N95-11040

OZONE VERTICAL PROFILE CHANGES OVER SOUTH POLE

S.J. Oltmans, D.J. Hofmann, W.D. Komhyr, J.A. Lathrop

Climate Monitoring and Diagnostics Laboratory
National Oceanic and Atmospheric Administration/ERL
Boulder, Colorado 80303, USA

ABSTRACT

Important changes in the ozone vertical profile over South Pole, Antarctica have occurred both during the recent period of measurement, 1986-1991, and since an earlier set of soundings was carried out from 1967-1971. From the onset of the "ozone hole" over Antarctica in the early 1980s, there has been a tendency for years with lower spring ozone amounts to alternate with years with somewhat higher (although still depleted) ozone amounts. Beginning in 1989 there have been three consecutive years of strong depletion although the timing of the breakdown of the vortex has varied from year to year. Comparison of the vertical profiles between the two periods of study reveals the dramatic decreases in the ozone amounts in the stratosphere between 15-21 km during the spring. In addition, it appears that summer values are also now much lower in this altitude region.

1. INTRODUCTION

Soon after the recognition that large ozone losses were being measured during the spring over Antarctica (Farman et al., 1985) the U.S. National Oceanic and Atmospheric Administration (NOAA) began a program of regular ozone profile measurements over South Pole. The soundings, begun in 1986, use balloon-borne, electrochemical concentration cell (ECC) ozonesondes to measure the ozone profile. The ECC sonde has the distinct advantage that the integrated ozone profile obtained from the sounding gives values very close to the total column ozone amount measured by the Dobson spectrophotometer (Oltmans et al., 1989). Of the approximately 350 soundings carried out since 1986 at the South Pole, 100 were made under conditions that allowed comparison with concurrent Dobson measurements. The normalization factor (equal to Dobson total ozone divided by sonde integrated ozone) at South Pole was 1.004 with a standard deviation of 0.057. This is important because during at least 8 months of the year, Dobson measurements at South Pole are impossible or very sparse. This includes the period from September through mid-October during the development of the "ozone hole." Thus for much of the year the sonde profiles are also the only measure of column total ozone.

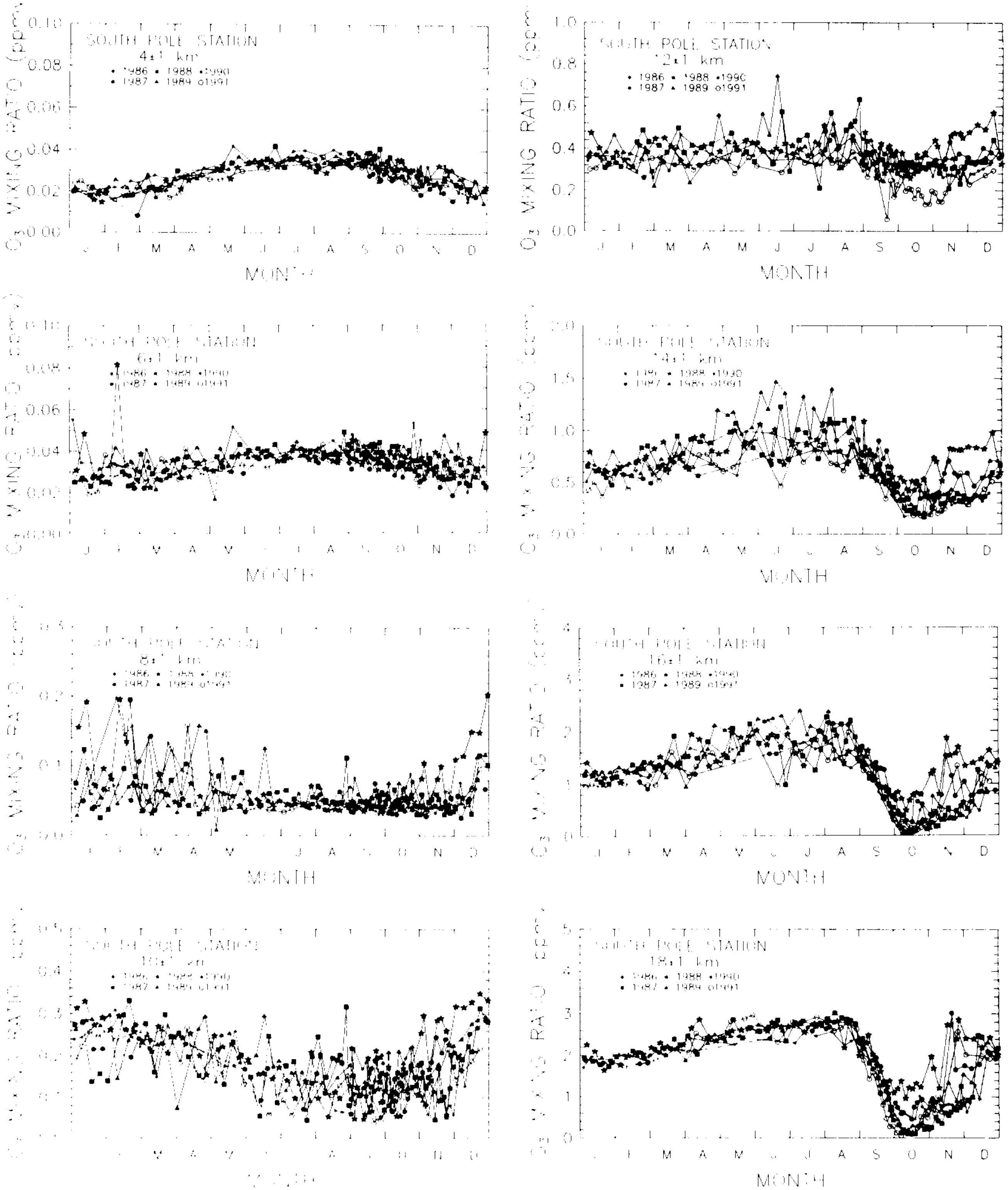
During an earlier program carried out by a predecessor of NOAA, 85 profiles were obtained from 1967-1971--about 1/4 of the number obtained during the more recent program. Although the ozonesonde itself was similar for both periods, the balloons used in the earlier period often did not reach altitudes above about 40 mb (~20 km) particularly during the very cold winter months.

2. VARIATIONS DURING 1986-1991

Figure 1 shows the 2 km averaged data in 2 km increments from 4-26 km. Each symbol represents the results from a single sounding and the data are plotted individually for each of the 6 years. The two lowest layers centered at 4 km and 6 km represent the behavior in the troposphere. At both the 8 and 10 km levels the relatively large values during the late spring in 1988 are evident and persist up to altitudes of about 20 km and point out significant year-to-year differences.

One of the striking features of the record is the development during austral spring 1991 at 12 km of a very pronounced minimum which is associated with a layer of greatly enhanced concentrations of volcanic aerosols. There appears to be heterogeneous processing by the aerosols eventually leading to ozone loss (Hofmann et al., 1992).

In the layers from 14-20 km the development in the spring of a very deep minimum has characterized each year. In 1988 and to a lesser extent in 1986, the progression to near zero ozone is interrupted in early October. This is seen best at the 18 km level. In 1991, on the other hand, ozone values dip to near zero levels but recover by early November as was the case in 1986 and 1988. It is this early recovery that leads to the year-to-year variability in the total ozone that is quasi-biennial in character (Garcia and Solomon, 1987). In 1987, 1989, and 1990, on the other hand, lower amounts persisted in much of the layer, but especially from 15-19 km, until early December. In 1989 ozone increased early in November in the region above 19 km but not until December below 19 km. The onset of the higher ozone values at South Pole is closely tied to the breakdown of the polar vortex (Komhyr et al., 1986). Thus the modulation of


SOUTH POLE STATION
4±1 km
• 1986 • 1988 •1990
• 1987 ▲ 1989 o1991
O3 MIXING RATIO (ppm)
MONTH
SOUTH POLE STATION
12±1 km
• 1986 • 1988 •1990
• 1987 ▲ 1989 o1991
O3 MIXING RATIO (ppm)
MONTH
SOUTH POLE STATION
6±1 km
SOUTH POLE STATION
14±1 km
MONTH
SOUTH POLE STATION
16±1 km
MONTH
SOUTH POLE STATION
18±1 km
• 1986 • 1988 •1990
• 1987 ▲ 1989 o1991
MONTH

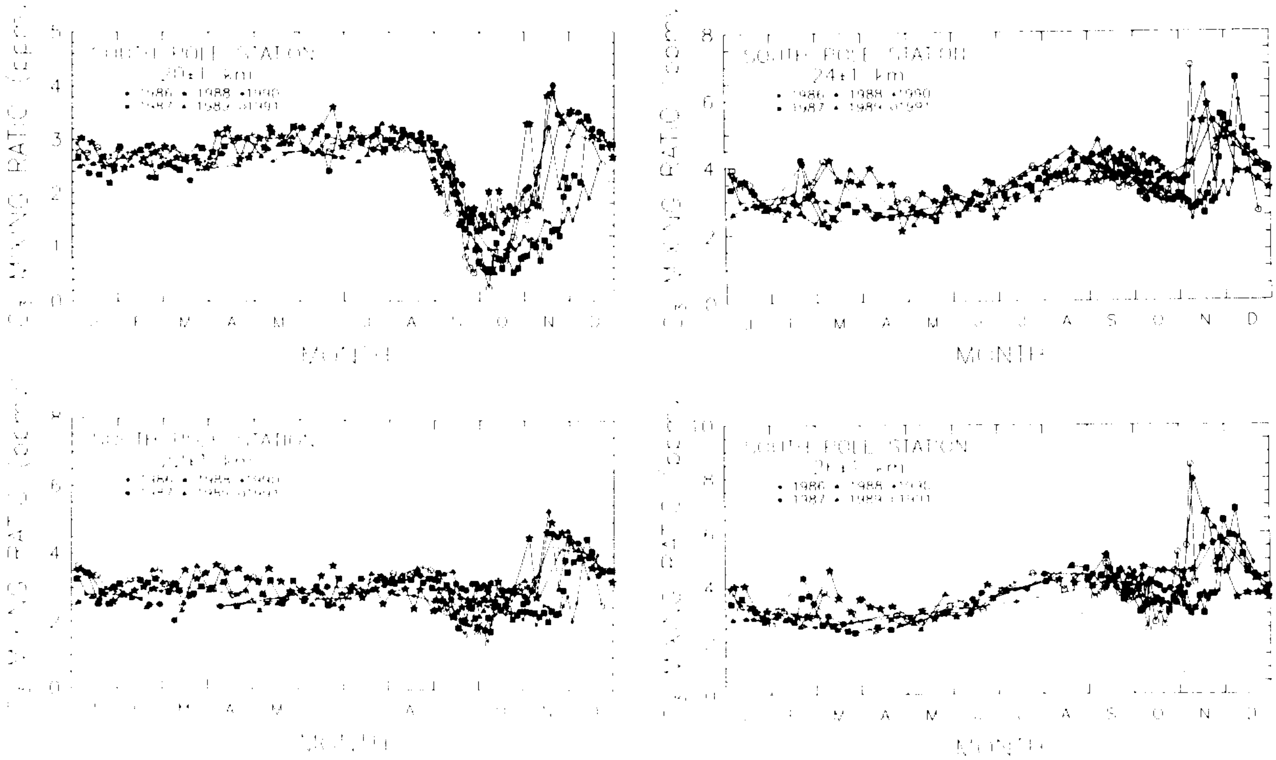


Fig. 1. Two kilometer average ozone mixing ratios (ppmv) for two kilometer levels from 4-26 km for each ozonesonde sounding made at South Pole during 1986-1991.

the timing of the appearance of extra-vortex air in the region from about 14-26 km is the mechanism responsible for the approximate quasi-biennial variation in magnitude of the "ozone hole."

3. COMPARISON OF 1986-1991 WITH 1967-1971.

The period from 1967-1971 was well before the rapid decline in the spring total column ozone amount over Antarctica (Komhyr et al., 1986). Figure 2 compares the average monthly values for each month at several levels. The values shown are smoothed using a weighted 3-month average (.25, .50, .25). Because there are a limited number of soundings during 1967-1971, the smoothed average total ozone from the soundings was compared with the average total ozone from the Dobson during the 5 months when there were a significant number of Dobson observations. The differences between the averaged total ozone amounts from the two methods did not exceed 7.5% for any of the months. At 400 mb (~6.5 km), a mid-tropospheric level, the winter values during the later period (squares and dashed lines) are higher than those for the earlier period (circles and solid lines).

At 200 mb (~10.5 km) in the lower stratosphere the differences between the periods are not large but throughout the spring and summer more recent amounts are always less than those seen earlier. Winter values, on the other hand, are nearly the same. For the next three levels (100 mb, 70 mb, and 40 mb), the spring differences are enormous with the recent October value (smoothed) only 1/3 of earlier amounts. The differences persist through the summer. At 100 mb (~14.5 km) the summer differences are particularly large while at 40 mb (~20.5 km) they are small. At 25 mb (~22.5 km) there are no winter data for the 1967-1971 period. There is still a sizeable difference in the spring but now it is shifted so that the largest deficit is in November instead of October which was the case at the lower levels.

During the 1967-1971 period, ozone at 200 and 100 mb showed a gradual decline during the winter. This decline is sharper than in more recent years because summer ozone values are now lower but by August the two periods are roughly the same. At 200 mb the amounts remain the same through September but at the higher levels major differences are evident by September. Interestingly at 70 and 40 mb in 1967-1971, there is a minimum in September. At 25 mb, on the other hand, September values are much higher than at 40 mb while January-May values are nearly the same. This suggests that there may have been losses taking place during spring even in 1967-1971, perhaps as a result of heterogeneous chemical reactions involving polar stratospheric clouds and natural levels of chlorine. Since during September air at higher levels has higher mixing ratios, subsidence is not a likely cause of lower values. Air is not easily transported from outside the vortex and this air

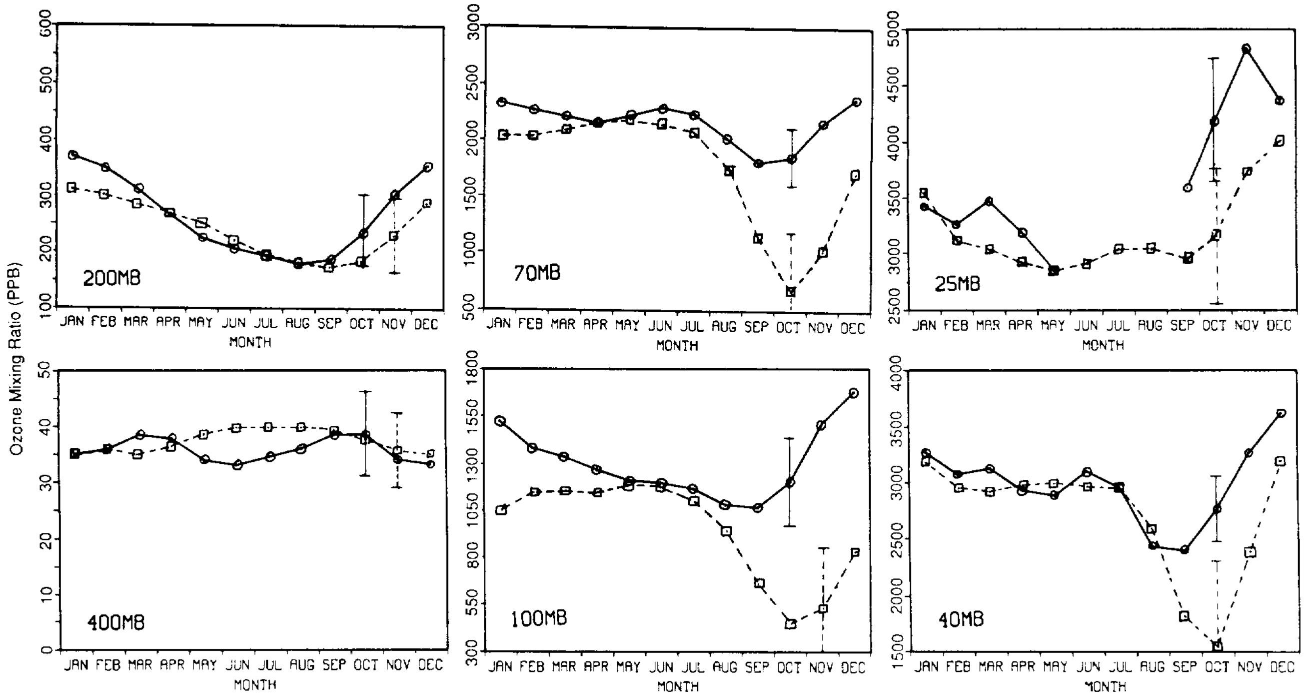


Figure 2. Monthly mean ozone mixing ratios for various levels. The circles connected by the solid line are for the period 1967-1971, the squares and dashed lines are for 1986-1991.

usually has higher ozone amounts than air within the vortex anyway. Thus actual losses seem to be the preferred mechanism for the observed spring decline even in the earlier period.

4. CONCLUSIONS

During the period 1986-1991 strong ozone depletion during the spring in the layer 14-22 km is a feature not seen in anything like its present form in an earlier set of soundings made from 1967-1971. This earlier set does, however, show a weak minimum in the spring that may have been the result of heterogeneous ozone loss caused by background levels of chlorine. Current summer ozone levels are also much lower in the 10-20 km layer than they were in the earlier period. It appears that ozone transported into Antarctica after the breakdown of the vortex now goes toward replenishing ozone lost during the spring rather than toward building the marked late spring and summer maximum that existed previously. Interestingly, however, winter values are very similar during the two periods studied raising the question as to what happens to the ozone found in the late spring maximum.

For the 1986-1991 period, the year-to-year differences in spring total ozone are related to the timing of the movement away from South Pole or breakdown of the antarctic polar vortex. In 1991 although the vortex broke down quite early, very low total ozone amounts were observed before this occurred. This was primarily a result of low ozone amounts observed around 12 km and at 26-28 km (figure 1). The additional low level depletion was in conjunction with a strong volcanic aerosol layer and it has been suggested that heterogeneous losses on particles may have been the cause (Hofmann et al., 1992).

REFERENCES

Farman, J.D., B.G. Gardiner, and J.D. Shanklin, 1985: Large losses of total ozone in Antarctica reveal seasonal ClO_x/NO_x interaction, Nature, 315, 207-210.

Garcia, R.R., and S. Solomon, 1987: A possible relationship between interannual variability in Antarctica ozone and the quasi-biennial oscillation, Geophys. Res. Lett., 14, 848-851.

Hofmann, D.J., S.J. Oltmans, J.M. Harris, S. Solomon, T. Deshler, and B.J. Johnson, 1992: Observation of new ozone depletion in Antarctica in 1991, Nature, 359, 283-287.

Komhyr, W.D., R.D. Grass, and R.K. Leonard, 1986. Total ozone decrease at South Pole, Antarctica, 1964-1985, Geophys. Res. Lett., 13, 1248-1251.

Komhyr, W.D., S.J. Oltmans, and R.D. Grass, 1988. Atmospheric ozone at South Pole, Antarctica in 1986, J. Geophys. Res., 93, 5167-5184.

Oltmans, S.J., W.D. Komhyr, P.R. Franchois, and W.A. Matthews, 1989: Tropospheric ozone: Variations from surface and ECC observations, Ozone in the Atmosphere, R.D. Bojkov and P. Fabian (Eds.), A. Deepak, Hampton, VA, 539-543.