switzerland. There was a positive shift of 2.41 per cent in sensitivity for the C wavelength pair during the period from 1977 to 1990, but no correction for this minor shift is imposed on the data. The measurements in Tromsø have been carried out only with the C wavelength pair. The data were gathered by direct sun, zenith sky, and moon measurements, and during the polar night the most reliable data were obtained by the moon measurements. The stability of the instrument was checked monthly by a set of standard lamps.

The comparison between direct sun and zenith sky measurements has been made systematically in Tromsø through several years. Theoretical umkehr curves have been calculated to study how different ozone profiles influence the shape of the profiles and introduce uncertainties in calculations of the ozone values. In addition, one has to apply cloud corrections which is a great problem. Our cloud correction charts are based on years of gathered data.

Concerning moon measurements we have taken into account a correction for using focused image on the slit. Whenever possible, the night-time moon measurements have been compared with the daytime, direct sun measurements to assure that the moon measurements are reasonable. Comparison between the Tromsø instrument on the moon and ozone sonde ascents in Sodankylä, Finland has been carried out for the last three years, showing reasonable agreements although the distance between the two places is more than 150 km.

As anywhere else the direct sun method gives the fundamental data, and the other methods are adjusted relative to this method. Therefore no systematic deviations have occurred between the fundamental data and values obtained by zenith sky or moon measurements.

Due to the long record with a stable instrument a reference for an average annual variation of the thickness of the ozone layer is calculated from the measurements carried out during the period 1935–1969, shown in Fig. 3. An estimate of the standard deviation of single measurements is obtained from the measurements from 1984 to 1992, and the 99.87% confidence interval consists of the range comprised by $\pm$ three times the standard deviation. The calculation of the confidence interval is based on the assumption that the daily measurements have a Gaussian distribution, and that they are independent. The large variation of ozone at Tromsø can be mainly due to changes related to meteorological factors such as low pressure centers and polar fronts, resulting in wide confidence limits. Therefore all the measurements obtained during the first months of 1992 are well within the limits, indicating that the variations of the ozone layer can be considered as stochastic.

3. SOVIET DATA

The Soviet data were obtained with the Soviet ozonometer M–124 since 1973. The calibration of each instrument were frequently updated by travelling standards and intercomparisons held at Feodosia (45° N) in Crimea. However, most of the routine measurements at these stations were initiated during IGY, 1956–1959 using another instrument, ozonometer M–83.

The measuring procedure of the Soviet ozonometers is outlined by Gushchin (1986), and these instru-

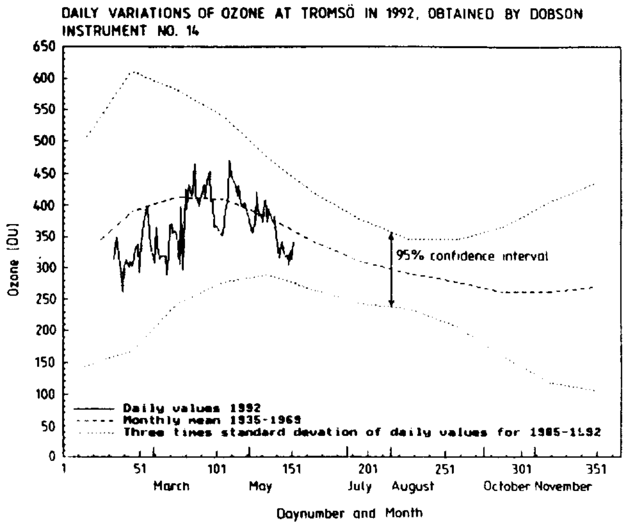

Fig. 3. **Average annual ozone variation, dashed curve obtained from measurements throughout the reference period 1935–1969. An estimate of the standard deviation is obtained from single measurements during the period 1984–1992. The 99.87% confidence interval consists of the area of ± three times standard deviation of the single, independent measurements.**

The continuous curve gives the existing daily ozone measurements in 1992. They are all well within the 99.87% confidence limits, indicating that all variation have been of statistical nature. Based on previous data such variations are to be expected.

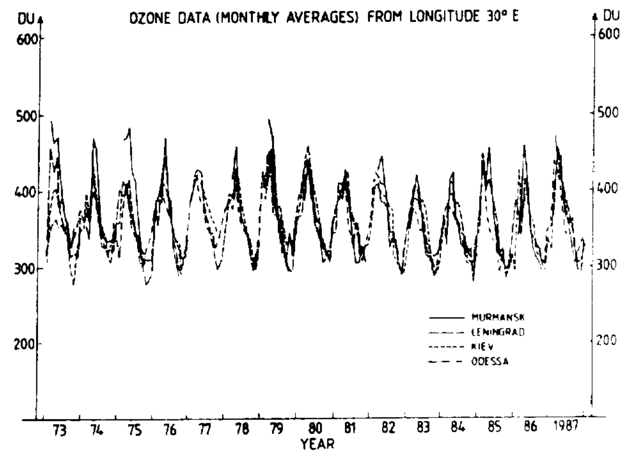

Fig. 4. Superposed ozone values for the ozone stations around the meridian 30° E.

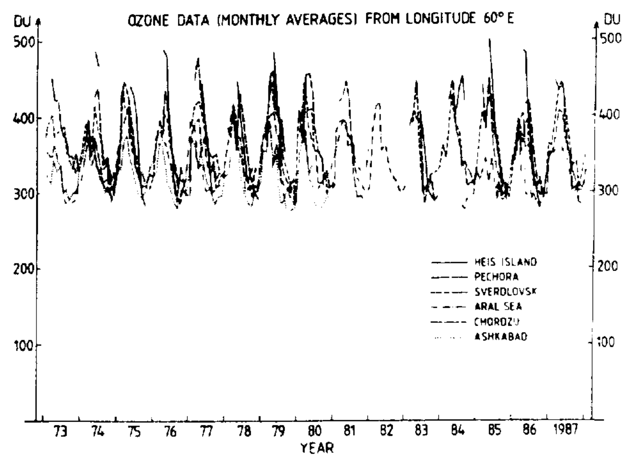

Fig. 5. Superposed ozone values for the ozone stations around the meridian 60° E.

ments are calibrated against the secondary calibration standard, Dobson spectrophotometer no. 108. These data are issued by The Main Geophysical Observatory (MGO), Leningrad in an annual data publication called *Total ozone and spectral transparency of atmosphere*, Leningrad Hydrometeoizdat 1975–1988 (in Russian). The statistical treatment of these data agrees fairly well with the results of the analysis of a large amount of Soviet data presented by Bojkov and Fioletov (1992), where certain amount of corrections of original data are carried out.

The main results of these two studies are negative ozone trends from 1 to 5% per decade. Some disagreements appear considering the confidence limits. Bojkov and Fioletov (1992) associate the observation with much smaller statistical uncertainties than our study and find that their calculated trends are significant.

The Soviet data are shown in Figs. 4 and 5, where monthly average ozone values from each station of both meridional chains are superposed. One meridional chain is around longitude 30° E, containing the four stations Murmansk (69° N), Leningrad (60° N), Kiev (50° N), and Odessa (46° N). The other chain is situated around longitude 60° E, containing Heis Island (80° N), Pechora (65° N), Sverdlovsk (56° N), Aral Sea (46° N), Chordzu (39° N), and Ashkabad (37° N). The superposition of the Soviet data reveals a stationary ozone behaviour with maximum in March and minimum in October.

Due to the disagreements about statistical confidence limits mentioned above, the formulas used in this analysis will be given. The linear regression coefficients, a_n, and the related error, err_n, are calculated by the expression given by Box et al. (1978)

$$a_n = \frac{\sum_i (X_i - \overline{X}_n)(y_i - \overline{y}_n)}{\sum_i (X_i - \overline{X}_n)^2} ,$$

Table I.

STATION and LATITUDE	$a_n \pm err_n$ YEAR	DEC–MAR	MAY–AUG	SEP–NOV	$\overline{y}_n \pm \sigma_n$
MURMANSK (69° N)	-5.88±4.8	-5.69±14.7	-6.63±3.8	-3.92±5.1	370.4±15.88
LENINGRAD (60° N)	-1.01±2.5	-4.16±7.6	+1.66±3.8	+0.22±4.0	358.3±6.73
KIEV (50° N)	-3.37±5.5	-3.29±7.8	-0.90±5.4	-3.89±5.8	356.1±14.94
ODESSA (46° N)	-3.32±6.3	-1.24±7.2	-4.50±5.7	-5.28±3.8	352.6±16.77
30° meridian	-2.82±3.2	-2.83±5.4	-2.18±3.5	-3.16±3.0	358.4±9.29
HEIS ISLAND (80° N)	-1.19±10.3	no data	-0.31±8.4	-5.12±48.8	382.5±20.46
PECHORA (65° N)	-2.51±4.3	+0.45±10.4	-2.99±3.7	-5.25±3.8	364.3±11.74
SVERDLOVSK (56° N)	-1.46±4.0	-1.76±9.2	-2.11±5.0	-1.44±4.5	358.4±10.28
ARAL SEA (46° N)	-2.75±5.1	-3.39±9.5	-1.03±5.6	-4.88±2.9	342.4±11.02
CHARDZHOU (39° N)	-0.52±7.3	-0.38±6.1	+1.16±9.4	+0.53±5.6	324.9±15.13
ASHKHABAD (37° N)	-3.77±3.7	-2.35±9.1	-4.18±4.4	-2.90±5.6	318.2±7.77
60° meridian	-0.32±2.1	0.17±2.5	0.20±2.7	-2.18±2.1	346.5±5.16

and

$$err_n = t_{\alpha/2}\sqrt{\frac{\sum(y_i-\overline{y}_n)^2 - a_n^2\sum_i(X_i-\overline{X}_n)^2}{(N-2)\sum_i(X_i-\overline{X}_n)^2}} \ ,$$

In these expressions X_i and y_i are the abscissa and ordinate of each measurement, N the total number of measurements at each station, $t_{\alpha/2}$ the quantile of Student's distribution for $(1-\alpha)$ probability, α being the probability outside the level of confidence. Only mean monthly values of ozone column densities are used in this analysis. The confidence interval for the regression coefficients, a_n, as indicated by the related errors, err_n, is 95%. The σ symbol indicates the standard deviation of the single values,

$$\sigma = \sqrt{\frac{\sum_i(y_i-\overline{y}_n)^2}{n-1}} \ .$$

The results of the statistical analysis of the Soviet data set for the individual stations and each chain for the whole data set and separate seasons are carried out and shown in Table I together with the corresponding errors and uncertainties (err_n). The units are (percent/decade). In the table all the data from the two chains are used, and all the calculations are carried out using mean ozone data at the individual stations.

The coefficients are normally smaller than the uncertainties, and no all-year significant trend can be stated on the basis of this data set. However, for the sake of completeness it must be noted that three stations show downward trends in the fall, statistically significant on the 95% confidence level, and such larger deviations can be expected from a statistical point of view.

In the last column of Table I it can be seen that the ozone content along the chains increases northwards, and therefore grouping of stations in latitudinal intervals may mask real gradients. The relatively large standard deviations, however, are mostly caused by averaging the inherent annual amplitude of 100 DU. It must be remarked that no trend is calculated for Heis Island during winter since there exist too little data.

The trends of the two chains are -2.8 ± 3.2 (percent/decade) for the 30° chain and -0.3 ± 2.1 (percent/decade) for the other chain. Therefore the summed data do not show any significant trend on the 95% confidence level during the period 1973–1987, and the result is in agreement with the trends obtained for the individual stations.

4. CONCLUDING REMARKS

The long-term data set from Tromsø and the extensive data set from Soviet do not show any significant decreasing trend of the measured ozone content when the complete data sets are examined by the methods outlined in this study. There are both longitudinal and latitudinal variations in the ozone content, which can obviously be of dynamical origin as shown by Rabbe and Larsen (1991). In order to find the effect of the physical processes, adequate statistical analysis of the measured variations must be carried out, deleting the well-documented annual variations, and making correlations with meteorological data as wind and temperature in the stratosphere. The large ozone increase in the beginning of 1940's in Tromsø is also obvious in the data from Arosa (Dütsch and Staehlin, 1989), but the decreasing trend from the beginning of the 1950's in the Arosa data is not present in the Tromsø data.

It must be admitted that the small negative trend quoted by Bojkov and Fioletov (1992) in the Soviet data also appears from our analysis, but Bojkov and Fioletov (1992) find that the negative trend is significant while we do not. This disagreement with Bojkov and Fioletov (1992) can be due to the calculation and interpretation of the statistical uncertainty, and to some extent to their correction of the original Soviet ozone data. They postulate that the Soviet data are influenced by physical processes as quasi-biennal oscillations and solar activity and include several such driving forces into a regression model together with one term taking care of trends. The driving forces of the ozone layer and their effects are not sufficiently understood, and including such effects into a regression model introduces unpredictable uncertainties. It seems by this mathematics of Bojkov and Fioletov (1992) that the measured ozone variations are smoothed, and significant negative trends appear.

Our analysis, however, uses the original data as they are issued by MGO, Leningrad. Then trends are calculated both for the whole data set and for specific seasons, and the uncertainties and confidence limits are derived by well-known formulas. The over-all result indicates that the ozone layer is stable both in Norway and USSR.

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