GOME observations of the NH and SH ozone holes in 1996 and 1997

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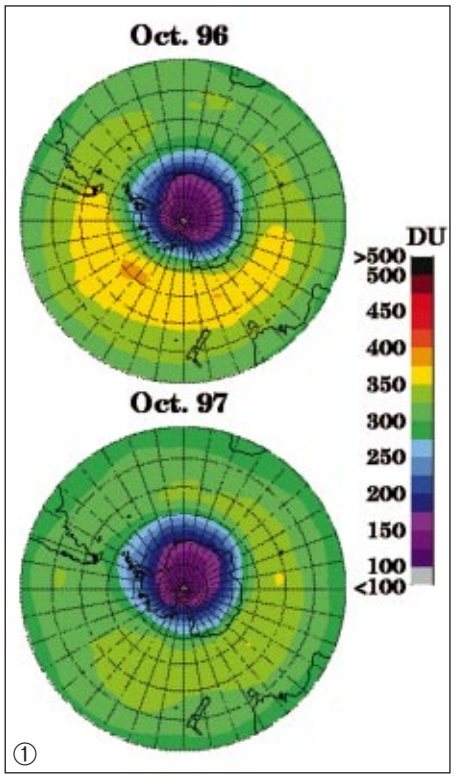
A common observable feature of the Antarctic winter/spring atmosphere during the last two decades has been the low ozone amounts and the appearance of the ozone hole. This effect can be related to human activities since man-made chlorofluorocarbons (CFCs) and halons, which are chemically inert in the troposphere, enter the stratosphere, where they are photolysed, releasing reactive ozone destroying bromine and chlorine compounds. Severe chemical ozone loss in the polar region is observed, when two conditions are met: firstly, the temperatures are sufficiently cold (- 80° C in the lower stratosphere) to form polar stratospheric clouds (PSCs) and secondly, there is sufficient sunlight during spring time to enable the rapid ozone depletion via catalytic chain reactions.

During the polar night, low temperatures occur inside the cyclonic wind system (polar vortex) in the lower stratosphere (10-30 km). Heterogeneous chemical reactions on the ice particles of PSCs convert the inactive chlorine species (reservoirs) in its active forms. When the sun enters the polar region during spring, catalytic reactions involving ClOx rapidly destroy large parts of the ozone layer.

The Antarctic ozone hole reaches its maximum extent in October as seen in the GOME images (GDP level-2 data Version 2.0) from 1996 and 1997 in Figure 1. The ozone hole above Antarctica as defined by the area with total ozone amount of less than 220 Dobson units (DU) reached the size of continental North America. Figure 2 shows monthly means of total ozone in the Northern Hemisphere between January and May 1997. Low ozone amounts inside the Arctic vortex were observed during March and April, although the minimum values observed are not as low as observed during the Antarctic spring. The main differences between the Arctic and Antarctic regions in terms of spring ozone depletion are the stratospheric temperatures that are generally warmer in the Arctic. The high dynamic activity in the northern hemispheric stratosphere permits frequent exchange between warm ozone-rich air masses from the mid-latitudes and cold ozone-poor air either from the polar region

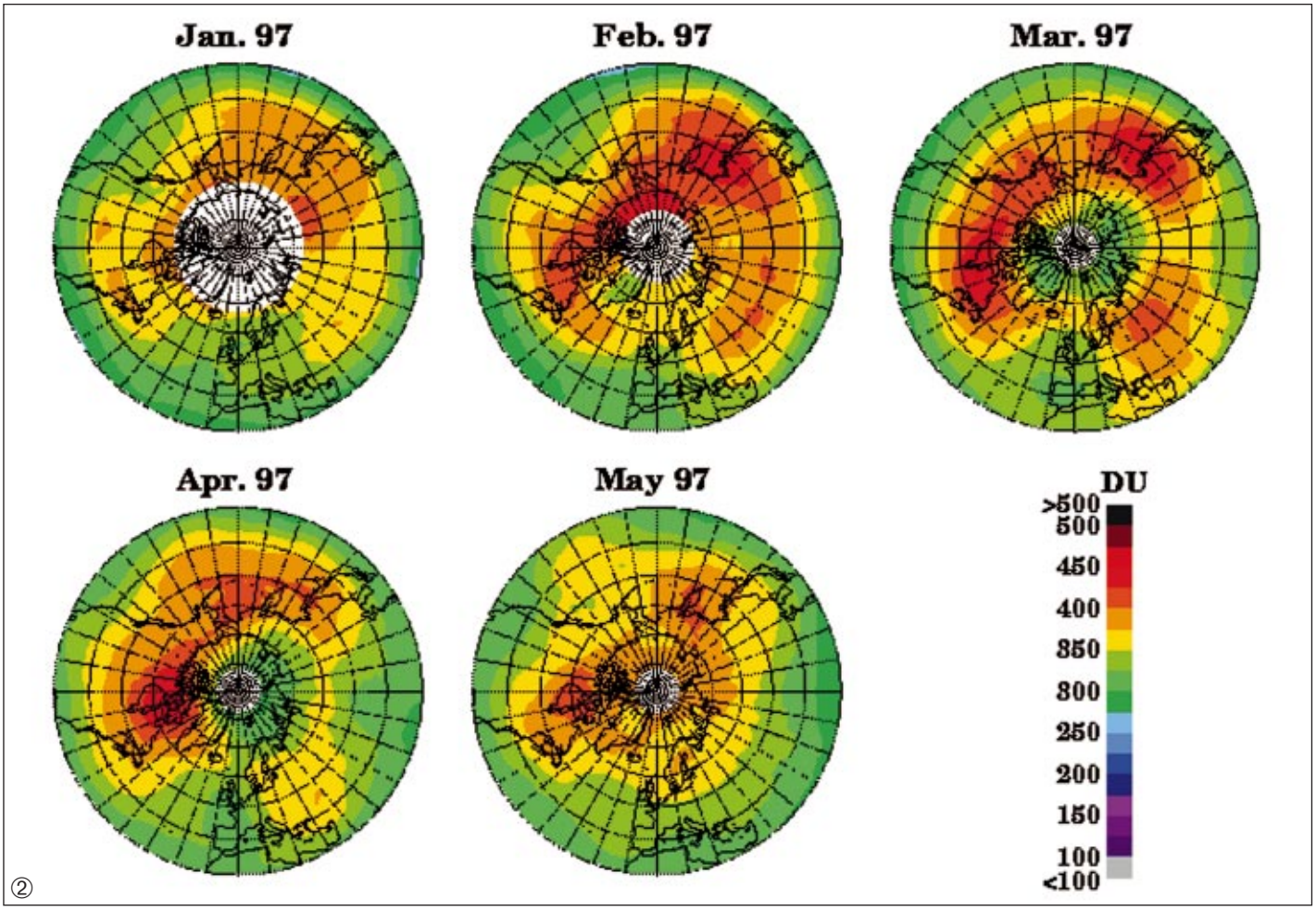


Monthly means of total ozone in the Southern Hemisphere as measured by GOME in October 1996 and 1997. GOME level-2 Version 2.0 data have been used to produce the image.

and/or from the subtropics and tropics as documented by the so-called mini-hole events. These events were observed on several days above North and Central Europe in 1996 (Fig. 3).

In 1997, the Arctic vortex was centred closer to the pole and cold temperature sufficient for PSC formation were not observed before January (as opposed to early December in winter 1995/96) and lasted until end of March about a month longer than the year before. In 1997, temperatures in the lower stratosphere were at a record low at the end of March 1997 and the Arctic vortex did not break up until early May. Both winter/spring seasons in 1995/96 and 1996/97 demonstrate the considerable year-to-year variability of total ozone in the north polar region. Maximum ozone concentration is normally expected at high latitudes during the winter/spring season due to enhanced transport of stratospheric ozone from the tropics where most of the ozone is photochemically produced. This can be seen in the collar region ('ozone ridge') with ozone values up to 400-500 DU around the Arctic vortex (Figs. 2-4). Furthermore, GOME observed polar vortex NO2 total columns which were lower than the NO2 levels measured outside the vortex (Fig. 4).

Part of the ozone depletion observed in the more recent Arctic winters may be associated with a cooling trend in the stratospheric temperatures. However, recent research results by *Müller et al. 1997* and *Rex et al. 1997* give the first clear evidence that chemical ozone depletion took place in the Arctic



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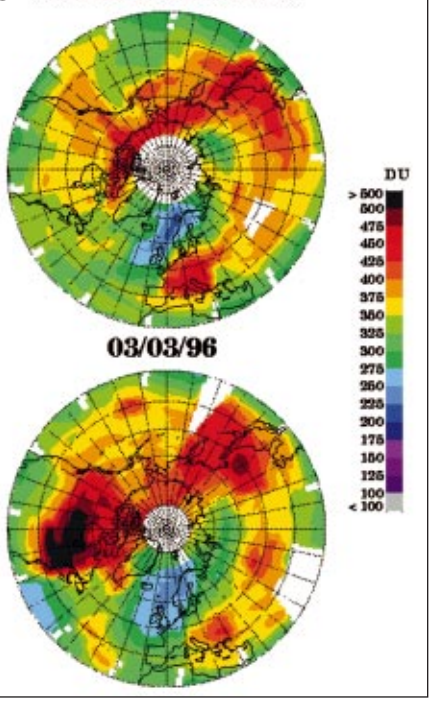
Time series of total ozone monthly means in the Northern Hemisphere between January and May 1997 as observed by GOME/ERS-2.

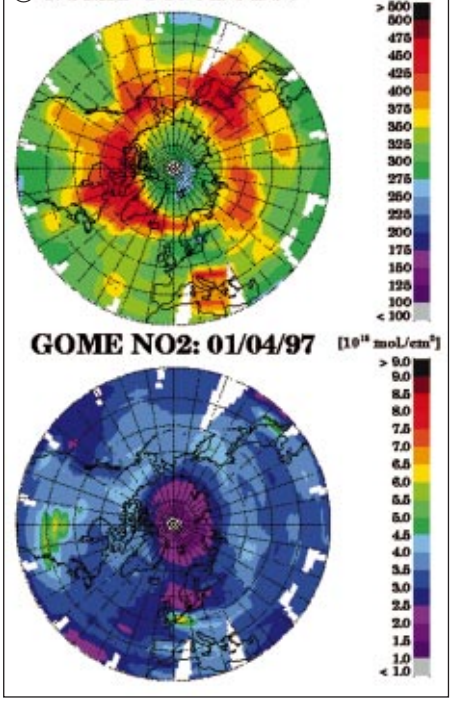
③ GOME O3: 21/02/96



< *GOME observations of 'mini-hole' events above Northern and Central Europe on 21 February and 3 March 1996.*

GOME observations of ozone (top) and nitrogen dioxide (bottom) vertical column densities on 1 April 1997. Inside the Arctic vortex low amounts of ozone and NO_2 are observed. High NO_2 levels are observed in the US, Central Europe and Japan, which stems from urban pollution and is mostly of tropospheric origin. >

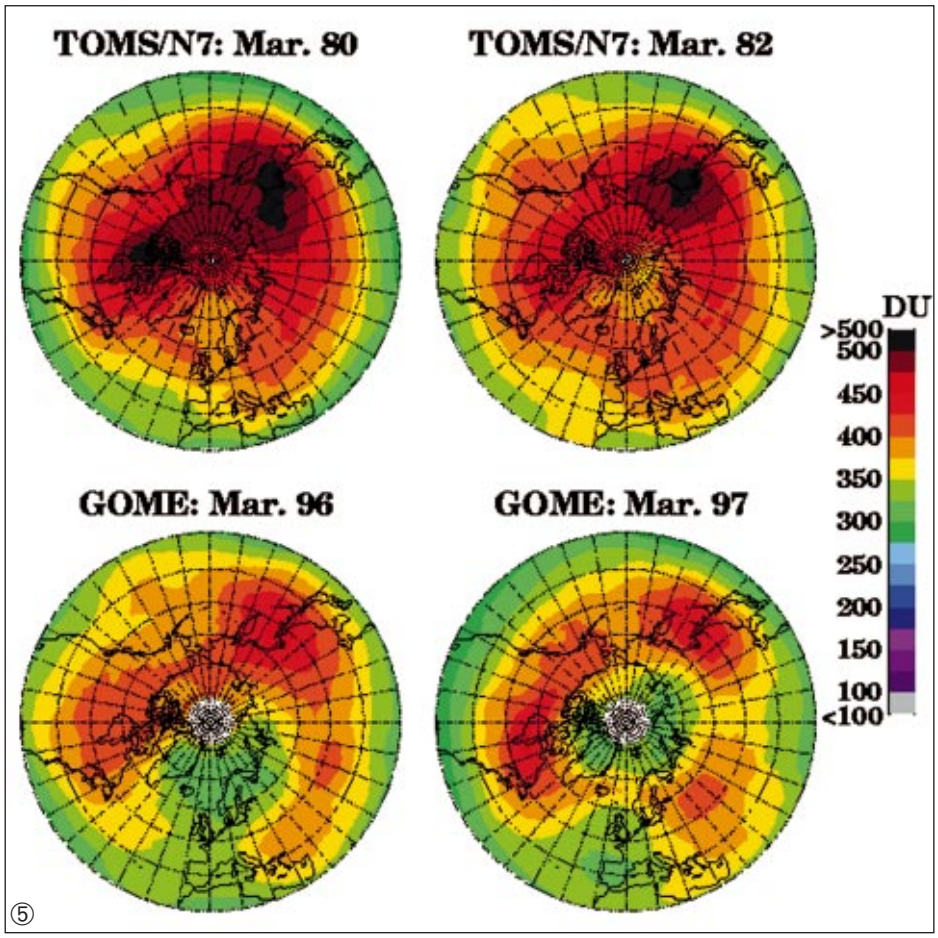
④ GOME O3: 01/04/97



winters 1995/96 and 1996/97. The estimated chemical ozone losses were of similar magnitude that were found in the Antarctic in the mid-80's (up to 64% in the lower stratosphere, *Rex et al. 1997*) when the ozone hole was first discovered. A comparison of the total ozone mean in March 1996 and March 1997 with the corresponding values observed by TOMS/Nimbus-7 (*McPeters et al. 1996*) in the early 1980's (Fig. 5) clearly shows the decline in total ozone in the Arctic spring.

Space-borne sensors such as the series of TOMS (Total Ozone Monitoring Spec-trometer) instruments have documented the dramatic ozone losses in the polar regions and also the continuous but less dramatic decline of stratospheric ozone in mid-latitude regions since 1978. GOME successfully continues this tradition since April 1995. Adherence to the Montreal Protocol and successive modifications to reduce and finally ban the CFCs, halons and related compounds, known to have a high ozone depletion potential (ODP), may enable a recovery of the chlorine level to pre-1970 levels by the end of the next century (*WMO 1993*). It remains essential to continue monitoring the progress of the political measures taken to reverse the global decline in ozone.

GOME/ERS-2 and successor remote sensing instruments such as Sciamachy/ Envisat-1 and GOME-2/ Metop-1 can be used for long-term monitoring of the ozone layer and relevant minor trace gases involved in the ozone chemistry.



Arctic March total ozone (monthly means) observed in 1980 and 1982 by TOMS/Nimbus-7 (top) and in 1996 and 1997 by GOME/ERS-2 (bottom) document the decline in polar total ozone in spring.

References

McPeters RD et al., *Nimbus-7 Total Ozone Mapping Spectrometer (TOMS) data products user's guide*, NASA Ref. Publ. 1384, 1996.

Müller R et al., Severe chemical ozone loss in the Arctic during the winter of 1995-96, *Nature*, 389, 709-712, 1997.

Rex M et al., Prolonged stratospheric ozone loss in the 1995/96 Artic winter, *Nature*, 389, 835-838, 1997.

WMO - World Meteorological Organisation, Press release 21.03.1993, Geneva.