

Depletion of ozone over Antarctica during 2006

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सार – वर्ष 2003 से 2004 तक ओजोन छिद्र क्षेत्र में अत्याधिक कमी और तत्पश्चात् पुनः वर्ष 2004 से 2005 तक तथा पुनः वर्ष 2005 से 2006 तक अत्याधिक वृद्धि को अंत वार्षिक गतिकीय भिन्नता के कारण होने वाली समतापमंडलीय हैलोजेन भारण के परिवर्तनों द्वारा स्पष्ट रूप से बताया नहीं जा सकता है। इस भिन्नता से एंटार्कटिका में ओजोन की वापसी के आरम्भ का पता लगाने में कठिनाई होगी और विशेष रूप से ओजोन का कम करने वाले तत्वों से ओजोन में क्षीण होती हुई मात्रा को किसी भी प्रकार के सकारात्मक परिवर्तन को बताने में कठिनाई होगी। मौसम वैज्ञानिक आँकड़ों और उपग्रहों पर आधारित विश्लेषण के अतिरिक्त इस शोध-पत्र में बहुत से केन्द्रों से प्राप्त परिणामों को सम्मिलित किया गया है। वर्ष 2006 के कुल ओजोन और ओजोनसौन्दे आँकड़ों की तुलना गत वर्षों के आँकड़ों से की गई है। कई स्टेशनों में कुल ओजोन स्तम्भों को प्रेक्षण किया गया है जो उन केन्द्रों के लिए हमेशा न्यूनतम के निकट रहे हैं। कुछेक मामलों में रिकार्ड न्यून कुल ओजोन स्तम्भ अभिलेखित किए गए हैं।

ABSTRACT. The large decrease in the ozone hole area from 2003 to 2004 and the large increase again from 2004 to 2005 and again from 2005 to 2006 cannot be explained by changes in stratospheric halogen loading but are due to interannual dynamical variability. This variability will make it difficult to detect the onset of ozone recovery in Antarctica and in particular it will be difficult to attribute any positive change in ozone to declining amounts of ozone depleting substances. In addition to analysis based on meteorological data and satellites, this paper contains results from a number of stations. Total ozone and ozonesonde data for the 2006 season have been compared to data from previous years. Several stations have observed total ozone columns that are close to the all time low for those stations. In some cases record low total ozone columns have been recorded.

Key words – Ozone, Ozone hole, Total ozone, Brewer ozone spectrophotometer, Ozone sonde, Vertical distribution of ozone.

1. Introduction

The meteorological conditions in the Antarctic stratosphere found during the austral winter (June-August) set the stage for the annually recurring ozone hole. Low temperatures lead to the formation of clouds in the stratosphere, so called polar stratosphere clouds (PSCs).

The amount of water vapour in the stratosphere is very low, only 5 out of one million air molecules are water molecules. This means that under normal conditions there are no clouds in the stratosphere. However, when the temperature drops below -78°C , clouds that consists of a mixture of water and nitric acid start to form. These clouds are called PSCs of type I. On the surface of particles in the clouds, chemical reactions occur that transform passive and innocuous halogen compounds (*e.g.* HCl and HBr) into so called active chlorine and bromine species (*e.g.* ClO and BrO). These active forms

of chlorine and bromine cause rapid ozone loss in sun-lit conditions through catalytic cycles where one molecule of ClO can destroy thousands of ozone molecules before it is passivated through the reaction with nitrogen dioxide. (McCormick *et al.*, (1982); Toon *et al.*, (1986) and Crutzen and Arnold (1986).

When temperature drop below -85°C , clouds that consist of pure water ice will form these ice clouds are called PSCs of type II. Particles in both cloud types can grow so large that they no longer float in the air but fall out of the stratosphere. In doing so they bring nitric acid with them. Nitric acid is a reservoir that liberates under sunlight conditions. If NO_2 is physically removed from the stratosphere (a process called denitrification), active chlorine and bromine can destroy many more ozone molecules before they are passivated. The formation of ice clouds will lead to more severe ozone loss than that caused by PSC type I alone since halogen species are

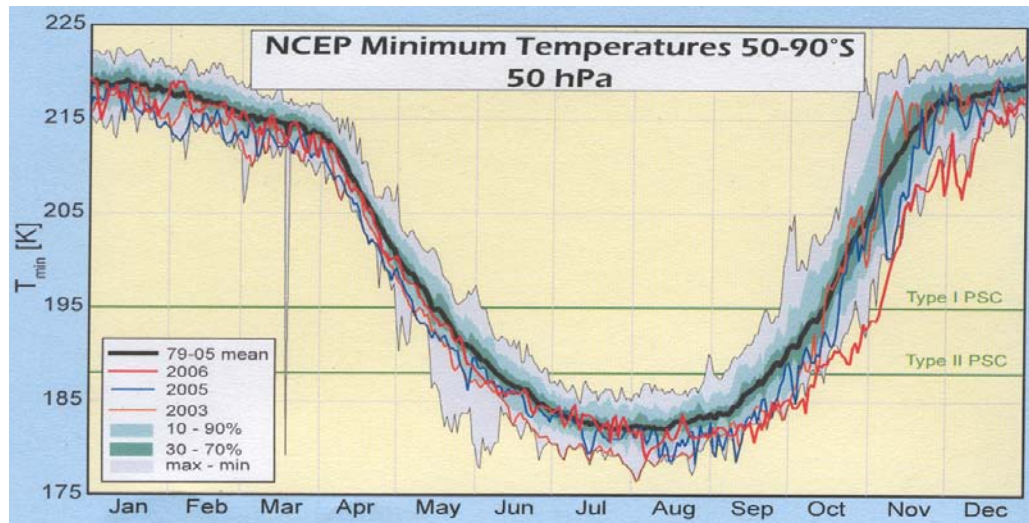


Fig.1. Time series of daily minimum temperature at the 50 hPa isobaric level south of 50° S. The thick red curve shows 2006. The blue line shows 2005 and orange line 2003. The average of the 1979-2005 period is shown for comparison in black. The grey shaded area represents the highest and lowest daily minimum temperature in the 1979-2005 time period. The plot is made with NCEP data downloaded from ozone watch web site at NASA

more effectively activated on the surfaces of the larger ice particles. Peshin *et al.*, (1997) and Kulandaivelu & Peshin (2003).

The Antarctic polar vortex is a large low-pressure system where high velocity winds (polar jet) in the stratosphere circle the Antarctic continent. The region poleward of the polar jet includes the lowest temperatures and the largest ozone losses that occur anywhere in the world. The situation with annually recurring Antarctic ozone holes is expected to continue as long as the stratosphere contains an excess of ozone depleting substances as stated in the recently published Executive Summary of the 2006 edition of the WMO/UNEP Scientific assessment of ozone depletion, severe Antarctic ozone holes are expected to form during the next couple of decades.

2. Instrumentation and data

Total ozone has been measured with Dobson/Brewer spectrophotometer. Details are given below:

2.1. Dobson ozone spectrophotometer

The Dobson spectrophotometer is the standard instrument for measuring the amount of total ozone in a vertical column of the atmosphere. The principle of the Dobson spectrophotometer is based on the fact that the

absorption coefficient of the ozone in the Huggin's band in the near ultraviolet region is a rapidly changing function of wavelength. A pair of wavelength is chosen such that the absorption coefficient of ozone in one wavelength is much greater than that in the other.

By measuring the ratio of intensities of the solar ultraviolet radiation at the ground, received at the two-wave length, it is possible to calculate the total ozone present in the atmosphere in a vertical column above the instrument. [Dobson (1957a); Dobson (1957b) and Dobson & Normand (1962)].

2.2. Brewer ozone spectrophotometer

The Brewer is fully automated allows for near simultaneous observations of total column ozone, Sulphur dioxide, Nitrogen dioxide as well as Ultraviolet radiation. Two axis tracking, appropriate filter sections, wavelength calibration and selection alongwith logging are managed through internal electronics and an IBM compatible PC host computer. Control software for the host computer allows twenty four hour scheduling and for remote unattended operation. The instrument is having accuracy $\pm 1\%$ (on direct sun total ozone).

Details of the Brewer instrument are described by Ker *et al.*, (1980 & 1985).

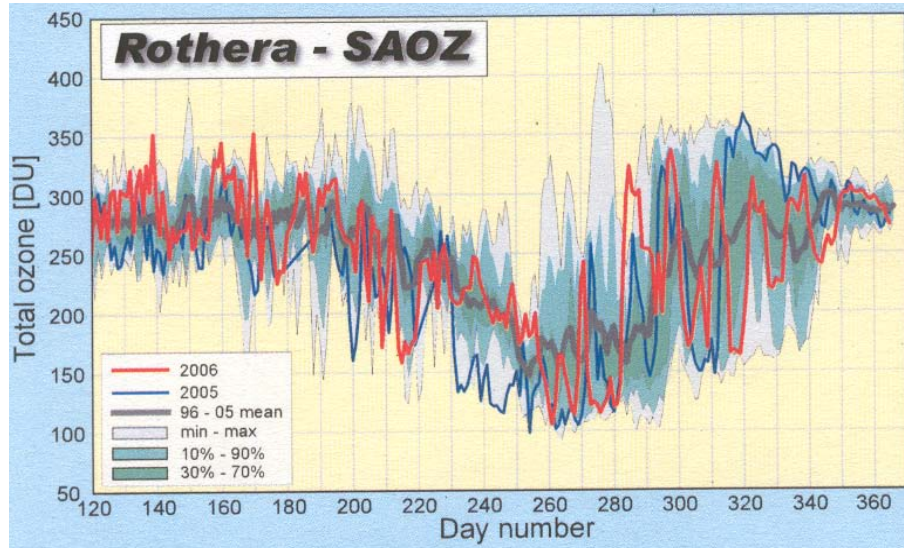


Fig. 2. Total ozone measured at the British station Rothera (67.6° S, 68.1° W). The red and blue curve shows 2006 and 2005, respectively. The thick grey curve shows 1996-2005 average and shaded areas show the range of extreme values, 10th to 90th percentile and 30th to 70th percentile for the 1996-2005 time period

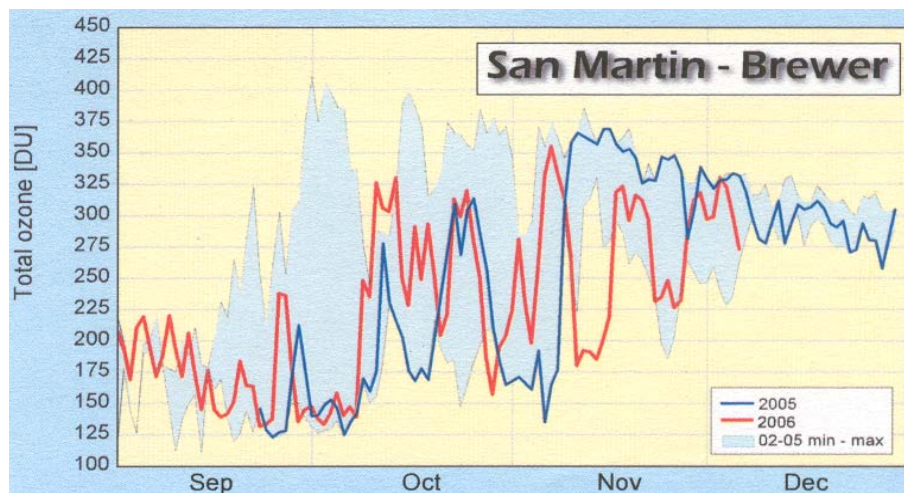


Fig. 3. Total ozone as measured with Brewer spectrophotometer at the Argentine station San Martin (68.1° S, 67.1° W). The red and blue curves show 2006 and 2005 respectively. The shaded areas show the range of extreme values for the 2002-2005 time period

3. Data analysis and discussion

3.1. Meteorological conditions

Minimum temperatures

The Antarctic winter of 2006 was colder than usual, in particular at the end of the winter and into the spring.

Fig. 1 shows the daily minimum temperature at 50 hPa (approx. 20 km) south of 50° S for 2006 in

comparison with some recent years and compared to statistics for the 1979-2005 time period. Minimum temperatures dropped below the threshold for existence of nitric acid trihydrate (polar stratospheric clouds of type I) from mid May and below the ice threshold from early June. During most of the winter until late August the minimum temperature was somewhat below the 1979-2005 average. From early September the minimum temperatures remained very low and on most days during October, November and the beginning of December, they lower than even observed during the 1979-2005 time period.

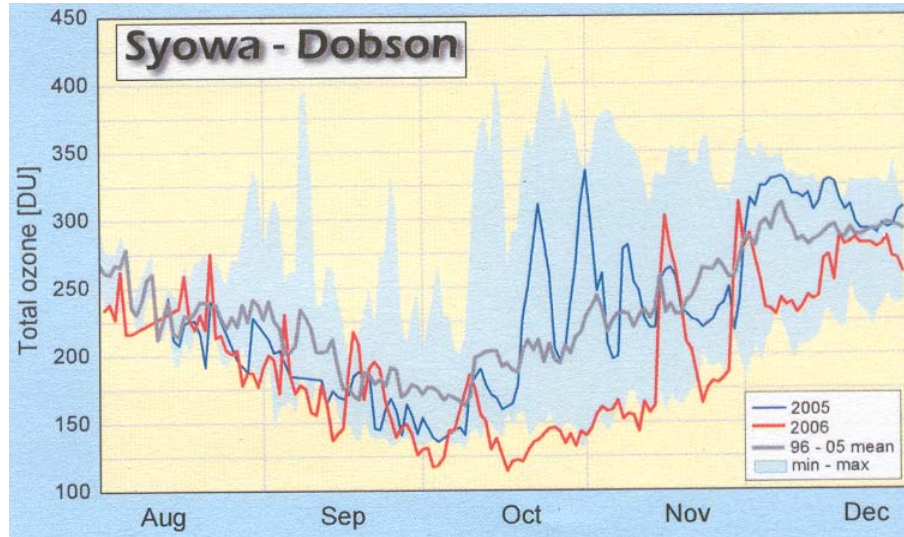


Fig. 4. The series of total ozone observations from the Japanese station Syowa (69.0° S, 39.6° E). The red, blue and grey line represent 2006, 2005 and 1996-2005 average respectively. The light blue shaded region shows the range of values for each day over the same time period. The data has been provided by Japan Meteorological agency

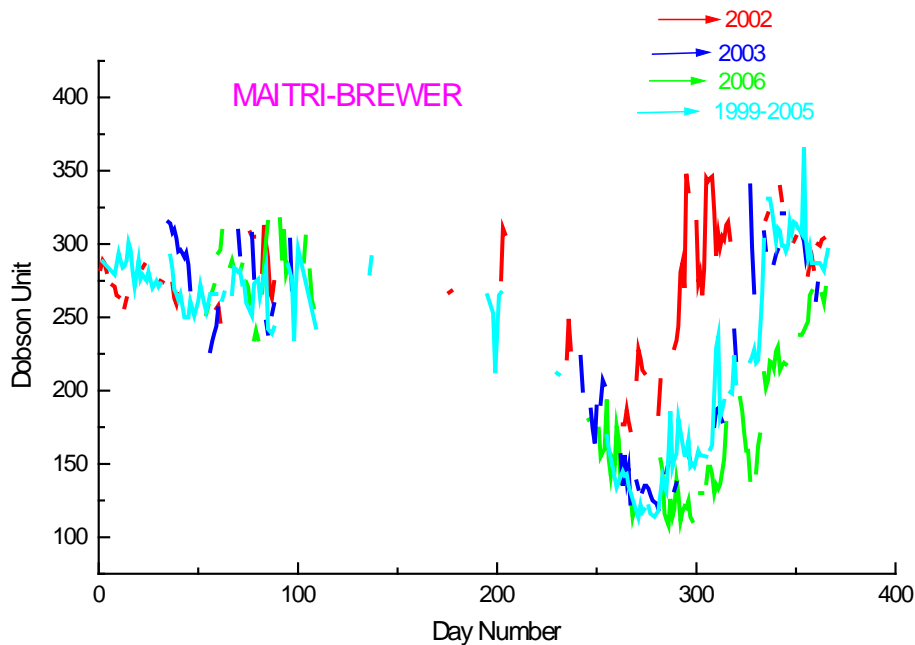


Fig. 5. Total ozone as measured with Brewer ozone spectrophotometer at the Indian station Maitri (70.7° S, 11.7° E). The green, blue, red and cyan curve shows 2006, 2003, 2002 and 1999-2005 respectively

3.2. Ground based ozone observations

Halley

Halley station (73.5° S, 26.7° W) is operated by the British Antarctic Survey. A few moon observations

carried out on August 8 suggested that ozone values were not far from normal at around 300 DU. Mean values were then dropped fairly steadily, reaching around 110 DU in early October (65% down on the normal for the time of year). This corresponds to a decline of roughly 1% per day since early August. Provisionally, the minimum daily

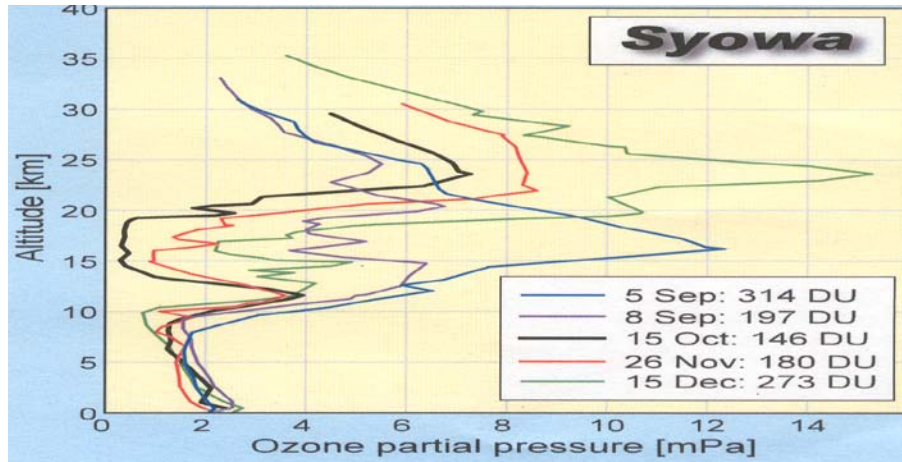


Fig. 6. Ozone profiles from Japanese station Syowa. The blue curve is the average of eight profiles measured during July and August 2006. The blue curve shows the profile recorded on 9th October when total ozone reached the lowest measured in 2006

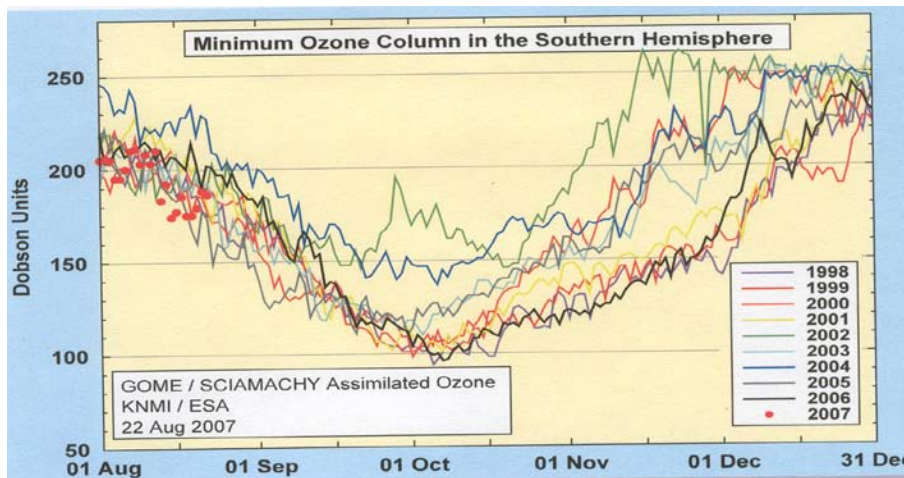


Fig. 7. Daily minimum total ozone columns in the southern hemisphere as observed by GOME and SCIAMACHY end from 1997 to 2006. The plot is provided by Netherlands Meteorological Institute

value recorded was 99 DU on 7 October; the lowest ever recorded at the station. Values rose to just above 180 DU (50% down on the normal for the time of year), but remained roughly constant until late November, when a spring warming began. There was something of a standstill in early December, but after mid month values rose again to reach around 300 DU (15% depletion).

Rothera

Fig. 2 shows total ozone measured with the SAOZ spectrometer at the British NDACC-GAW station Rothera. With this instrument it is possible to measure around the year at this latitude, since it measures at solar

zenith angles around 90. After reaching a minimum of 105 DU on 18 September, the total ozone value varied around the 1996-2005 average as the vortex moved back and forth over the station. Although 2006 saw ozone columns well below the 1996-2005 average on many days, one was never near the record low value of 92 DU, measured on 21 September 2000.

San Martin

San Martin station is operated by Argentina's Servicio Meteorologico Nacional. Total ozone has been measured at this station with Brewer spectrophotometer since 2002.

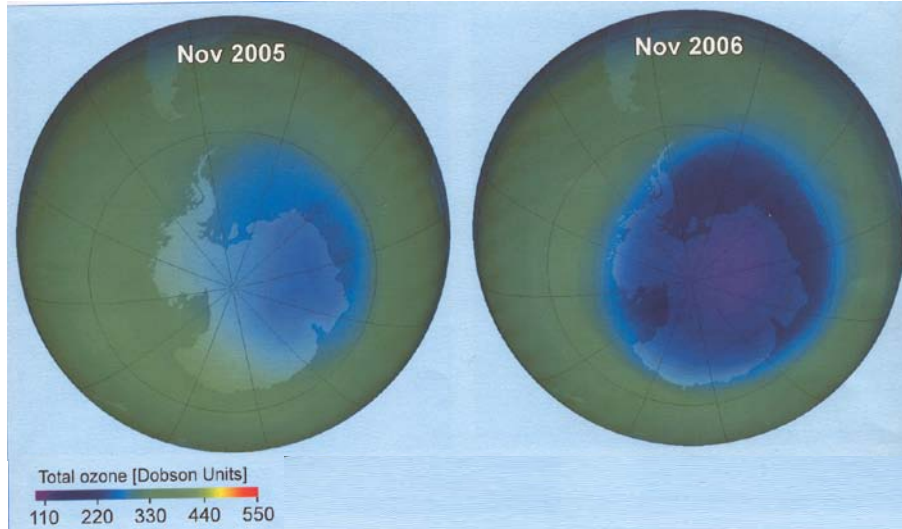


Fig. 8. Average total ozone maps for the month of November for 2005 and 2006 based on data from OMI on board the AURA satellite. The data are processed and mapped at NASA

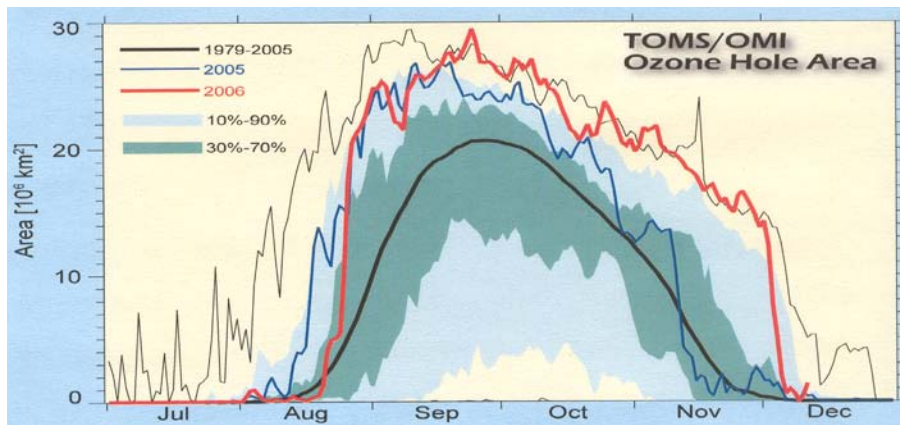


Fig. 9. Area (million of km) where the total ozone column is less than 220 Dobson units. The plot is downloaded from the NASA ozone watch web site and is based on data from OMI instrument on the AURA satellite

Fig. 3 shows the development of the ozone column in 2006 from 1 September to early December in comparison with 2005 and the minimum values.

Syowa

Fig. 4 shows total ozone measured with Dobson spectrophotometer at the Japanese GAW station Syowa. Dobson measurements have been carried out since 1961 at

this station. During the month of August the total ozone column oscillated around the 1996-2005 average. During September, the total ozone column fell rapidly and on 3 October a record low value of 117 DU was recorded. The lowest value recorded before 2006 was 128 DU on 6 October 1995. Column values increased somewhat after 6 October due to a shift of the polar vortex, but then declined again and reached a new minimum of 114 DU on 17 October.

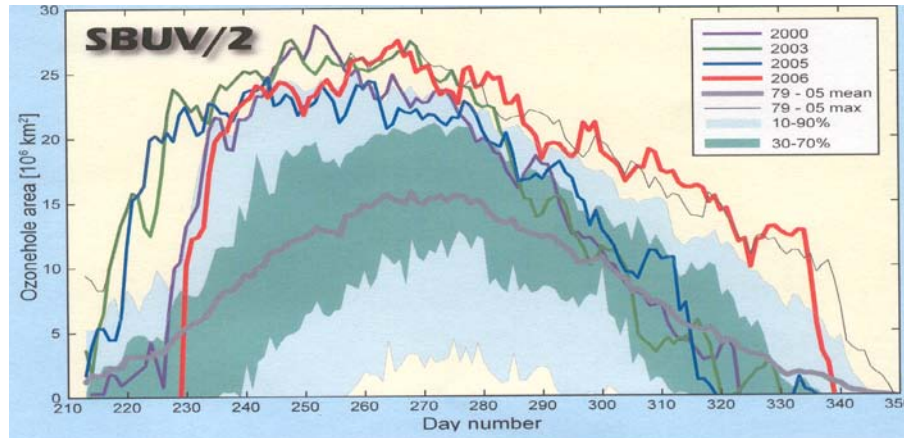


Fig. 10. The area of the region with less than 220 DU as deduced from SBUV/2 data. Data for 2006 shown in red. The blue curve is for 2005. The green for 2003 and the purple for 2000. The 1979-2005 average is given by the thick grey curve

Altogether, nine days during the 2006 season experienced total columns below the previous record low value from 1995.

Maitri

Maitri station (70.7° S, 11.7° E) is operated by India Meteorological Department. Total ozone has been measured at this station with Brewer Ozone spectrophotometer No.153 since 1999.

Fig. 5 shows during September, the total ozone column fell rapidly and on 13 October a record low value of 108 DU was recorded.

4. Ozone observations from balloons

Syowa

The Japanese GAW stations Syowa has a very long record of ozone sonde data, dating back to 1968. This long time series make it possible to see the year-to-year development of the Antarctic ozone hole in a long-term perspective.

The development during the 2006 season is shown in Fig. 6. The first profile (5 September) was taken when the station was outside the polar vortex. The next profile (8 September) was taken inside the vortex and already shows clear signs of depletion in the 15-20 km height range. The 2006 seasonal minimum in total ozone according to the Dobson measurements occurred on 17 October when 114 DU were measured. There was no sounding on that day, but the sounding from 15 October shows nearly complete ozone destruction in the 14-19 km altitude range. After that date ozone recovers, first slowly

until late November (see red curve in the figure) and then more rapidly until mid December (green curve).

5. Ozone observation by satellite

GOME and SCIAMNCHY

Daily minimum values of ozone in the Antarctic region are shown in Fig. 7. The minimum values reached in the beginning of October. Minimum ozone remained very low during all of October and most of November.

TOMS and OMI

Monthly averaged total ozone from OMI, retrieved at NASA, is shown in Fig. 8. One can clearly see that the 2006 ozone hole in November was both larger and deeper than its 2005 counterpart.

6. Ozone hole area and mass deficit

TOMS and OMI

Fig. 9 shows the ozone hole area as derived by NASA from the TOMS and OMI instruments. It is clearly seen that ozone depletion started relatively late. Once the depletion started the ozone hole area increased very rapidly. A maximum of 29.5 million km² was reached on 25 September. This is slightly more than the 29.4 million km² reached in September 2000. One can therefore say that the 2000 and 2006 ozone hole was equally large. During many days of November the ozone hole area was larger than the 1979-2005 maximum. From early December the ozone hole area dropped more rapidly than the average.

SBUV/2

The region where total ozone is less than 220 DU (ozone hole area) as deduced from the NOAA-operated SBUV/2 instrument is shown in Fig. 10. The ozone hole area reached a maximum of 27.5 million km² on 23 September. This is the same as the maximum reached on 25 September 2003, but still somewhat short of the maximum of 28.7 million km² reached on 9 September 2000. During the first two weeks of October, the ozone hole area as measured with SBUV/2 was higher than any year since 1979, for that time of the year. After that, the ozone hole area decreased fairly rapidly but from late October until the end of November, the ozone hole area has on most days been as large as, or larger than any year since 1979.

7. Conclusion

The 2006 south polar vortex was one of the coldest, largest and most stable on record (1979-present). Minimum temperature inside the vortex was closed to the long-term average until late July. After that they started to deviate from the average. From early September, the minimum temperature remained very low and most days during October, November and the beginning of December, they are lower than ever observed during 1979-2005 time period. The area of the region with temperatures cold enough, the formation of PSCs of type 1 (NAT) was near average from the onset on mid May until late June. After that the so-called PSC area increased rapidly and remained well above the average until the end in late October. On many days in September and in particular in October, the PSC area was higher than ever (1979-2005) for that time of the year. From min May until late July the area of south polar vortex was slightly above the 1979-2005 average. After that the vortex size increased more rapidly than normal and was above the 90th percentile until mid November. From then until the breakdown in December, the vortex on most days larger than ever during the 1979-2005 time period. The longitudinally averaged poleward heat flux was significantly lower than the 1979-2005 average from late May until mid December. During most of the winter it was much smaller than the heat flux calculated for some recent winter, such as 2003 and 2005. However, the heat flux was larger than in the 1987 winter, showing that even colder and even more stable vortices than the one seen in 2006 could be expected. Continued observations from the ground, from balloons and from satellites of the three dimensional distribution of ozone, and substances that affect ozone are necessary to obtaining the understanding we need to identify ozone recovery and to attribute it to changes in the stratospheric halogen loading. A better understanding of vortex dynamics and its coupling to

external forcing, such as quasi-biannual oscillation, as well as the effects of changes in greenhouse gases and temperature is also needed to interpret the observations of the Antarctic ozone layer.

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