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ON LONG-TERM OZONE TRENDS AT HOHENPEISSENBERG

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ABSTRACT

More than 2000 ozone soundings and a large number of Dobson observations have been performed since 1967 in a unique procedure. The achieved very homogeneous data sets were used to evaluate significant long-term trends both in the troposphere and the stratosphere. The trend amounts to about +2% per year in the troposphere and to about -0.5% per year in the stratosphere.

Extremely low ozone records obtained during winter 1991/92 are discussed in the light of the long term series. The winter mean of the ozone column is the lowest one of the series. The ozone deficit occured mainly in the lower stratosphere. One cause may be the Pinatubo cloud. Even compared with the extreme winter mean following the El Chichon eruption the ozone content was lower. Additionally ozone was reduced by dynamical effects due to unusual weather situations.

1. INTRODUCTION

The main goal of this paper is to investigate the long-term changes in ozone based on the Hohenpeissenberg long-time series. These time series have been examined in the past (*Attmannspacher* et al. 1984, *Bojkov* et al. 1990, *Wege* et al. 1989) and although the previously detected trends have been repeatedly confirmed, new investigations are nevertheless valuable. The data set has grown longer and the strength of the resulting conclusions is considerably more reliable. The statistical processes used allow a refinement of the almost 25-year data set so that the spatial and temporal course of ozone concentration can be more precisely examined. Further, an estimation of the low ozone concentration during winter 1991/92 is only possible in view of this long data set. The initial effects of the eruption of the Mount Pinatubo can certainly be demonstrated in this case. However the data can also be used to show that this volcanic eruption, the greatest of this century, cannot totally be responsible for the reduction in ozone concentration.

2. DATASET

Measurements of the vertical ozone have been made since 1967 with electrochemical Brewer Mast sondes on every Wednesday. Since 1977 the sounding frequency has been twice a week during the summer and three times a week during the winter. The careful pre-flight preparation of the sondes has never changed and is described in *Claude* et al. 1987. The measured ozone raw data has been corrected for decreasing pump efficiency and other sources of errors. The integrated column amount of ozone from each sounding was ratioed with the column amount measured by a Dobson spectrophotometer to calculate a correction factor, which has been applied to all ozone values. The so-called normalization is in any case an improvement of the ozone sonde data and identifies totally erroneous soundings. On the other hand a miscalibration of the Dobson instrument has an influence on the sonde data. A change in the absorption coefficients, for example, implemented on January 1, 1992, shifts the sonde data if this correction is applied. The Hohenpeissenberg data set is not completely free of such influences either, but great care has been taken in the past to minimize them. All total column ozone data are based on "the old" absorption coefficients according to *Vigroux*, so that both the total ozone data and the sonde data are very homogeneous.

Nevertheless, how much the applied Dobson normalization affects detected trends in an ozone data set requires clarification, whereby each of the over 2000 profiles used was an individual measurement. Figure 1 shows an intercomparison of two such data sets with the vertical distribution of ozone trends 1967 - 1990 at Hohenpeissenberg. It is obvious that within the troposphere there is almost no difference between corrected and uncorrected data. The relative tropospheric trend is approximately +2.2% per year, significant at the 99.9% level. The largest difference between the normalized and the raw data appears within the lower stratosphere below the ozone maximum at 22 km. Within the stratosphere this is the range with the most pronounced trend amounting to approximately -0.5% per year.

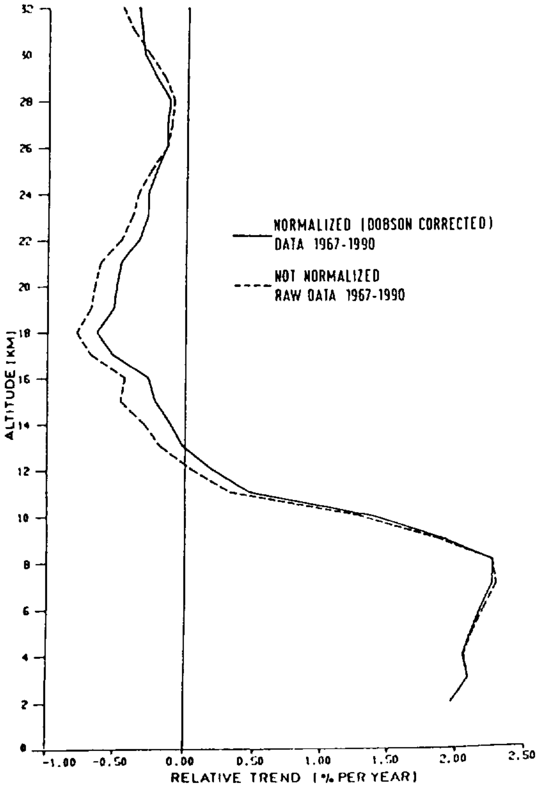

Figure 1: Mean trend profiles based on balloon sonde data.

The evaluation of the raw data reveals a very similar trend profile with a slightly stronger ozone decrease in that range. This examination shows that the fundamental trends in the Hohenpeissenberg sonde data are practically independent of the Dobson normalization. The following investigations are based on the normalized data.

3. TROPOSPHERIC OZONE

Time series of tropospheric ozone have been investigated repeatedly in the past (*Logan* 1985; *Bojkov* 1988; *Staehelin* and *Schmid* 1991). Almost without exception a trend of increasing ozone at rates of about 1% per year or more was found, most pronounced within the lower troposphere.

Figure 2 shows annual means at 2, 4, 6, and 8 kilometers a.s.l. above Hohenpeissenberg with corresponding regression lines from 1967 - 1990. The calculated correlation coefficients of ozone versus time are highly significant at between 0.94 and 0.96. The regression analysis reveals a significant increase of more than 2% per year throughout the whole troposphere. Compared with other stations this is one of the strongest tropospheric trends but it is in remarkable agreement with the +2.2% per year observed at the summit of the Zugspitze (42 km south of Hohenpeissenberg, 2964m a.s.l.) for the period 1978 - 1989 (*Schneider*, 1992).

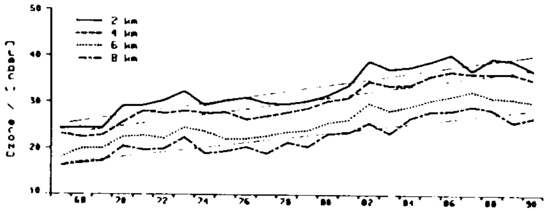

Figure 2: Annual means of ozone at different altitudes within the troposphere with regression lines.

About 50 years ago *Ehmert* (1949/50) described ozone measurements on an aircraft over Bavaria using *Regener's* (1938) potassium iodide method. The partial pressures of that time were between 2 and 9 nbar throughout the whole troposphere. Figure 3 shows an attempt to combine these observations with our tropospheric ozone records. The extrapolated regression lines of the corresponding present data agree with the very low ozone data of that time. Even if such intercomparisons are problematical because of uncertainties they point out that our strong tropospheric ozone increase might be the effect of a marked change in human activities within the last decades.

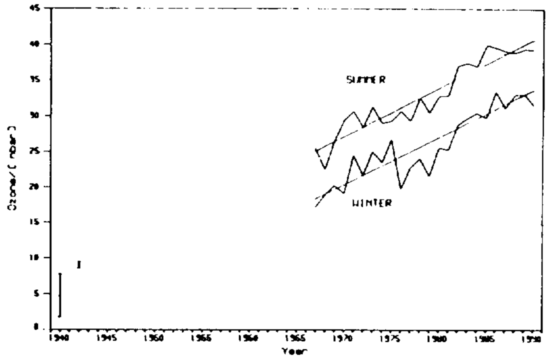

Figure 3: Course of tropospheric ozone at Hohenpeissenberg with regression lines extrapolated back to the fourties when Ehmert *performed measurements on aircraft.*

4. STRATOSPHERIC OZONE

Figure 1 reveals the vertical trend distribution. Besides the tropospheric increase mentioned above, a stratospheric decrease clearly dominates. It is significant only between 17 and 25 km. In regard to the long term mean this -0.7 nbar per year corresponds to approximately -0.5% per year (*Wege* et al., 1989).

To gain more insight into the temporal and spatial course of the ozone trend, a dynamic trend analysis was performed (fig. 4). It was carried out by shifting a 10-year time span along the entire period year by year. The trend was calculated for each of these 10-year windows. Hatched and cross-hatched areas represent time-altitude ranges where trends are statistically significant at the 2 and 3 σ-level respectively. It reveals that stratospheric regions with significant trends are exposed to marked spatial and temporal changes. During the first years the largest decreases were observed below 26 km, prevailing at around 20 km and between 12 and 15 km.

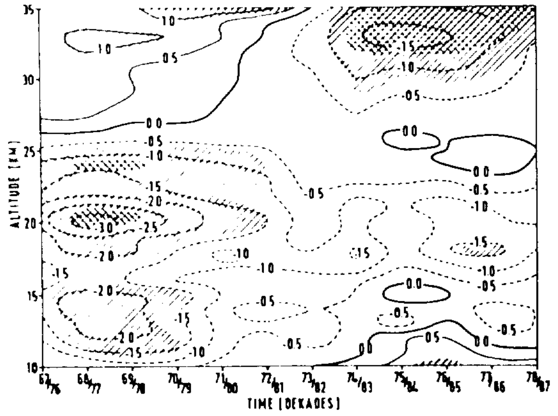

Figure 4: Time-height cross-section of the stratospheric ozone trends at Hohenpeissenberg. The units on the contours are nbar/year.

This decrease became smaller in the following years and reached significance only at the 2 σ-level in the period from 1977 to 1986 at approximately 18 km. The centre of ozone decrease seems to be shifted to higher altitudes at levels above 30 km. However, it must be considered that the sonde reliability decreases generally at those altitudes.

5. TOTAL COLUMN OZONE

The long-term series of total ozone measured with the Dobson 104 (fig. 5), exhibits a relative change of approximately -0.1% per year, i.e. almost no trend. Significance tests prove negative here. The reason for this lies in the counteraction of stratospheric ozone decrease by tropospheric ozone increase, which amounts to about 45% since 1967. That is, there has been a shift of the proportion of ozone between the stratosphere and the troposphere. Whereas in 1967 the troposheric ozone made up only about 7% of the total ozone, the value today is 10%.

In addition figure 5 also displays a very pronounced year to year variability. For example the years 1975, 1983, and 1990 exhibit very conspicuous minima. The minima in 1975 and 1983 can almost certainly be connected with the volcanic eruptions of Fuego and El Chichon.

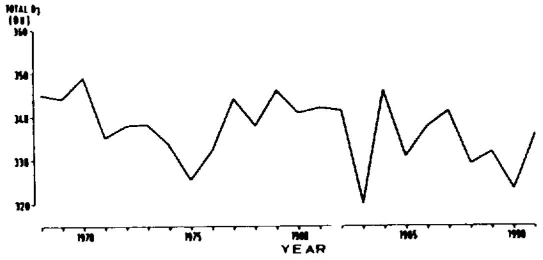

Figure 5: Course of total ozone based on annual means.

This connection can also be identified in the longer total ozone series from Arosa (*Dütsch*, 1984). The counteractions between volcanic products and ozone are not yet completely understood, possible causes for the reduction in ozone concentration could be:

1. direct ozone destruction due to injected chlorine.
2. heterogeneous processes involving long-living stratospheric aerosols.
3. dynamic processes due to the warming of the aerosol-loaded stratosphere, associated with a shift in the circulation pattern.

6. RECORD OZONE LOWS FOLLOWING THE MOUNT PINATUBO ERUPTION

During the whole of the winter of 1991/92 very low ozone values were measured at Hohenpeissenberg. This led, as figure 6 shows, to the lowest total ozone winter mean of the series, a decrease of about -9.7% compared with the long-term winter mean, and -1.6% lower than the minimal values of the winters of 1974/75, 1982/83, and 1989/90.

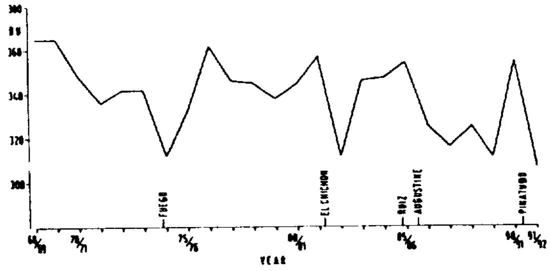

Figure 6: Course of total ozone winter means with marked volcanic eruptions.

The low values measured in the winter of 1989/90 and indeed the whole of 1990 (fig. 5) can hardly be directly related to a large volcanic eruption, unlike the other "minimal" years. It is doubtful whether the two weak volcanic events indicated have any appreciable influence.

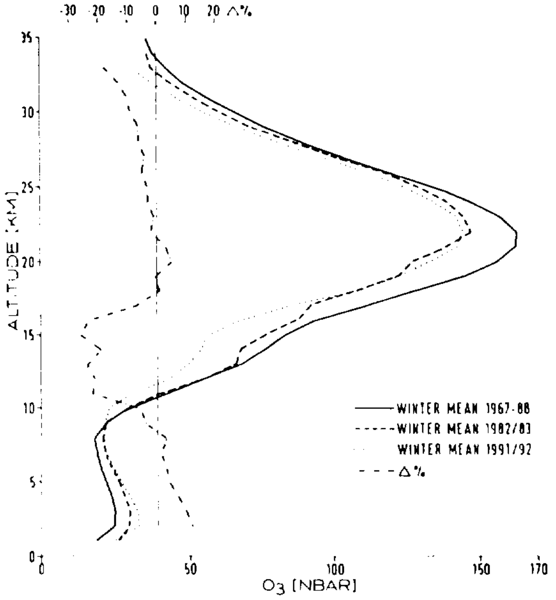

Figure 7: Mean ozone profiles for the winter months December - February and relative difference between winter 91/92 and 82/83.

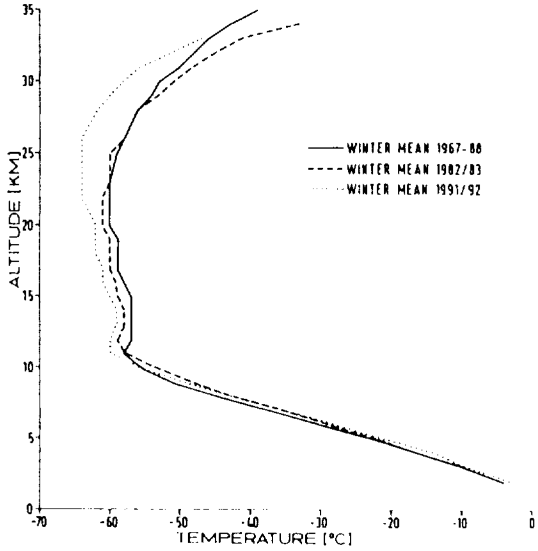

Figure 8: Mean temperature profiles for the winter months December - February.

Figure 7 shows the mean ozone profiles for several winters. As well as the long-term mean for 1967-88, the means for the winter of 1982/83 after the El Chichon eruption, and that for the past winter were chosen.

It is obvious that almost the complete ozone profile between 9 and 33 km for the last winter lies well below that of the long-term mean profile. Even compared with the extreme El Chichon winter, the ozone concentration was vastly reduced at most altitudes. This is pointed out by the relative difference profile Δ %, i.e., in the lower stratosphere between 11 and 16 km an especially great reduction of 20-30% compared to 1982-83 occured.

Moreover, the altitudes above the main maximum show a conspicuous decrease compared to the winter of 1982/83. Because of the height this can hardly be attributed to a direct effect of Pinatubo aerosols. Here again the question arises as to other additional causes.

The soundings show, besides the extremely low ozone values, very low temperatures in almost the whole stratosphere. Figure 8 shows the temperature profiles analagously to the last figure. It can be seen that the past European winter was very unusual. Just as in the ozone profiles, the temperatures at altitudes between 9 and 33 km were very low, so that at an altitude of approximately 26 km a reduction in temperature of 5 K occured. This is very extreme for a 3-month average.

Therefore, it must be assumed that, besides the direct ozone reduction by volcanic products, other ozone-reducing processes are involved, whereby the dynamic processes must be given primary consideration. The past winter has been distinguished by almost persistent pressure and temperature anomalies over vast areas of Europe (*Geb* and *Naujokat,* 1991/92). Because of the superimposition of the Pinatubo effects and the dynamic processes the individual causes cannot be separated or determined quantitatively. In addition it must be remembered that the long-term downwards trend in the stratosphere favours the minima. This trend might be the anthropogenic component of the observed stratospheric ozone loss over Europe during the last winter.

7. CONCLUSIONS

The long-term sounding data from Hohenpeissenberg exhibit pronounced ozone trends. Both increase in tropospheric ozone and decrease in stratospheric ozone are highly statistically significant. However, the long-term record of total column ozone shows practically no trend. The past winter is distinguished by record low values in both total column ozone as well as stratospheric ozone profiles.

The causes of this are recognized, however, the size of the effect of each cause cannot be determined. Nevertheless, it is certain that the eruption of Mount Pinatubo and abnormal dynamic processes played the dominant roles.

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