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LARGE-SCALE VARIATIONS IN OZONE AND POLAR STRATOSPHERIC CLOUDS MEASURED WITH AIRBORNE LIDAR DURING FORMATION OF THE 1987 OZONE HOLE OVER ANTARCTICA

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NTD210491
S476829
MV341214-1
NC999
NJ920144

A joint field experiment between NASA and NOAA was conducted during August-September 1987 to obtain in situ and remote measurements of key gases and aerosols from aircraft platforms during the formation of the ozone (O_3) hole over Antarctica. The ER-2 (advanced U-2) and DC-8 aircraft from the NASA Ames Research Center were used in this field experiment. The NASA Langley Research Center's airborne differential absorption lidar (DIAL) system was operated from the DC-8 to obtain profiles of O_3 and polar stratospheric clouds in the lower stratosphere during long-range flights over Antarctica from August 28 to September 29, 1987. The airborne DIAL system was configured to transmit simultaneously four laser wavelengths (301, 311, 622, and 1064 nm) above the DC-8 for DIAL measurements of O_3 profiles between 11-20 km ASL (geometric altitude above sea level) and multiple wavelength aerosol backscatter measurements between 11-24 km ASL. A total of 13 DC-8 flights were made over Antarctica with 2 flights reaching the South Pole.

Polar stratospheric clouds (PSCs) were detected in multiple thin layers in the 11-21 km ASL altitude range with each layer having a typical thickness of <1 km. Two types of PSCs were found during this experiment. Prior to September 15, 1987, many PSCs had aerosol backscattering ratios (aerosol backscattering/molecular backscattering) of >50 at 1064 nm and >10 at 622 nm, which are typical for predominantly water ice clouds (Type II PSC). This was also the period when the temperatures over Antarctica were the coldest with many regions below 190 K. After that date, the predominant type of PSC had aerosol scattering ratios an order of magnitude lower than those of the ice clouds. The scattering characteristics of these PSCs (Type I), which are expected to be present when temperatures are between 190-195 K, are consistent with the modeling of binary solid nitric acid/water clouds discussed in a companion paper (Poole et al.). Type I PSCs were also found in the warmer regions adjacent to Type II PSCs, and Type II PSCs were found as late as September 29 at latitudes >75°S on the last DC-8 mission. Many PSCs were found to be very large in vertical and horizontal extent. The larger PSCs were observed to extend from below 13 km ASL to above 18 km ASL with considerable vertical structure. These PSCs were found to extend more than 5° in latitude at the lower altitudes and more than 10° in latitude at the upper altitudes. The source of some of the thin layers seen at the upper altitudes in other locations was the result of wind shear and advection of air from the tops of these larger systems. Figure 1 shows an example of the atmospheric backscattering ratio (aerosol backscattering ratio + 1) profiles across a major PSC event with temperatures below 190 K across the 13-17 km ASL altitude

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region. At these low temperatures, the aerosols are expected to be composed of ice crystals, and the magnitude of the backscattering ratio and the wavelength dependence of the aerosol backscattering ratio are also consistent with this assumption. The multilayer structure seen in both the 622 and 1064 nm scattering ratio profiles was common to most of the PSCs observed during this experiment. An example of the backscattering ratios observed from PSCs following the large-scale warming over Antarctica between September 14 and 16 is shown in Figure 2. The aerosol scattering ratios found for these Type I PSCs were more than an order of magnitude smaller than those found in the colder temperature regions prior to the warming, and temperatures across the 13-22 km ASL altitude region were in the 190-195 K range. These characteristics are both consistent with the modeling of the binary solid nitric acid/water PSCs.

Two distinct altitude regions were observed for aerosols across the polar vortex "wall." Below 13-14 km ASL, there was not a significant change in the aerosol properties upon going from outside to inside the vortex. This is consistent with other evidence that there is not a strong barrier to meridional transport across the vortex "wall" below 14 km ASL. At the upper altitudes (>14 km ASL), PSCs were found in conjunction with cold temperatures (<190 K) at latitudes typically >64°S. Over the period of this experiment, the tops of the highest aerosol layers at latitudes >75°S were observed to descend from 19.5 to 18.5 km ASL at a rate of about 1.5 km mo^{-1}. This is consistent with the subsidence rate determined from SAM-II (Stratospheric Aerosol Measurement-II) satellite aerosol extinction data. Over this same period, the tops of the primary PSCs were found to have a nearly constant average height of 17.1 km ASL. Details of the distribution and scattering characteristics of the PSCs observed during the O_3 hole formation are discussed in this paper.

Large-scale cross sections of O_3 distributions were obtained between 11-20 km ASL inside and outside the vortex with vertical and horizontal resolutions of 300 m and 12 km, respectively. Trends seen in the airborne DIAL O_3 data compared well with the trends in the O_3 column abundance data obtained from the TOMS (Total Ozone Mapping System) satellite instrument. Figure 3 shows an example of the trend in the DIAL O_3 data integrated between 13-18 km ASL as a function of latitude. The same relative trend was seen in the TOMS data with the major change in the O_3 column content along the outbound flight track at about 64°S. The location of the maximum horizontal gradient in the DIAL measured O_3 was found to consistently occur near the 250 DU (Dobson Unit) O_3 isopleth obtained from TOMS. The O_3 depletion trend seen by TOMS inside the vortex was strongly reflected in the DIAL measurements above 100 mb. Figure 4 shows the variation in the average O_3 concentration at high latitudes (>76°S) in two altitude regions from late August until late September. The average concentration of O_3 did not change substantially below 15 km ASL over that period; however, between 15-20 km ASL, O_3 decreased by more than 50%. Measurements on September 26 provided evidence that even strong O_3 depletion was taking place near 21 km ASL. At 72°S, where TOMS had indicated an O_3 level of 170 DU, the DIAL measured an O_3 mixing ratio of 0.5 ppmv, which was the lowest level observed at 21 km in real time during this field experiment.

Evidence was found for tropopause fold events occurring inside the vortex. During DIAL measurements on September 5, a tongue of high O_3 air in a layer having a thickness of about 2 km was observed near 68°S to be inclined from above 17 km ASL to below 14 km ASL. This layer also had low aerosol scattering, which is also an indicator of a descending clean, dry air mass. An enhancement in the O_3 mixing ratio was also noted by in situ O_3 instruments on the DC-8 at an altitude of 9.4 km ASL. These data provide additional information about a potentially important transport mechanism that may influence the O_3 budget inside the vortex. There is also some evidence that strong low pressure systems in the troposphere are associated with regions of lower stratospheric O_3. The implications of these transport processes in affecting the O_3 depletion inside the vortex are addressed in other papers at this conference. This paper discusses the spatial and temporal variations of O_3 inside and outside the polar vortex region during the development of the O_3 hole and relates these data to other measurements obtained during this field experiment.

The authors would like to thank Neale Mayo, William McCabe, and Jerry Williams for assisting in acquiring the airborne DIAL data during this experiment; Patricia Robinette for producing the color display graphics for the reduced DIAL data; and Arlen Carter, James Siviter, Jr., Neale Mayo, William McCabe, Jerry Williams, Robert Allen, Noah Higdon, Byron Meadows, and Loyd Overbay for modifying the DIAL system for this mission and for installing it for the first time in the DC-8.

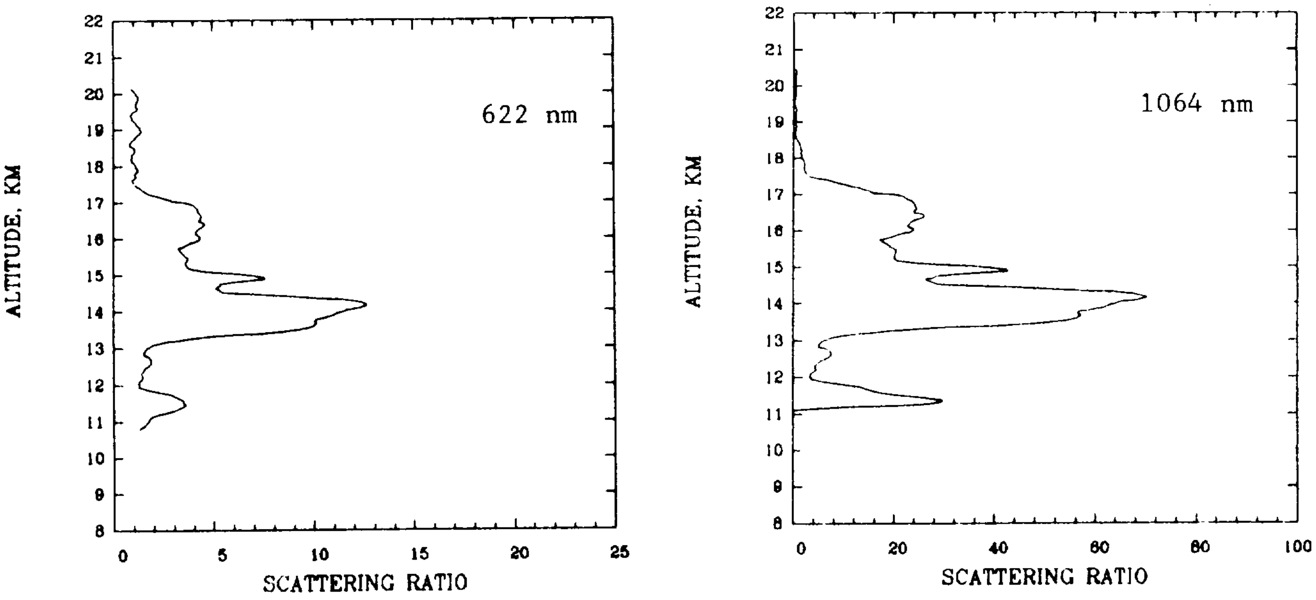

Figure 1. Atmospheric backscattering ratios on September 14, 1987, at 1125 UT and 77°S/48°W.

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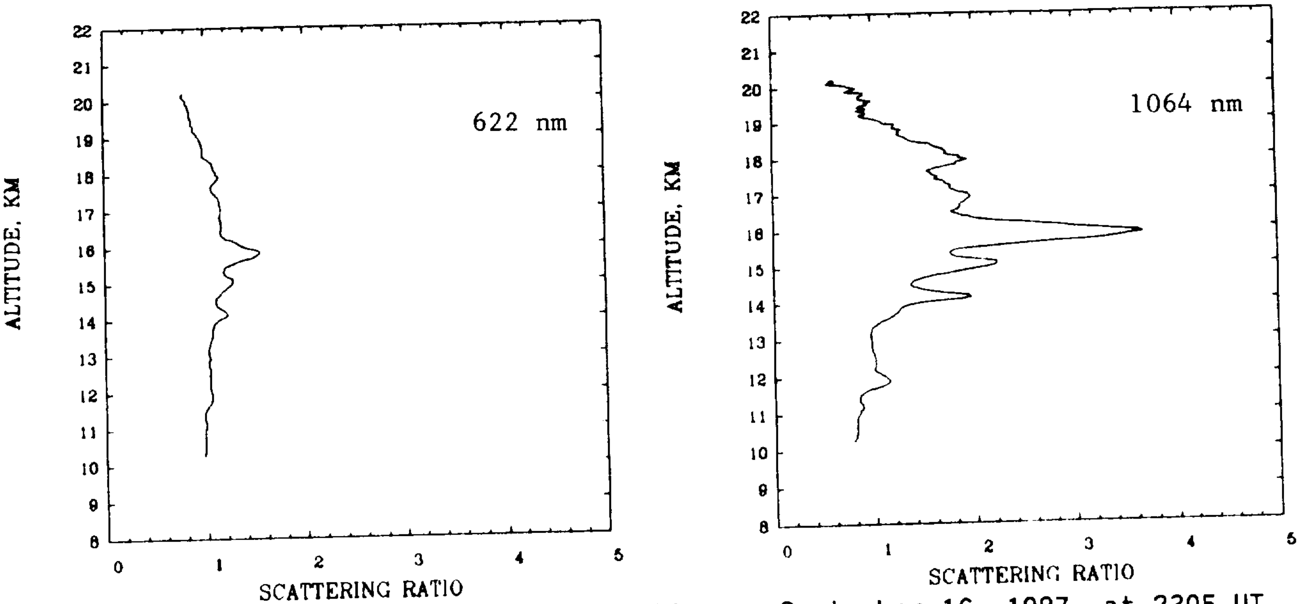

Figure 2. Atmospheric backscattering ratios on September 16, 1987, at 2305 UT and 75°S/56°W.

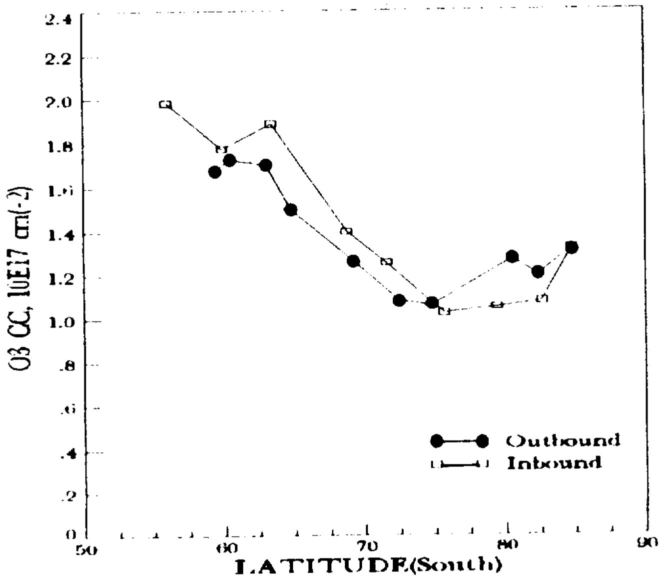

Figure 3. Ozone column content between 13-18 km ASL on September 16, 1987.

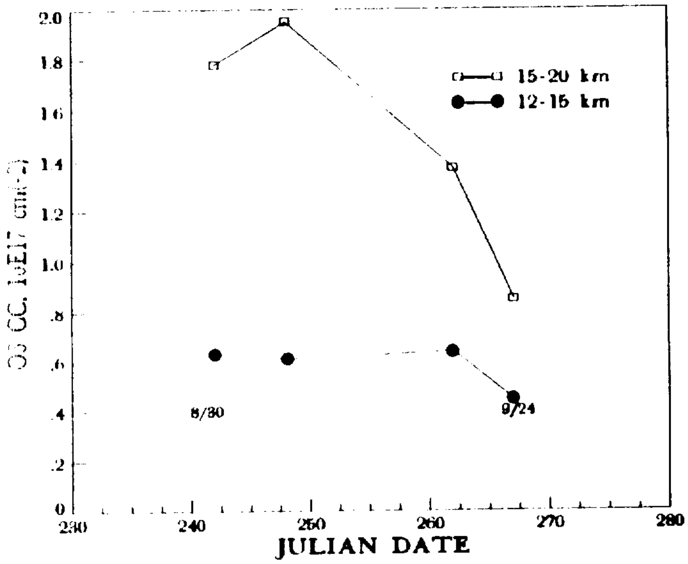

Figure 4. Ozone column content in two altitude regions at latitudes >76°S.