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# OZONE PROFILES OVER MCMURDO STATION, ANTARCTICA, DURING AUGUST, SEPTEMBER, AND OCTOBER OF 1986 - 1991

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*Abstract.* Vertical profiles of ozone and temperature have been measured at McMurdo Station, Antarctica, during the springs of 1986 to 1991, roughly every two days from 25 August to 31 October. Comparisons of temporal histories and average vertical structure for these years reveals some striking consistency in the ozone depletion process. Ozone depletion generally begins in early September, and with a half-life of 20 - 30 days, reaches its maximum in mid October. The depletion occurs almost exclusively between 12 and 20 km. At the time of maximum depletion total ozone has been decreased roughly 40% while ozone between 12 and 20 km has been reduced 80%. Recovery generally begins in late October with the influx, above 20 km, of ozone rich air from the lower latitudes. From this record the worst years for ozone depletion were 1987, 1989, and 1990. A new region of ozone depletion, below 12 km, was observed in 1991, coinciding with the entrainment of a volcanic cloud into the polar vortex.

## INTRODUCTION

Soon after the initial report of ozone depletion over Antarctica (Farman et al., 1985) intense research efforts were undertaken to understand the underlying causes (See for example the special issues of *J. Geophys. Res., 94,* 1989, and *Geophys. Res. Lett., 17,* 1990). It is now understood (Solomon, 1990) that ozone depletion over Antarctica occurs because of a catalytic reaction with chlorine and to some extent bromine. Reactive chlorine appears in the Antarctic stratosphere due to heterogeneous chemistry on the surface of cloud particles in the polar stratosphere (PSCs) which converts chlorine from its reservoir species, $ClONO_2$ and HCl, to $Cl_2$ gas. These reactions occur primarily during polar winter. With sunrise in the spring $Cl_2$ is rapidly photolyzed and begins reacting with ozone. As part of the research effort directed at understanding these processes the University of Wyoming has been involved in the measurement of vertical profiles of aerosol, PSCs, ozone, and temperature over McMurdo Station, Antarctica (78° S, 167° E), since 1986 using balloons. The measurements of aerosol and PSCs have been reported by Hofmann et al. (1989a), Hofmann (1989), Hofmann and Deshler (1989), Hofmann and Deshler (1991), Deshler et al. (1991), and Adriani et al. (1992), and the measurements of ozone by Hofmann et al. (1987), Hofmann et al. (1989b), Deshler et al. (1990a), Deshler et al. (1990b), Deshler and Hofmann (1991), and Johnson et al. (1992). We here present an overview of the 1986 - 1991 seasonal measurements of ozone.

## OBSERVATIONS AND DISCUSSION

To measure vertical profiles of ozone the University of Wyoming used a digital interface with electrochemical cell ozonesondes (Science Pump Corporation) and digital radiosondes (Vaisala Corporation), and small polyethylene or rubber balloons, to measure temperature and ozone up to balloon burst, typically 30 - 35 km. Data are transmitted every 5 seconds, providing approximately 15 m resolution. The ozone pumps were individually calibrated for flow rate at low pressures since it was found that the manufacturer's recommended flow rate correction overestimates the flow rate at pressures less than 15 hPa by factors of 15 to 20%. The high altitude (low pressure) values are critical for the calculation of total ozone since to complete the integration the ozone measured at balloon burst is extrapolated at constant mixing ratio. This system was first used at McMurdo in the spring of 1986 and has continued through 1991. Typically 35 - 40 ozonesonde measurements are made each season between 25 August and 31 October.

During the six years of measurements the severity of ozone depletion has varied, but several characteristics are quite repeatable. Generally ozone reaches a minimum near the middle of October and total ozone is, by then, reduced by 40 to 50%. The majority of this decrease occurs between 12 and 20 km which suffers, during severe years, an 80% reduction in ozone. The half-life for this decay is roughly 20 days. A fair assessment of the years of severe ozone depletion can be obtained by comparing initial ozone profiles with those at minimum ozone, as in Figure 1. The years 1986 and 1988 stand out from this figure as years of moderate ozone depletion and this is borne out by subsequent analysis. Although in this view the last 3 years and 1987 stand out as being years of severe depletion, 1990 is unique because ozone between 15 and 17 km on 9 October of that year was below the detection threshold of the instrument, suggesting that ozone within that 2 km layer had been completely destroyed. It is also clear from Figure 1 that ozone depletion is most complete between

**15 and 18 km, the layer of the atmosphere where ozone is initially at its maximum.**

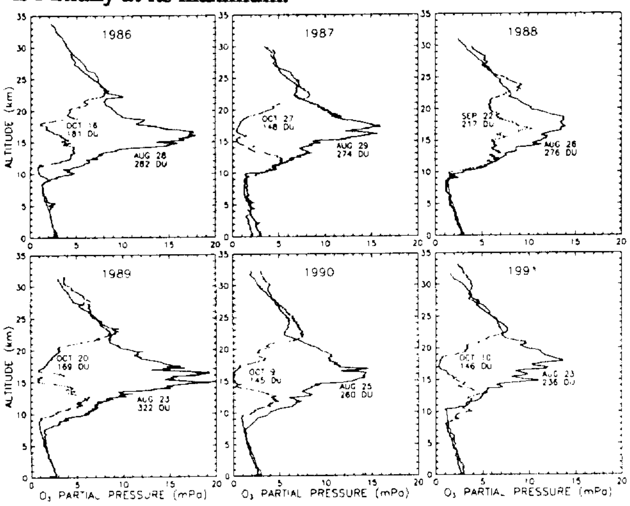


Fig. 1. Comparison of initial ozone profile measurements at McMurdo Station, Antarctica, with the profiles at maximum ozone depletion for the years 1986 to 1991.

A time history of total ozone, 12 - 20 km column ozone, and 18 ± 1 km temperature and ozone mixing ratio are shown in Figure 2. Except for 1986 and 1988, and occasional fluctuations in column ozone in 1990 and 1991, the quite steady and repeatable rate of ozone decline is apparent in Figure 2a. The fluctuations in 1990 and 1991 correspond to times when the wall, or edge, of the polar vortex was over or near McMurdo, bringing in higher ozone from the mid-latitudes. Also apparent in Figure 2a is that the minimum is reached around day 285, and except for 1987 and 1990, quite rapid recovery begins about 10 days later. Note that the recovery of total ozone is much more rapid than the 12 - 20 km ozone, indicating that recovery begins with the influx of high ozone above 20 km. Recovery was delayed by over a month in both 1987 and 1990.

A further examination of the important 12 - 20 km region is shown in Figure 3 where a time history of 2 km layers of column ozone is presented for the years 1988 - 1991. Except for 1988, the rates of ozone decrease in this figure are quite similar for 1989 - 1991. The most rapid decreases occur between 14 and 20 km. Also the minimum reached in each of these layers occurs near day 285 for each year. Recovery is slowest between 14 and 18 km. In 1990 for the 14-16 km layer, ozone is reduced from an initial value near 30 DU to a minimum value of less than 1 DU, indicating over 98% removal of ozone in this layer. Above 18 km the recovery period is marked by rapid increases in ozone, further demonstration of the rapid intrusion of high altitude ozone towards the end of October. Ozone in the 22-24 km layer is very constant every year up until the recovery period. In the 12 - 14 km layer, although ozone still steadily decreases, the rate of decrease is much slower, while below 12 km ozone amounts are very constant and quite similar from year to year. Below 14 km the recovery period is marked, not by increases and rapid changes in ozone, but rather by a suspension of the decay rate, such that ozone remains

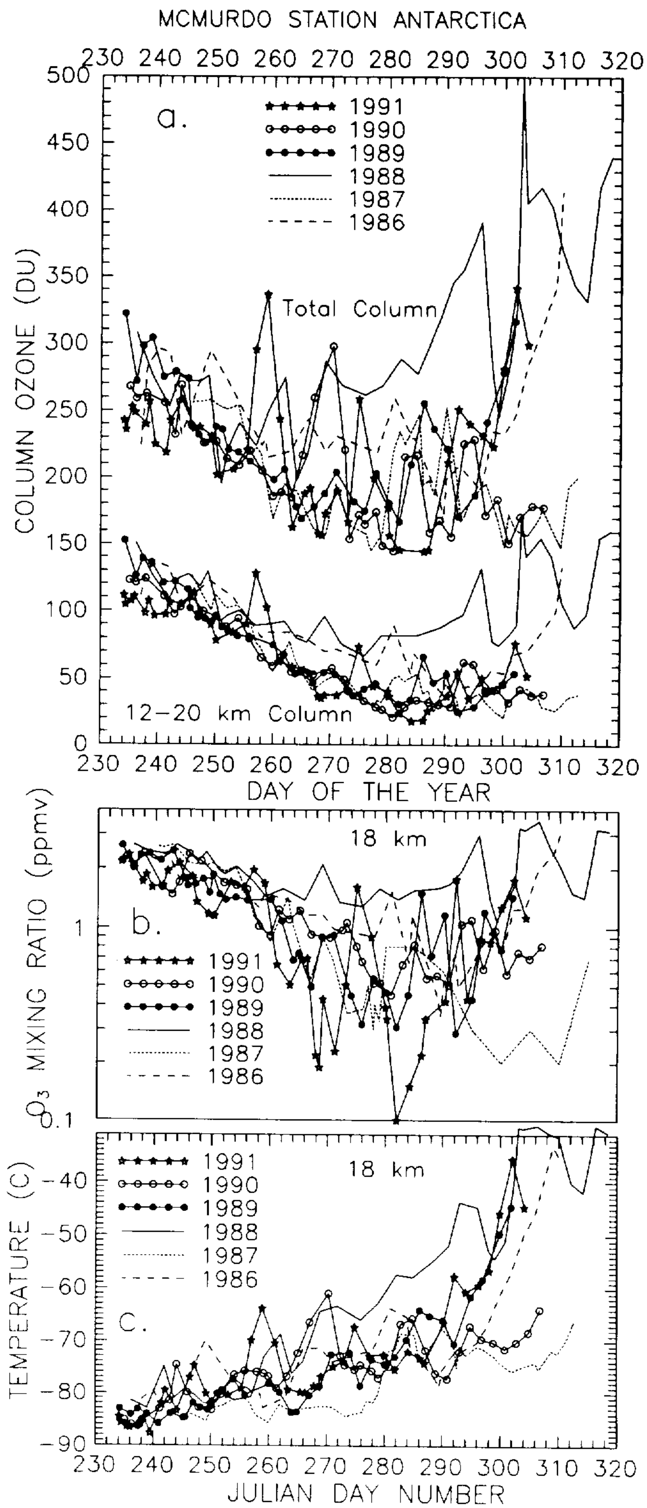


Fig. 2. Comparisons of the austral springs 1986 to 1991 for: a) Integrated total column, and 12-20 km column, and b) 18 ± 1 km ozone mixing ratio and temperature.

relatively unchanged after mid October. Unusual in the 10 - 12 and 12 - 14 km layers is the fact that ozone in 1991 is clearly lower than the previous 3 years. This is particularly noticeable in the 10-12 km layer. This characteristic remains true when comparing to the 1986 and 1987 data as well, and is examined in further detail by Deshler et al. (1992).

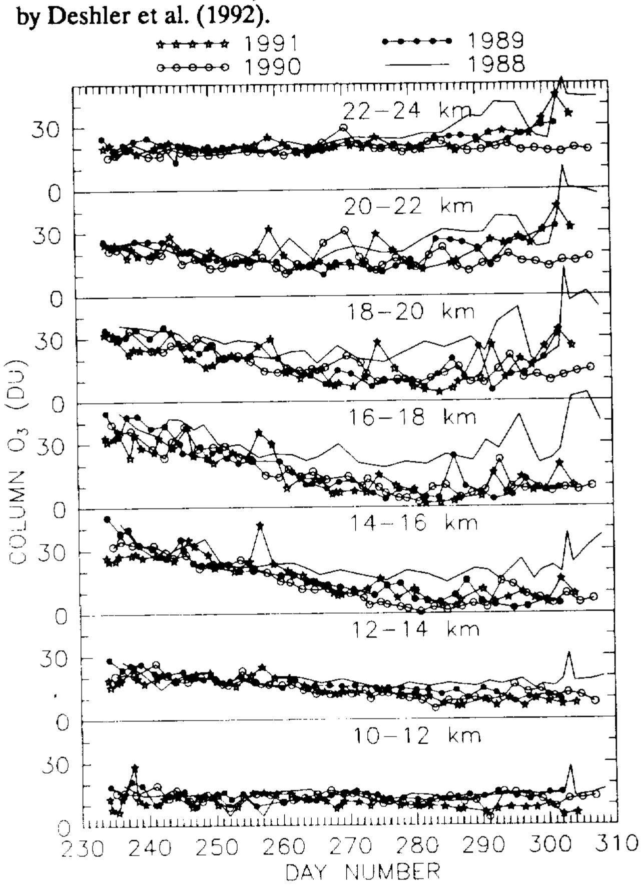


Fig. 3. Integrated column ozone in 2 km layers, 10 to 24 km, during austral spring 1986 - 1991.

Another picture of the vertical structure of the ozone cavity is obtained if for each of the 6 years, temperature and ozone mixing ratio are averaged over the period inside the polar vortex when ozone was near its lowest values. These are compared to each other and to an average of the initial profiles in each year in Figure 4 which also shows the dates for the averaging each year. This view is consistent with the previous figures in showing that 1986 and 1988 are years of only slight to moderate ozone depletion, while the 4 bad years, 1987, 1989, 1990, 1991, all have roughly comparable ozone mixing ratio profiles. This is somewhat surprising when temperature profiles are considered as well. Although 1988 is significantly warmer than the other 5 years, 1986 and 1989 have nearly identical average temperature profiles, and both are warmer by several degrees than the 3 cold years, 1987, 1990, 1991, yet ozone depletion is significantly worse in 1989 compared to 1986. In fact ozone depletion is worse in 1989 than it is in 1991 which has the coldest average temperature profile, although this could partly be a reflection of the fact that the averaging period in 1991 is earlier in the year by about a week due to earlier breakup of the polar vortex. Besides 1991, 1987 is the coldest year of the record and ozone depletion that year was very severe as well. The altitude structure is similar to 1991, but ozone mixing ratios in the 16-18 km layer are lower by about a factor 2. The other year of cold temperatures was 1990, and although the profile begins to warm earlier than 1987 and 1991, the ozone profile is arguably the worst of the record. Significant ozone depletion is displaced to lower altitudes and average ozone mixing ratio reaches a value less than 2 ppmv at 16 km, 50% below the minimum ozone mixing ratio observed in 1987.

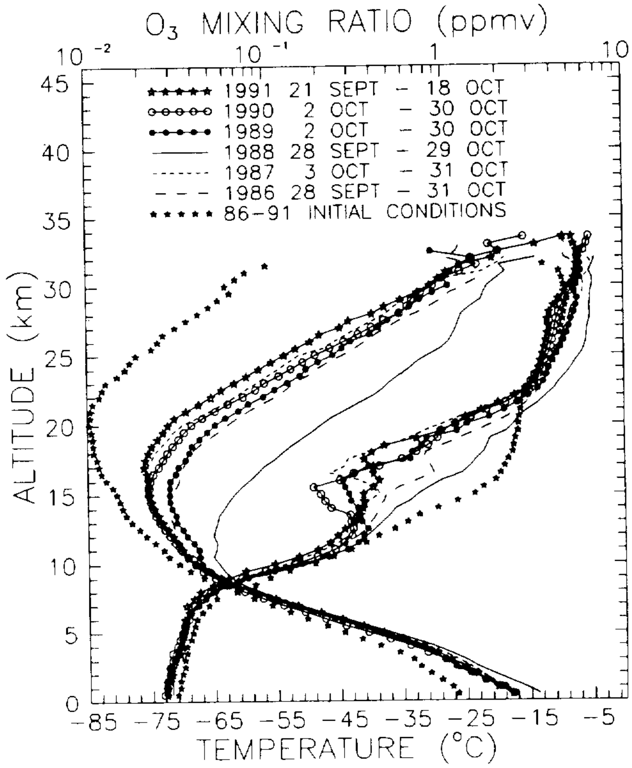


Fig. 4. Averages of profiles of temperature and ozone mixing ratio within the polar vortex during the month of maximum ozone depletion at McMurdo Station, Antarctica, for 1986 to 1991. For reference the average of the 6 initial profiles in late August is also shown.

In this comparison 1987, 1989, 1990, stand out as the 3 worst years for ozone depletion and in each year the altitude of minimum ozone mixing ratio has progressed to a lower altitude. This tendency was reversed in 1991, but ozone depletion was not as severe. Although the 1986, 1989, comparison stands out as one in which the average temperature through the month of severe depletion is not a good predictor of ozone depletion, in general the altitude of minimum ozone mixing ratio in each year corresponds with the minimum average temperature. Quite likely the winter of 1989 was colder than 1986 allowing stronger PSC activity to condition the stratosphere prior to the spring sunrise.

A further comparison of ozone depletion for the 6 years is presented in Table 1. This details the consistency of the measurements from year to year, concerning the initial conditions, and the amount and rate of ozone depletion. The initial ozone in 1991 was lower than the previous years. From the table 1987, 1989, 1990, 1991, all appear as bad years for ozone depletion.

Table 1. Comparison of initial and minimum ozone profile measurements at McMurdo Station, Antarctica, during the springs of 1986 to 1991.

| | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 |
|---|---|---|---|---|---|---|
| Initial Measurements | | | | | | |
| Total $O_3$ (DU) | 271 | 274 | 276 | 322 | 269 | 236 |
| 12-20 km (DU) | 111 | 125 | 127 | 153 | 120 | 105 |
| 18 ± 1 km | | | | | | |
| $O_3$ (ppmv) | 2.2 | 2.6 | 2.4 | 2.7 | 2.2 | 2.2 |
| Temp(xC) | -84 | -87 | -83 | -83 | -86 | -85 |
| Minimum Measurements | | | | | | |
| Total $O_3$ (DU) | 181 | 148 | 217 | 167 | 145 | 146 |
| 12-20 km (DU) | 41 | 21 | 77 | 31 | 20 | 18 |
| 18 ± 1 km | | | | | | |
| $O_3$ (ppmv) | 0.4 | 0.2 | 1.4 | 0.3 | 0.4 | 0.1 |
| Temp(xC) | -78 | -74 | -74 | -84 | -75 | -78 |
| Percent Decrease | | | | | | |
| Total $O_3$ (DU) | 33 | 46 | 21 | 48 | 46 | 38 |
| 12-20 km (DU) | 63 | 83 | 39 | 80 | 83 | 83 |
| 18 ± 1 km | | | | | | |
| $O_3$ (ppmv) | 82 | 92 | 42 | 89 | 82 | 95 |
| Half-life (days) | | | | | | |
| 18 q 1 km | 28 | 12 | 29 | 10 | 18 | 12 |
| 12-20 km | 37 | 17 | 35 | 22 | 20 | 22 |

## SUMMARY AND CONCLUSIONS

Vertical profiles of ozone and temperature have been measured at McMurdo Station, Antarctica, from late August to late October during the years 1986 to 1991. From comparison of these profiles the following characteristics are quite constant. Ozone depletion begins in early September and reaches its maximum in mid October. The half-life for this decay is 20 - 30 days, depending to some extent on altitude. Ozone depletion is confined almost exclusively to between 12 and 20 km, with the most rapid decay occurring between 14 and 18 km, coinciding with the coldest temperatures in the stratosphere. In 1990 at maximum depletion the removal of ozone was complete between 15 and 17 km, ozone was below the detection threshold of the ozonesonde. During the years of severe depletion (4 of 6), at the time of maximum depletion, 45% of the total column of ozone is destroyed, while between 12 and 20 km over 80% of the ozone is removed. Except for 1987 and 1990, when recovery was delayed by a month, the period of minimum ozone is less than a week, and recovery begins with the influx of ozone rich air above 20 km.

The worst years for ozone depletion were 1987, 1989, and 1990, with 1987 and 1990 being the most similar. The least depletion occurred in 1988, a year with an unstable and short lived polar vortex. Even though temperatures in 1986 were similar to 1989, the amount of depletion was only about half of that observed in 1989. Considering the large amount of volcanic activity in 1991, the polar stratosphere in 1992 will be highly perturbed with new aerosol and the consistency displayed these pasts 6 years may be quite altered in 1992.

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