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## Meteor-3/TOMS observations of the 1994 ozone hole

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**Abstract.** The development of the 1994 springtime (September - November) Antarctic ozone hole was observed by the Meteor-3/TOMS (Total Ozone Mapping Spectrometer) to result in a very low minimum ozone value,  $90 \pm 5$  DU (Dobson Units) on September 28, 1994. During late September and early October, the region of extremely low ozone values was centered on the geographical pole between  $85^\circ\text{S}$  and  $90^\circ\text{S}$ . The geographical extent of the ozone hole region, the area within the 220 DU contour, reached a maximum during the first week in October with an elliptical area covering  $24 \times 10^6 \text{ km}^2$ , reaching to the southern tip of South America. This approximately matched previous area records. After the maximum area was reached in early October, the 1994 ozone hole region was very similar to the 1993 ozone hole throughout the remainder of the month. The area of low temperatures ( $<196 \text{ K}$ ), where polar stratospheric clouds (PSCs) can form and heterogeneous chemistry is significant, has not increased over the past 16 years. During this period, the large trends in the area and minimum ozone amounts of the Antarctic ozone hole do not appear to be related to atmospheric temperature trends.

### Introduction

Each year since 1979, a TOMS instrument (Total Ozone Mapping Spectrometer) has observed the changes in the amount of ozone over the entire globe (Krueger et al., 1987; 1988; 1989; 1992; Newman et al., 1988; 1991; Stolarski et al., 1986; 1990; Schoeberl et al., 1989; Herman et al., 1993; Herman and Larko, 1994; Herman et al., 1995). These have included annual observations of the decline in ozone amounts in the sun-lit springtime Antarctic region, and in the region outside of the south polar vortex wind system. Observations of the Antarctic ozone hole by Meteor-3/TOMS have been made each year since 1991 and were in agreement with the last data from Nimbus-7/TOMS during 1991 and 1992 (Herman et al., 1995).

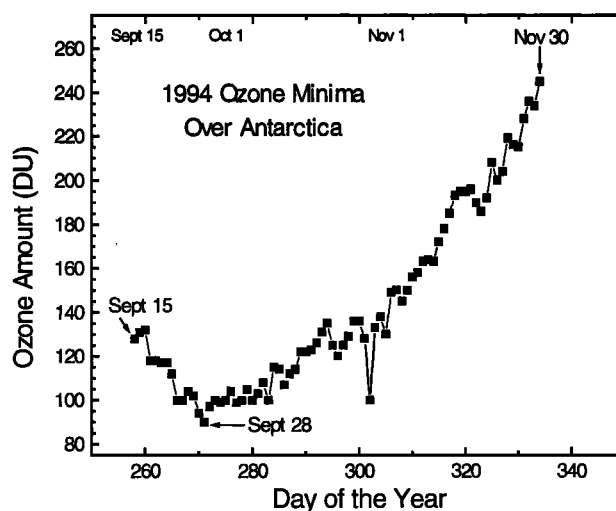
### Discussion

Because of the orbital geometry of Meteor-3/TOMS in 1994, observations of the ozone hole region were not available until mid September and ended in late November. Meteor-3/TOMS ceased operation on December 28, 1994 because of chopper motor failure. In previous years the depletion region started to

form in late August to early September and is mostly recovered by the beginning of December. As shown in Figure 1, the minimum ozone value,  $90 \pm 5$  DU, observed by Meteor-3/TOMS occurred on September 28 in a small region near the center of the ozone hole area. Similar low ozone-hole values observed by Meteor-3/TOMS were confirmed by ground based observations during the previous year (Hofmann et al., 1994) under equivalent conditions. During the period surrounding the ozone minimum, the areal distribution of ozone was not significantly different than during 1993 (Herman et al., 1995).

The decline in minimum Antarctic ozone values has been rapid over the past 16 years, where during the last two years the minimum values have reached between 80 and 90 DU (Dobson Units). Figures 2 and 3 show the evolution of the minimum ozone value and average area within the 220 DU contour as measured by TOMS.

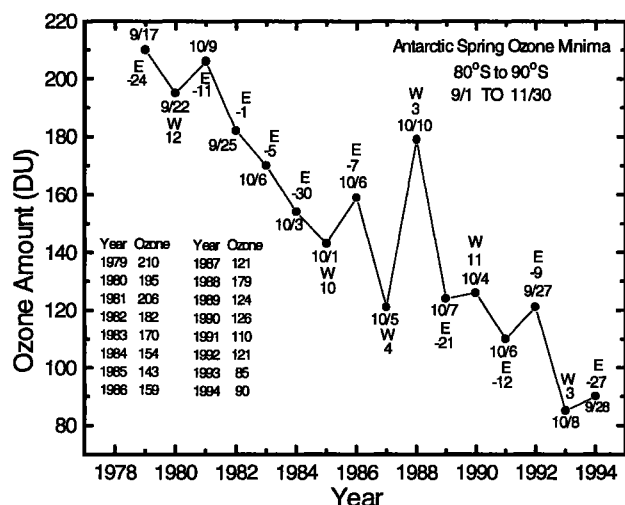
It is not expected that the spring ozone-hole minimum will substantially decrease in future years because most of the ozone has been removed in the altitude region ( $\sim 10 - 22 \text{ km}$ ) Hofmann et al., (1994) where polar stratospheric clouds (PSCs) are present and heterogeneous chemistry operates. Similarly, the maximum area covered by the ozone hole within the 220 DU contour is nearing its limiting value set by the low-temperature area contained within the polar vortex wind system. From 1980 to 1994, the rate of change in area,  $R_A$ , and rate of change in minimum ozone amount,  $R_n$ , can be estimated from linear least-squares fits,  $R_A = 1.7 \text{ million km}^2 \text{ per year}$  and  $R_n = -7.6 \text{ DU per year}$ .



**Figure 1.** Time series of minimum ozone values over Antarctica during the spring 1994 ozone hole season.

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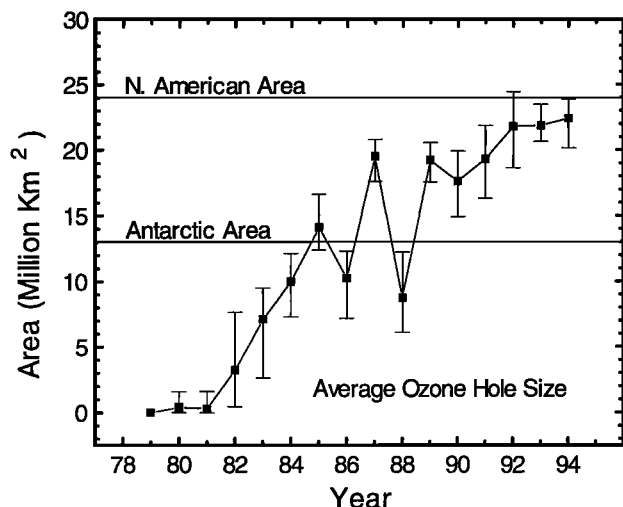
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**Figure 2.** Minimum ozone value observed by TOMS within the Antarctic ozone hole region from September 1 to November 30. E and W represent the Easterly and Westerly QBO phases (from 30-50 mb Singapore winds), and the wind strength (m/s).

The geographical extent of the ozone hole region, the area within the 220 DU contour, reached a maximum during the first week in October with an elliptical area covering  $24 \times 10^6 \text{ km}^2$ . This approximately matched previous area records (see Figure 3). After the maximum area was reached in early October, the 1994 ozone hole region was very similar to the 1993 ozone hole throughout the remainder of the month. On October 2, and October 17, the shape of the ozone hole elongated and rotated over the tip of South America, as it did during 1993 (Herman et al., 1995). The lowest ozone amounts over the southern portions of Argentina and Chile occurred on October 17, 1994 and reached 160 DU. Ozone amounts remained in the range below 170 DU for a period of 3 days.

The Antarctic ozone hole forms when the temperatures within the south polar vortex wind system fall below 196 K and PSCs form. Within the low-temperature region, heterogeneous



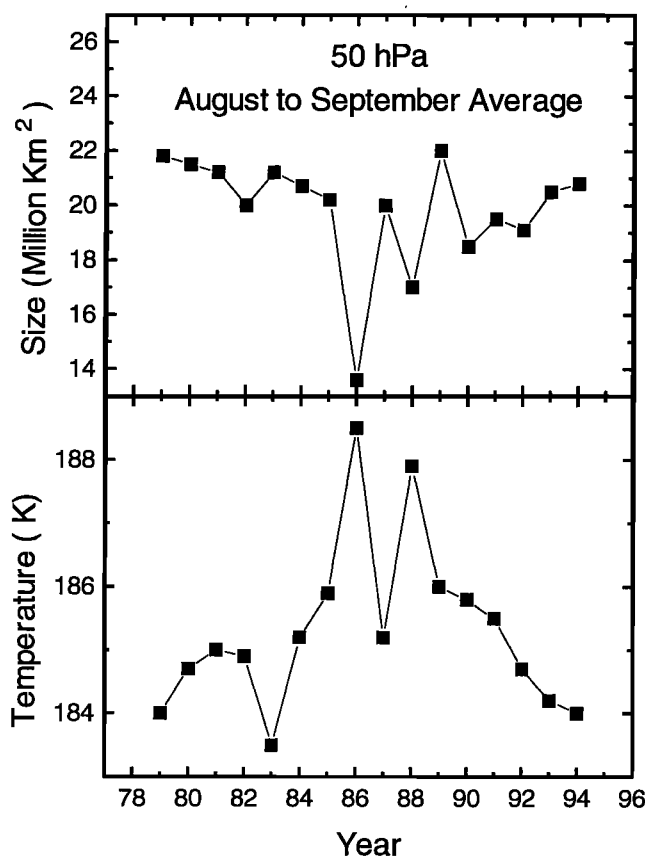
**Figure 3.** Average area within the 220 DU contour line for the period between September 15 and October 15. The vertical bars represent the range of observed areas used for the average.

reactions on the surfaces of PSC ice particles release chlorine into radical forms that can rapidly destroy ozone (Solomon et al., 1986; McElroy et al., 1986; Toon et al., 1986; Prather et al., 1990). Temperatures near or below 196 K have been observed via aircraft measurements in the southern hemisphere during the Antarctic Airborne Ozone Expedition (Fahey et al., 1989). Figure 4 shows that the average area during the August-September period containing the region with temperatures below 196 K on the 50 hPa pressure surface has remained relatively constant ( $\sim 20 \text{ million km}^2$ ) for each year since 1979.

The areal coverage of cold temperatures has an average of about 20 million  $\text{km}^2$  with a variance of a few million  $\text{km}^2$ . The temperatures for Figure 4 were obtained from the National Meteorological Center (NMC) Climate Analysis Center (CAC) stratospheric temperature analyses (Newman et al., 1988). Figure 4 shows that there has been no significant trend in temperature or in the area covered by cold temperatures during the ozone hole formation period each year. This is in contrast to the total ozone trend (Figure 2) and the increase in ozone-hole area (Figure 3).

In addition to the areal coverage of cold temperatures, the lower portion of Figure 4 displays the average minimum temperature over Antarctica on the 50 hPa pressure surface during the September-October period.

This average is computed by finding the coldest temperatures for each day between 45°S and 90°S, and then averaging those daily minima during the period August 1 to



**Figure 4.** The average area covered by temperatures below 196 K on the 50 hPa pressure surface during the August-September period for each year since 1979 and the average minimum temperature of the 50 hPa surface.

September 30. As with the areal coverage, the cold temperatures reveal almost no trend and  $\pm 2^\circ$  variability. The interannual variability of the temperatures seems to have a clear effect on the ozone hole, as is seen via the relatively warm years on 1986 and 1988 and their direct relationship to the relatively weaker ozone holes of 1986 and 1988. The above data provide additional evidence that the trends in the ozone hole size and depth shown in Figures 2 and 3 are not related to corresponding trends in atmospheric temperature.

A relationship of the Quasi-biennial Oscillation (QBO) and the ozone hole was originally pointed out by Garcia and Solomon (1987) and further investigated by Lait et al. (1989). However, during the last few years the QBO effect caused, at most, a weak correlation with the minimum ozone amount (see Figure 2 for date, QBO wind direction, and QBO wind speed), and is not readily apparent in the temperature data (Figure 4). Furthermore, the QBO was in the easterly phase during both late 1992 and 1994, and was in the westerly phase in 1993, yet all 3 of these years exhibited large ozone holes.

## Summary

On September 28, 1994, Meteor-3/TOMS observed the annual minimum ozone value,  $90 \pm 5$  DU, over the Antarctic. The value was only slightly larger than the record low value of 86 DU obtained during 1993. The area within the 220 DU contour was observed to increase to 24 million  $\text{km}^2$ . The trend of decreasing ozone and increasing ozone-hole area is not related to atmospheric trends in temperature. Since the region containing very low temperatures below 196 K, where PSCs can form, is not increasing, it is not likely that the ozone hole area will increase much further.

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