The record large 2006 Antarctic ozone hole

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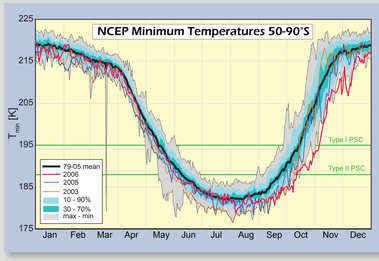

Figure 1. Time series of daily minimum temperatures at the 50 hPa isobaric level south of 50°S. The thick red curve shows 2006. The blue line shows 2005 and the orange line 2003. The average of the 1979-2005 period is shown for comparison in black. The grey shaded area represents the highest and lowest daily minimum temperatures in the 1979-2005 time period. The light blue-green shaded area represents the 10th and 90th percentile values and the dark blue-green shaded area the 30th and 70th percentiles. The two horizontal green lines at 195 and 188 K show the thresholds for formation of PSCs of type I and type II, respectively. The plot is made with NCEP data downloaded from the Ozonewatch web site at NASA. It can be seen from the figure that the minimum temperatures from mid-September until early December on many days were the coldest ever since 1979.

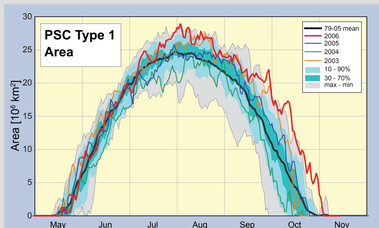

Figure 2. Time series of the area where temperatures are low enough for the formation of PSCs of type I at the 450 K isentropic level. This isentropic level corresponds to an altitude of approximately 17 km. The thick red curve shows 2006. The blue, green and orange curves represent 2005, 2004 and 2003, respectively. The average of the 1979-2005 period is shown for comparison in black. The grey shaded area represents the largest and smallest daily PSC areas in the 1979-2005 time period. The light blue-green shaded area represents the 10th and 90th percentile values and the dark blue-green shaded area the 30th and 70th percentiles. The plot is based on data from NOAA's Climate Prediction Center. It can be seen from the figure that the PSC area just reached the highest ever for the 1979-2005 time period in early August 2006 and that it was significantly higher than for any other year of this time period on most days in late September and October.

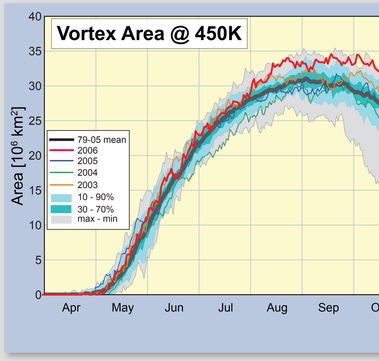

Figure 3. Time series of the area of the south polar vortex at the isentropic level of 450 K (~17 km). The area is defined as the region where potential vorticity is less than -32·10⁻⁶ Km²/kgs. The thick red curve shows 2006. The blue, green and orange curves represent 2005, 2004 and 2003, respectively. The average of the 1986-2005 period is shown for comparison in dark grey. The grey shaded area represents the largest and smallest daily vortex sizes in the 1979-2005 time period. The light blue-green shaded area represents the 10th and 90th percentile values and the dark blue-green shaded area the 30th and 70th percentiles. The plot is based on data from NOAA's Climate Prediction Center. It can be seen from the figure that the vortex area was near the 1979-2005 average during the early stages of the winter and that it was larger than normal for the season from August until mid-December. On some days it was larger than ever measured for those days since 1979.

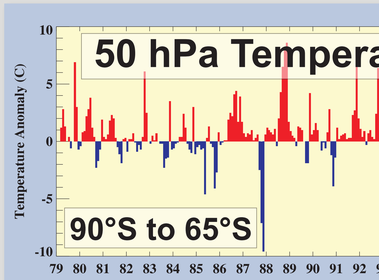

Figure 4. Temperature anomaly at the 50 hPa isobaric level for the region south of 65°S. Anomalies are deviations of monthly mean temperatures from the long-term (1979-2005) average for each month. Temperatures are from NOAA's Climate Prediction Center. One can see a cooling trend since the mid-1990s, and this trend is strengthened by the low temperatures in the 2006 south polar vortex.

Ground-based observations

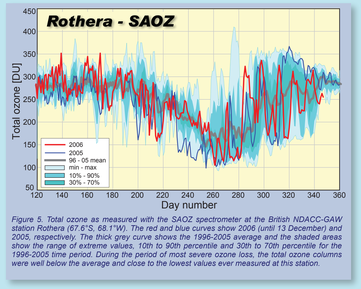

Figure 5. Total ozone as measured with the SAOZ spectrometer at the British NDACC-GAW station Rothera (67.6°S, 68.1°W). The red and blue curves show 2006 (until 13 December) and 2005, respectively. The thick grey curve shows the 1996-2005 average and the shaded areas show the range of extreme values, 10th to 90th percentile and 30th to 70th percentile for the 1996-2005 time period. During the period of most severe ozone loss, the total ozone columns were well below the average and close to the lowest values ever measured at this station.

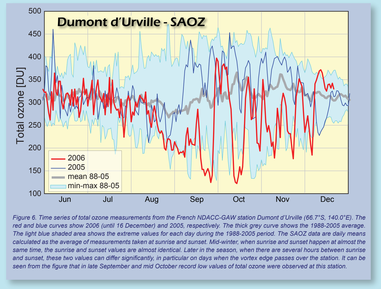

Figure 6. Time series of total ozone measurements from the French NDACC-GAW station Dumont d'Urville (66.7°S, 140.0°E). The red and blue curves show 2006 (until 16 December) and 2005, respectively. The thick grey curve shows the 1988-2005 average. The light blue shaded area shows the extreme values for each day during the 1988-2005 period. The SAOZ data are daily means calculated as the average of measurements taken at sunrise and sunset. Mid-winter, when sunrise and sunset happen at almost the same time, the sunrise and sunset values are almost identical. Later in the season, when there are several hours between sunrise and sunset, these two values can differ significantly, in particular on days when the vortex edge passes over the station. It can be seen from the figure that in late September and mid October record low values of total ozone were observed at this station.

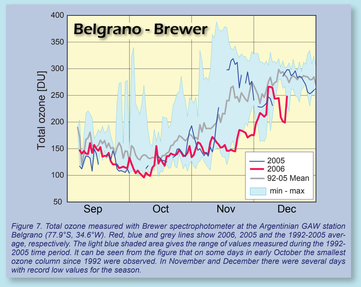

Figure 7. Total ozone measured with Brewer spectrophotometer at the Argentinian GAW station Belgrano (77.9°S, 34.6°W). Red, blue and grey lines show 2006, 2005 and the 1992-2005 average, respectively. The light blue shaded area gives the range of values measured during the 1992-2005 time period. It can be seen from the figure that on some days in early October the smallest ozone column since 1992 were observed. In November and December there were several days with record low values for the season.

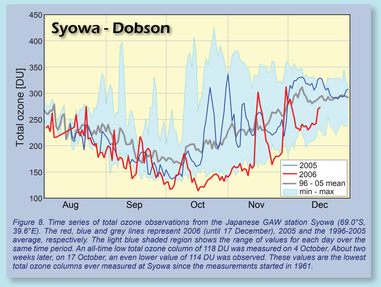

Figure 8. Time series of total ozone observations from the Japanese GAW station Syowa (69.0°S, 39.6°E). The red, blue and grey lines represent 2006 (until 17 December), 2005 and the 1996-2005 average, respectively. The light blue shaded region shows the range of values for each day over the same time period. An all-time low total ozone column of 118 DU was measured on 4 October. About two weeks later, on 17 October, an even lower value of 114 DU was observed. These values are the lowest total ozone columns ever measured at Syowa since the measurements started in 1961.

Ozonesonde observations

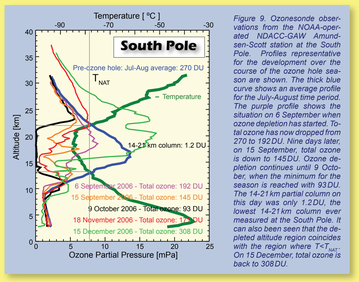

Figure 9. Ozonesonde observations from the NOAA-operated NDACC-GAW Amundsen-Scott station at the South Pole. Profiles representative for the development over the course of the ozone hole season are shown. The thick blue curve shows an average profile for the July-August time period. The purple profile shows the situation on 6 September when ozone depletion has started. Total ozone has now dropped from 270 to 192 DU. Nine days later, on 15 September, total ozone is down to 145 DU. Ozone depletion continues until 9 October, when the minimum for the season is reached with 93 DU. The 14-21 km partial column on this day was only 1.2 DU, the lowest 14-21 km column ever measured at the South Pole. It can also been seen that the depleted altitude region coincides with the region where T<T NAT. On 15 December, total ozone is back to 308 DU.

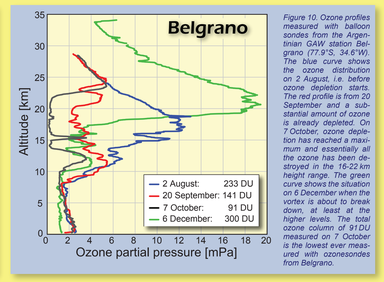

Figure 10. Ozone profiles measured with balloon sondes from the Argentinian GAW station Belgrano (77.9°S, 34.6°W). The blue curve shows the ozone distribution on 2 August, i.e. before ozone depletion starts. The red profile is from 20 September and a substantial amount of ozone is already depleted. On 7 October, ozone depletion has reached a maximum and essentially all the ozone has been destroyed in the 16-22 km height range. The green curve shows the situation on 6 December when the vortex is about to break down, at least at the higher levels. The total ozone column of 91 DU measured on 7 October is the lowest ever measured with ozonesondes from Belgrano.

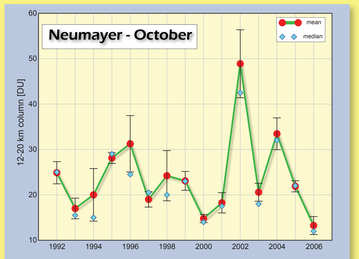

Figure 11. October monthly means and medians of the partial ozone column in the 12-20 km height range. The data are based on ozone soundings from the German GAW station at Neumayer. Data from the beginning of the time series in 1999 until present have been included. The 12-20 km range has been chosen since this is the region where ozone depletion usually is the most severe. The green curve with the red dots shows the arithmetic mean and the cyan diamonds show the median. The error bars on the arithmetic mean curve are standard errors of the mean (1σ).

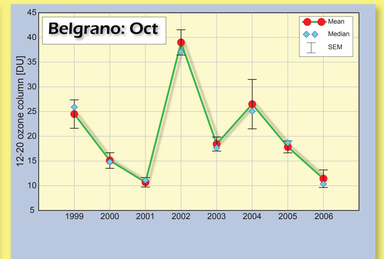

Figure 12. October monthly means and medians of the partial ozone column in the 12-20 km height range. The data are based on ozone soundings from the Argentinian GAW station at Belgrano. Data from the beginning of the time series in 1999 until present have been included. The 12-20 km range has been chosen since this is the region where ozone depletion usually is the most severe. The green curve with the red dots shows the arithmetic mean and the cyan diamonds show the median. The error bars on the arithmetic mean curve are standard errors of the mean (1σ).

Satellite observations

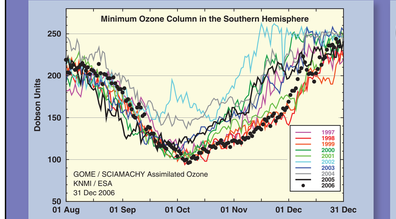

Figure 13. Daily minimum total ozone columns in the Southern Hemisphere as observed by GOME and SCIAMACHY from 1997 to now. The plot is provided by the Netherlands Meteorological Institute (KNMI).

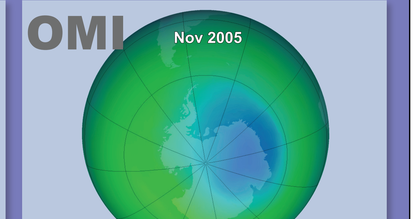

Figure 15. Average total ozone maps for the month of November for 2005 and 2006 based on data from OMI on board the AURA satellite. The data are processed and mapped at NASA.

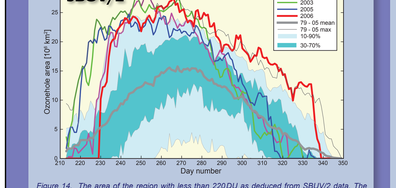

Figure 14. The area of the region with less than 220 DU as deduced from SBUV/2 data. The 1979-2005 average is given by the thick grey curve and the maximum for any given day during the 1979-2006 time period is given by the thin black line. The dark green-blue shaded area represents the 30th to 70th percentiles and the light green-blue shaded area represents the 10th and 90th percentiles for the time period 1979-2005.

Ozone hole statistics

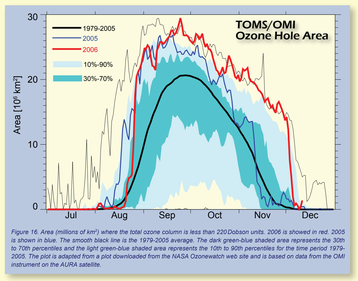

Figure 16. Area (millions of km²) where the total ozone column is less than 220 Dobson units. 2006 is showed in red. 2005 is shown in blue. The smooth black line is the 1979-2005 average. The dark green-blue shaded area represents the 30th to 70th percentiles and the light green-blue shaded area represents the 10th to 90th percentiles for the time period 1979-2005. The plot is adapted from a plot downloaded from the NASA Ozonewatch web site and is based on data from the OMI instrument on the AURA satellite.

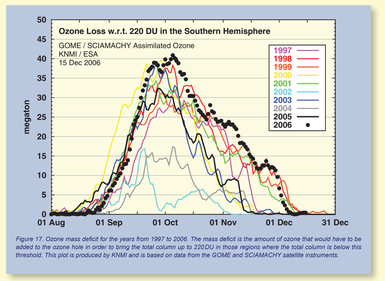

Figure 17. Ozone mass deficit for the years from 1997 to 2006. The mass deficit is the amount of ozone that would have to be added to the ozone hole in order to bring the total column up to 220 DU in those regions where the total column is below this threshold. This plot is produced by KNMI and is based on data from the GOME and SCIAMACHY satellite instruments.

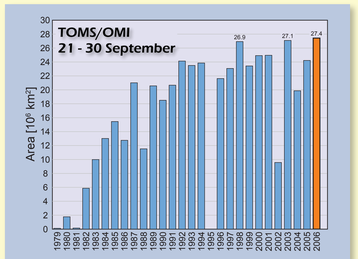

Figure 18. The size of the Antarctic ozone hole averaged over the last ten days of September as derived from the TOMS and OMI satellite data. The data cover the time period from 1979 to 2006, but in 1995 there were no measurements. The three years with the largest ozone hole, averaged over this time period are 1998, 2003 and 2006 with 26.9, 27.1 and 27.4 million km², respectively. The numbers used to generate this plot was provided by the NASA Goddard Space Flight Center.

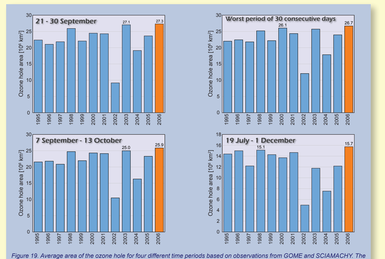

Figure 19. Average area of the ozone hole for four different time periods based on observations from GOME and SCIAMACHY. The upper left panel is for the last ten days of September, a period when the ozone hole usually is at its largest. The lower left panel is for the period 7 September - 13 October, which covers the period of both largest area and most severe mass deficit. Since the date of the peak area can vary from one year to another it also makes sense to look at the period of 30 consecutive days that gives the largest average ozone hole area. This is shown in the upper right panel. Finally, one can also look at the entire ozone hole season from before the onset of ozone depletion until the ozone hole is virtually dissolved. The period chosen is from 19 July to 1 December, and this is shown in the lower right panel. Data for these plots were provided by KNMI.