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THE EVOLUTION OF OZONE OBSERVED BY UARS MLS IN THE 1992 LATE WINTER SOUTHERN POLAR VORTEX

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Abstract. The evolution of ozone (O_3) observed by the Microwave Limb Sounder on board the Upper Atmosphere Research Satellite is described for 14 Aug through 20 Sep 1992, in relation to the polar vortex. The development of an ozone hole is observed in column O_3, and a corresponding decrease is seen in O_3 mixing ratio in the polar lower stratosphere, consistent with chemical destruction. The observations also suggest that poleward transport associated with episodes of strong planetary wave activity is important in increasing O_3 in the mid-stratosphere.

Introduction

The Microwave Limb Sounder (MLS) on board the Upper Atmosphere Research Satellite (UARS) measures concentrations of several species of interest in the middle atmosphere, including O_3 and ClO. This letter describes results from initial analyses of O_3 data from the 205 GHz radiometer, which has horizontal resolution of ≈400 km and vertical resolution of ≈4 km. The MLS instrument is described and retrieval methods are summarized by Waters et al. [1993a]; data validation is still in progress.

These measurements provide unprecedented coverage of the polar winter stratosphere. The MLS took continuous measurements covering ≈30°N to ≈80°S, from 14 Aug through 20 Sep 1992. The evolution of O_3 in the southern polar stratosphere is discussed for this time period, in relation to changes in the polar vortex seen in Rossby-Ertel potential vorticity (PV) derived from National Meteorological Center (NMC) data.

Data and Analysis

O_3 data are gridded using Fourier transform techniques that separate time and longitude variations [L. S. Elson, unpublished manuscript]. PV is calculated from NMC geopotential heights and temperatures [Manney and Zurek, 1993]. Since MLS temperatures are only available for pressures ≤ 22 hPa, NMC temperatures are used to interpolate gridded MLS O_3 to isentropic (potential temperature) surfaces.

The amount of O_3 in the polar vortex is estimated by integrating to get the mass of O_3 in a volume bounded in the horizontal by a PV contour representing the "edge" of the polar vortex, and in the vertical by isentropes surrounding the desired level (these isentropes are chosen to enclose a layer ≈2--2.5 km thick). The mass of air is also estimated; dividing the mass of O_3 by the mass of air gives an average O_3 mixing ratio in the polar vortex. A "liberal" definition of the vortex is used, i.e., the PV contour used is near the outside of the region of strong gradients that tends to isolate the polar vortex.

Time Evolution of Ozone in the Polar Vortex

Figure 1 shows time series, calculated as described above, for 14 Aug through 20 Sep 1992 of the mass of O_3 (left, column 1), the mass of air (center, column 2) and average O_3 volume mixing ratio (right, column 3) in the

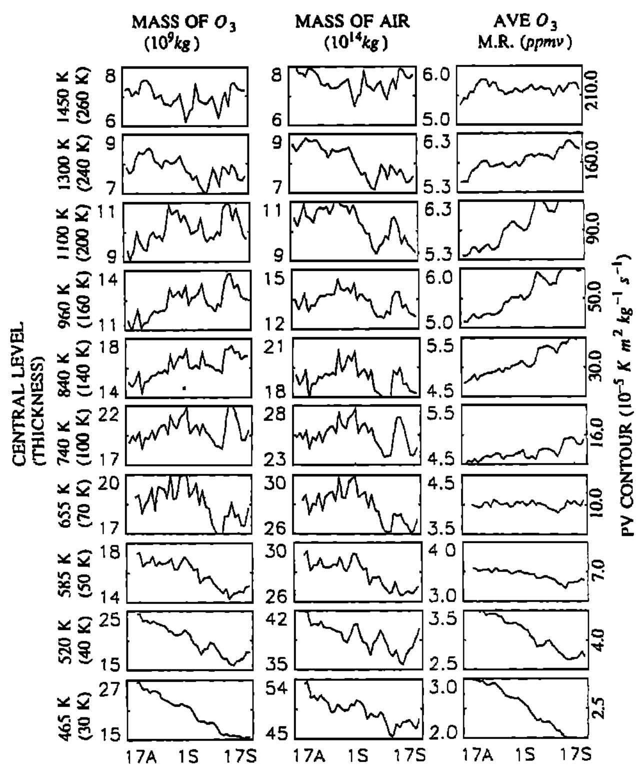

Fig. 1. Left column -- mass of O_3 in a volume bounded in the horizontal by a PV contour defining the "edge" of the polar vortex, and in the vertical by two isentropic surfaces surrounding the labeled level (thickness of layer is given in parentheses). Center column -- mass of air in the same volume. Right column -- quotient of the left and center columns scaled to give average O_3 volume mixing ratio. The PV contours used are given on the right.

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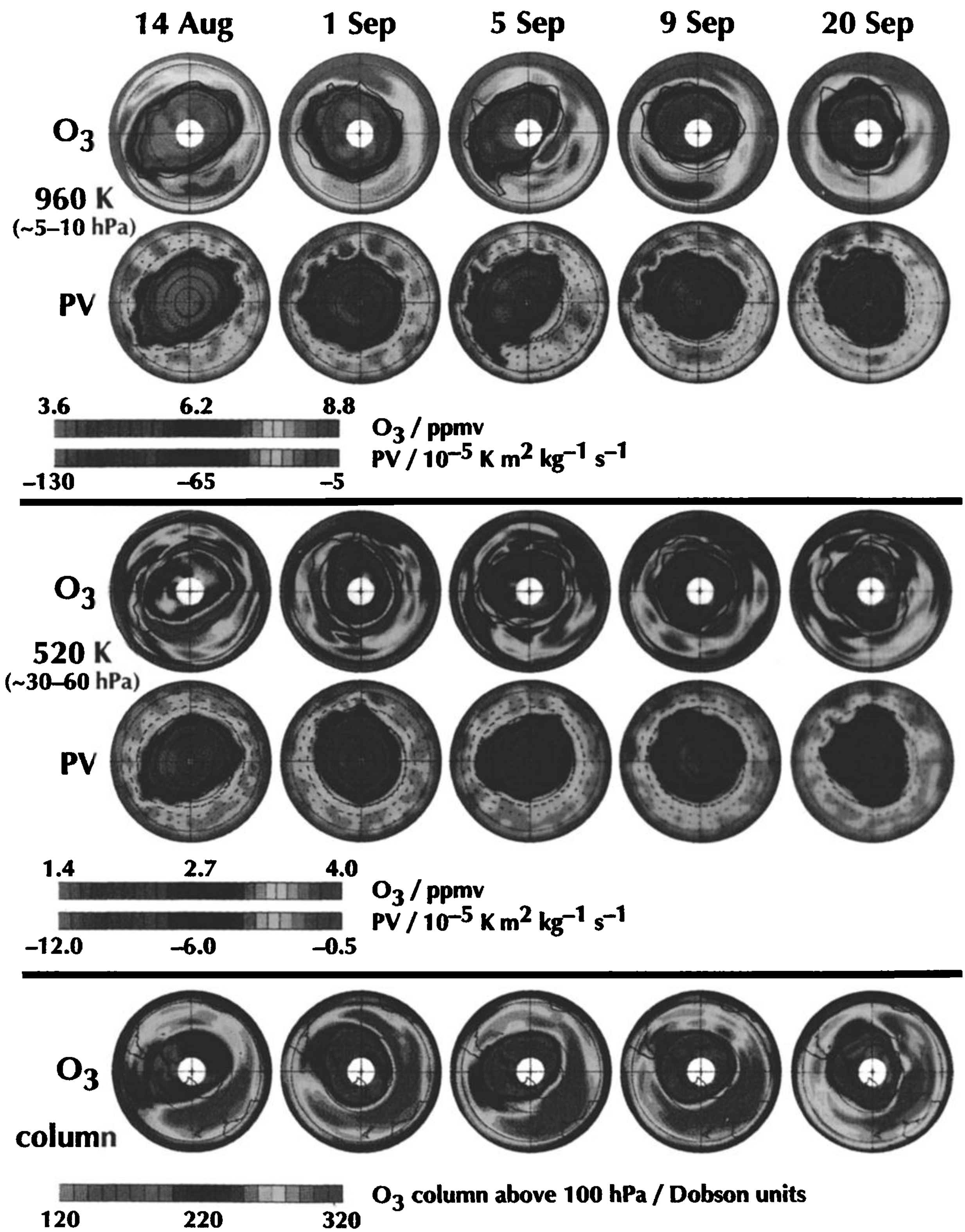

Fig. 2. O_3 and PV at 520 K and 960 K, and O_3 column above 100 mb, at 12 Z. The projection is orthographic, with the Greenwich meridian toward the top of the page; 30° and 60° latitude circles are shown. PV contours of -50 and -80 $\times 10^{-5}$ $Km^2kg^{-1}s^{-1}$ are shown on the 960 K O_3 plots, and -4 and -6 $\times 10^{-5}$ $Km^2kg^{-1}s^{-1}$ on the 520 K O_3 plot, showing "liberal" and "conservative" definitions of the polar vortex.

polar vortex, from 465 K (≈50-60 hPa) to 1450 K (≈1-2 hPa). Column 2 shows that the polar vortex decreases in size. This happens gradually in the lower stratosphere, at 465 and 520 K. At higher levels (especially between 840 and 1100 K), a rapid decrease in vortex size occurs in the first week of September, due to a minor stratospheric warming [Fishbein et al., 1993].

O_3 mass in the polar vortex (column 1) decreases in the lower stratosphere (465 K through 585 K). An overall increase is seen in the mid-stratosphere (840 to 1100 K). O_3 mass decreases during the minor warming at levels above 655 K, but returns to higher values afterwards. To the extent that O_3 and PV behave as conservative tracers, the trends in O_3 mass should reflect those in the vortex size [e.g., Haynes and McIntyre 1987], and the average O_3 mixing ratio (column 3) should be approximately constant.

Column 3 shows average O_3 mixing ratio in the polar vortex. The steady decrease in O_3 at 465 and 520 K appears consistent with the dominant mechanism for changing O_3 being destruction by chlorine chemistry [e.g., Solomon 1990]. Waters et al. [1993b] show that ClO is elevated in the polar vortex throughout this time period, with largest values in August, and elevated values up to pressures of 22 hPa. At 585 K and 655 K (near 22 hPa), little change is seen in O_3 mixing ratio. This, and the slower decrease in O_3 at the beginning of the time series at the lower levels, suggests that dynamical effects mask some photochemical destruction.

In the upper stratosphere, O_3 becomes more sensitive to local temperature-dependent photochemistry, which has short time scales compared to those for transport [e.g. Perliski et al., 1989]; hence, O_3 is generally anti-correlated with temperature. Since temperature increases in the upper stratosphere at this time, O_3 is expected to decrease. This change to photochemically controlled behavior is apparent in the flattening of the average O_3 mixing ratio trend at 1450 K.

In the mid-stratosphere, O_3 mixing ratios increase in the polar vortex. From 840 to 1100 K, an abrupt increase in O_3 mixing ratio is seen coincident with the decrease in vortex size during a minor warming. This suggests that transport associated with increased planetary scale wave activity contributes to increasing O_3 here. Previous studies [e.g., Rood and Schoeberl 1983; Wu et al. 1987] show strong diabatic descent in the middle and upper stratosphere, and poleward and downward O_3 transport at high latitudes throughout the stratosphere during late winter. A similar, although slightly smaller, sudden increase is seen at these levels when the integral is done using a "conservative" definition of the polar vortex, suggesting that the enhanced transport is not confined to regions near the "edge" of the vortex.

Figure 2 shows O_3 and PV at 520 K and 960 K, and column O_3 above 100 hPa. The large O_3 decrease in the polar vortex at 520 K is apparent, as well as the increase at 960 K. On 5 Sep a tongue of high O_3 extends from low latitudes into the polar regions, and low O_3 is drawn off the edge of the vortex. The corresponding PV map also shows values representative of low latitudes extending toward the pole, and the wind vectors show strong poleward flow associated with this. Evidence of transport into the polar regions is also seen at this level on the other days shown.

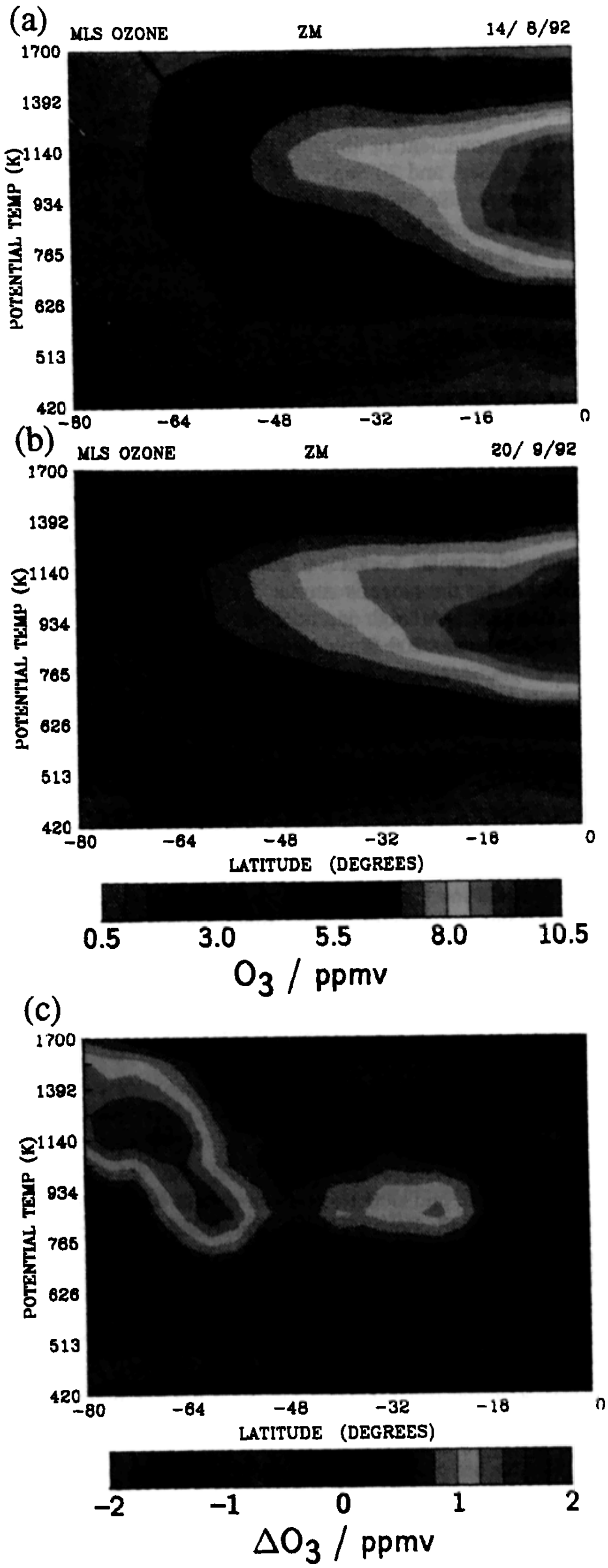

Fig. 3. (a) and (b) Zonal mean O_3 mixing ratio, and an indication of the "zonal mean polar vortex", on 14 Aug and 20 Sep 1992; (c) difference between (b) and (a), with negative values indicating ozone loss. The zero contour is outlined.

Planetary wave activity generally increases in August and September [Manney et al. 1991], leading to more transport. Much less distortion of the vortex is apparent in the lower stratosphere; however, the PV and O_3 maps do show some poleward movement of air from low latitudes, especially on 14 Aug, 1 Sep, and 20 Sep.

Figure 2 also shows column O_3 decreasing steadily in the polar regions; minimum values of column O_3 on 20 Sep are ≈30% lower than on 14 Aug. The increase in column O_3 outside the vortex region is expected from the climatological seasonal variation of O_3. The distortion of the polar vortex in the middle and upper stratosphere during times of strong planetary wave activity is large enough to be apparent in column O_3, although lower stratospheric ozone dominates this field; on 5 Sep, for instance, column O_3 is considerably more distorted than O_3 at 520 K.

Figure 3 shows zonal mean O_3 as a function of potential temperature on 14 Aug and 20 Sep, and the difference between the two days. Thick lines show an estimate of the "zonal mean polar vortex", a contour of zonal mean PV scaled so that the range is similar at all levels [Manney and Zurek, 1993]. At high latitudes, vertical gradients of O_3 are small above ≈700 K on 14 Aug, so although the direction of gradients implies that higher O_3 is transported to levels below approximately 1100 K by descent, this effect is not large enough to explain the observed increase in the mid-stratosphere (much of which in fact occurs near or slightly above the peak in O_3 mixing ratio). Downward transport could, however, account for the fact that the average O_3 mixing ratio in the vortex (column 3 of Figure 1) does not decrease at 585 and 655 K, as this influx of higher values would mask chemical destruction. By 20 Sep, vertical gradients have increased at high latitudes in the mid-stratosphere, and contours of relatively high O_3 have moved poleward and slightly downward in the mid-stratosphere. These changes suggest that horizontal transport plays a large role in the mid-stratospheric increase in O_3.

Summary and Conclusions

As shown in Figures 1 and 3c, O_3 mixing ratios observed by UARS MLS decrease in the polar vortex between 420 K and 600 K, consistent with the occurrence of chemical destruction, with the largest decrease (≈70% in the zonal mean) near 465 K. Downward transport appears to mask some of the chemical destruction. A decrease is seen as far equatorward as 40°S, well outside the polar vortex, and as high as 740 K near 80°S. O_3 increases in a broad region in the mid to upper stratosphere, with the largest (≈40% in the zonal mean) increase at high latitudes near 1100 K, where horizontal transport of O_3 during times of strong planetary wave activity appears to be important.

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