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O_3 Profiles from GOME Satellite Data–II: Observations in the Arctic Spring 1997 and 1998

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Abstract. Ozone observations by the Global Ozone Monitoring Experiment (GOME) on board the ERS-2 satellite during the Arctic spring periods 1997 and 1998 are presented. From the derived ozone vertical distributions, extensive regions of low ozone total column were observed and it is shown that the major decrease is dominating in the lower and middle stratosphere inside the polar vortex. The winter 1997/98 was warmer than the year before and less ozone depletion was observed. In spring 1998 an ozone mini-hole event was observed by GOME and ozone profiles under mini-hole conditions were derived for the first time.

1 Introduction

The discovery of the Antarctic ozone hole in 1985 (Farman et al., 1985) led to much scientific and public debate on anthropogenic ozone depletion. A similar ozone loss above the Arctic was initially considered less likely because of higher stratospheric temperatures and different dynamics observed in the Arctic polar region. However, since the beginning of the early 90s, reduced total ozone were observed during Arctic spring (McPeters et al., 1996). Record low northern polar total ozone amounts inside the vortex has been observed in 1995/96 (Newman et al., 1997; Santee et al., 1997). Despite the large dynamic ozone variability observed in the northern hemisphere (NH), chemical ozone loss due to heterogeneous chemical processes similar to that observed in the Antarctic have recently been identified (Müller et al., 1997a; Rex et al., 1997).

In winter/spring 1997 record low stratospheric temperatures sufficient to form polar stratospheric clouds (PSCs) persisted until late March (Coy et al., 1997). The PSCs drive the heterogeneous reactions, which activate chlorine compounds responsible for the rapid catalytic ozone depletion, when the spring sun enters the polar night. During March/April 1997 a chemical ozone loss of 70-80 Dobson units (DU) in the total column were observed inside the vortex (Müller et al., 1997b). The NH winter/spring period 1997/98 was warmer than in previous years and higher total ozone columns were observed in the Arctic by GOME.

An inversion algorithm called FURM (Full Retrieval Method), which calculates ozone profiles from GOME satellite data have been applied to derive NH vertical ozone distributions for the first time. Results for selected days during the Arctic spring seasons 1997 and 1998 are presented and discussed.

Low total ozone can frequently be observed in wintertime northern mid-latitude regions outside the vortex, which are termed ozone mini-holes (Newman et al., 1988; Hood, 1997). During such events exchange of air masses from the subtropics with low total ozone towards the polar vortex occur, which leads to a high tropopause at higher latitudes. These tropospheric ridges cause adiabatic cooling at the vortex edge and can possibly lead to the formation of polar stratospheric clouds (Grewe and Dameris, 1997). In March 1998 GOME ozone profiles inside an ozone mini-hole have been observed for the first time.

2 GOME Ozone Profile Retrieval

The Global Ozone Monitoring Experiment GOME measures the backscattered and reflected solar radiation from the atmosphere and surface of the Earth (Burrows et al., 1999). A primary objective of the GOME mission is the determination of global distributions of total ozone. Furthermore, total column amounts of other relevant atmospheric trace constituents, for instance, O_3, BrO, OClO, NO_2, HCHO, and SO_2, can be determined. Column amounts are operationally retrieved using the differential optical absorption spectroscopy method DOAS (Burrows et al., 1993). However, total O_3 and NO_2 columns are currently the only trace gases available as GOME level-2 data products (ESA, 1995).

Using the broad spectral range (240–790 nm) of GOME with its moderate spectral resolution (0.2–0.4 nm), height-

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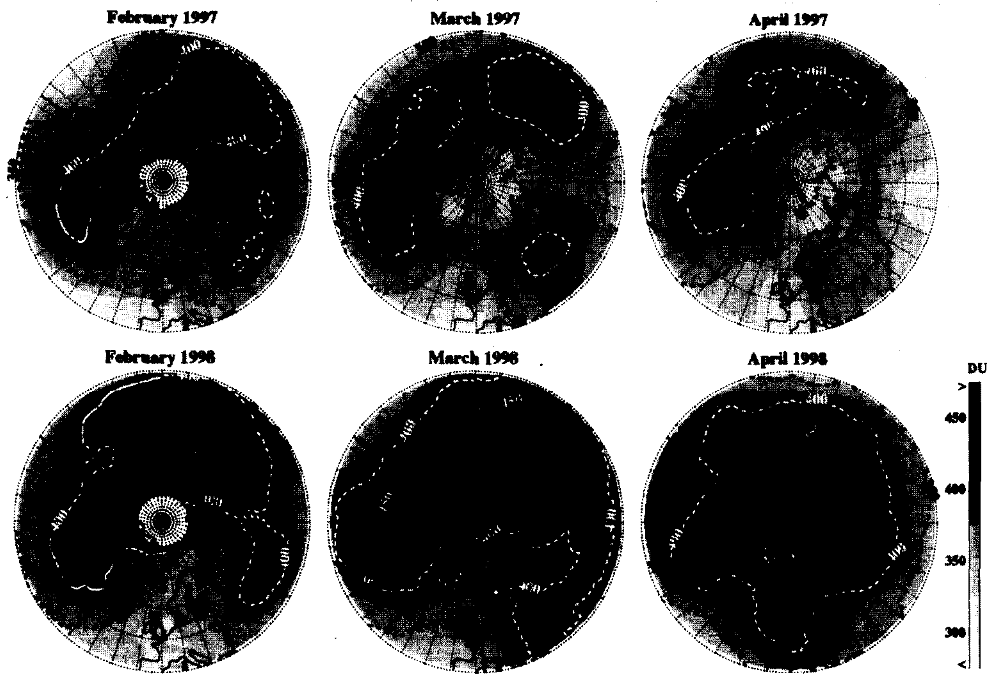

Fig. 1. GOME monthly means of total ozone for February, March and April 1997 (upper panel) and 1998 (lower panel). The stereographic projection extends from the North Pole to 40° N. GOME level-2 data Version 2.0 were used to derive the monthly means for 1997 and Version 2.3 for 1998.

resolved ozone information can be derived from the shortwave Hartley-Huggins ozone bands. The FUll Retrieval Method FURM derives ozone profiles from GOME sun normalized spectra (Hoogen et al., 1998b). It consists of two parts: (i) a forward model, the pseudo-spherical multiple scattering radiative transfer model (RTM) GOMETRAN (Rozanov et al., 1997) calculating the TOA (top of atmosphere) radiance for a given state of the atmosphere as defined by the ozone vertical distribution and other trace gas distributions, the surface albedo, and the aerosol scenario among others, and (ii) an inversion scheme which matches in iterative steps the calculated TOA radiance to the measured GOME radiance by adjusting the model atmospheric parameters such as the vertical ozone distribution using appropriate weighting functions provided by GOMETRAN. A detailed account on the retrieval methodology applied to GOME is given in the companion paper by Hoogen et al. (1998a).

3 Results

GOME measurements from July 1996 up to now are available. Selected monthly means of total ozone for the two recent winter/spring seasons 1997 and 1998, derived from the GOME level-2 Version 2.0/2.3 total ozone data, are shown in Fig. 1, which reveals the high year-to-year variability in the dynamics of total ozone in the northern hemisphere. The typical winter/spring ozone maxima expected for high northern latitudes are exemplified by values of more than 400 DU observed above the Sea of Ohkotsk (Far East) and above Hudson Bay (Canada), which are linked to preferred cyclone activity in these regions. Low ozone values, which occasionally drop below 300 DU, are detected above the North Atlantic and Northern Europe. Particularly in March/April 1997 mean ozone levels were low inside the polar vortex. In February and March 1998, the mean ozone levels were higher than in previous years, which agrees with the stratospheric temperatures observed at the 50 hPa pressure level that were closer to the longterm mean and higher than in the previous three years (L. McCoy, NASA, private communications).

3.1 Observations in the Arctic Spring 1997

In the NH winter/spring period 1996/1997 the polar vortex remained stable and stayed close to the North pole for the entire winter/spring period. Record low stratospheric temperatures at 50 hPa were reached from the middle of March until the first week of April 1997, which were cold enough for type I PSCs to form (Coy et al., 1997). As an example of the effects of this cold period, total ozone columns (TOZ) of less than 265 DU were observed inside the polar vortex still on 2 April 1997 (see Fig. 2, middle: dotted line at about 65° N, 45° E).

A latitude-altitude chart of ozone concentrations along one part of a selected GOME orbit, starting at mid-latitudes and crossing the vortex boundary region into the polar vortex, is depicted in Fig. 2 (top). The polar vortex edge runs across

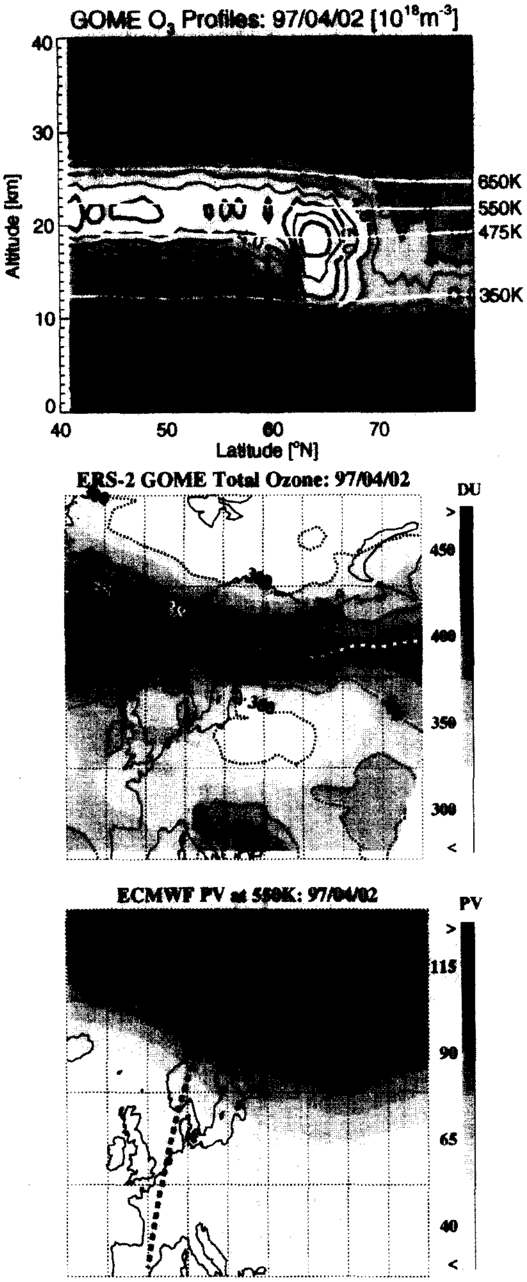

Fig. 2. Top: Ozone height distribution along the GOME orbit No. 10197. White contour lines indicate the various potential temperature levels. Middle: Total ozone field derived from the GOME Level-2 Version 2.0 data. The white PV contour line of 38 PVU at θ = 475K defines the polar vortex edge at the ozone profile maximum. Bottom: Potential vorticity in PVU at θ = 550K over Northern Europe derived from ECMWF analysis. The sub-satellite point of the GOME orbit No. 10197 is indicated by the dashed line. The latitude and longitude scales for both maps are ranging from 40 to 80° N and from 20° W to 70° E.

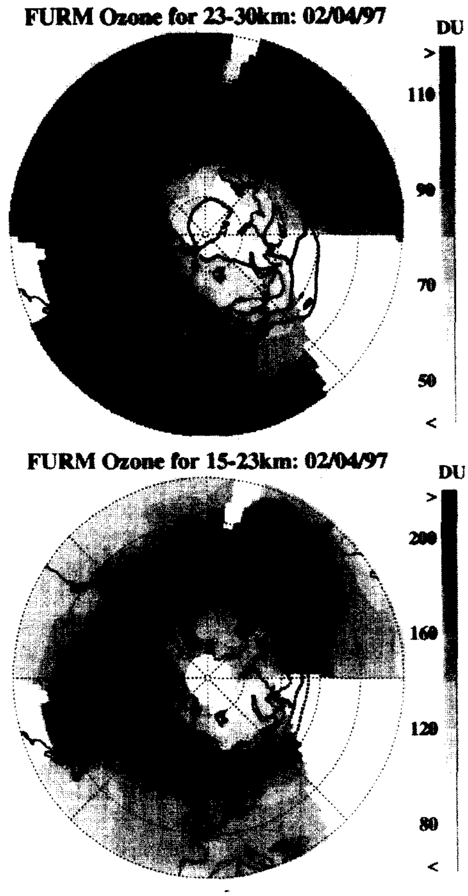

Fig. 3. Gridded ozone column distributions in DU for the altitude ranges 23-30 km (top) and 15-23 km (bottom) on 2 April 1997. The projection is stereographic with 0° W at the bottom and extends from 40° N to the North pole. Superimposed are the PV lines in PVU for the corresponding heights θ = 550K (top) and 475K (bottom) to show the vortex edge.

Northern Scandinavia (Fig. 2, middle and bottom). The PV values are expressed in PV units (PVU), where 1 PVU = 10^{-6}K m^{-2} kg^{-1} s^{-1}.

At latitudes of about 65°N, the ozone concentrations are strongly enhanced in the lower stratosphere at 11–22km altitude with a pronounced maximum at the height of 18km, which may be caused by subsidence of ozone rich air masses as it gets colder across the vortex edge. As one proceeds inside the polar vortex a drop of ozone by roughly 60% at θ= 475K is observed. A significant reduction inside the polar vortex can be also seen in the GOME Level-2 total ozone data as shown in the middle section of Fig. 2.

From the analysis of the fourteen daily GOME orbits a global 3D ozone distribution in the northern hemisphere can be derived. Fig. 3 shows the global ozone distribution in the lower (15–23km) and middle stratosphere (23–30km) on 2 April 1997. The layer column sizes are approximately defined by the full width at half maximum of the averaging kernels, which determines the vertical height resolution of the retrieved GOME profiles (Hoogen et al., 1998b). It is about 8km in the lower stratosphere. A significant reduction of ozone levels of roughly 50% is observed in both altitude regions.

3.2 Observation of an ozone mini-hole event in March 1998

On average, the stratospheric temperatures were warmer in the NH spring 1998 than in previous years and the polar vortex was rather weak and displaced towards Northern Europe and the North Atlantic most of the time. Very low total ozone in northern polar latitudes can occur when upper-tropospheric anti-cyclonic systems move beneath the polar vortex lifting the tropopause. These synoptic-scale areas of strongly reduced total ozone (<300 DU), known as ozone mini-holes (Newman et al., 1988), persists for several days over extra-tropical latitudes in the winter hemisphere.

An ozone mini-hole event was observed by GOME over the Northern Atlantic on 12 March 1998 (see Fig. 4). Subtropical air was advected to the North, as indicated by the low PV (<5 PVU) at 350 K over the Northern Atlantic region between the east coast of Greenland and the British isles (Fig. 4, bottom). The high tropopause of the subtropical air causes the stratospheric air on the above lying isentropic levels to be lifted, which in turn leads to adiabatic cooling and low TOZ (McCormack and Hood, 1997). The correlation between low PV and low TOZ (Fig. 4, bottom and middle) can clearly be seen.

The history of air masses at one subsatellite point of the GOME orbit (61° N, 40° E) on three isentropes 350 K (solid line), 475 K (dotted) and 550 K (dashed) is displayed in Fig. 5. The start time for the backwards trajectory is 12:00 UTC; UKMO wind fields have been used. Each circle stands for one day backwards. The lowermost air (350 K) is identified as coming from subtropical regions at 30° N. At 475 K the air mass is just outside of the vortex and remains close to the vortex edge, while at 675 K the air mass is inside the vortex. The effect of air masses from different heights coming together near the south-eastern coast of Greenland can be seen in the middle panel of Fig. 4. A thinning of the ozone concentrations in the layers above 350K is clearly detectable in the GOME latitude-altitude chart near 60°N (Fig. 4, top) which is the cause of the reduction in TOZ (Fig. 4, middle).

4 Conclusions

Using the FURM version 4.0 retrieval algorithm, vertical ozone distributions in the northern hemisphere during the Arctic winter/spring seasons 1996/1997 and 1997/1998 were derived from GOME satellite data. Low ozone concentrations in the lower and middle stratosphere were measured inside the polar vortex during spring 1997. GOME ozone profiles have successfully been analyzed to identify an ozone mini-hole event in early March 1998. Investigations to quantify

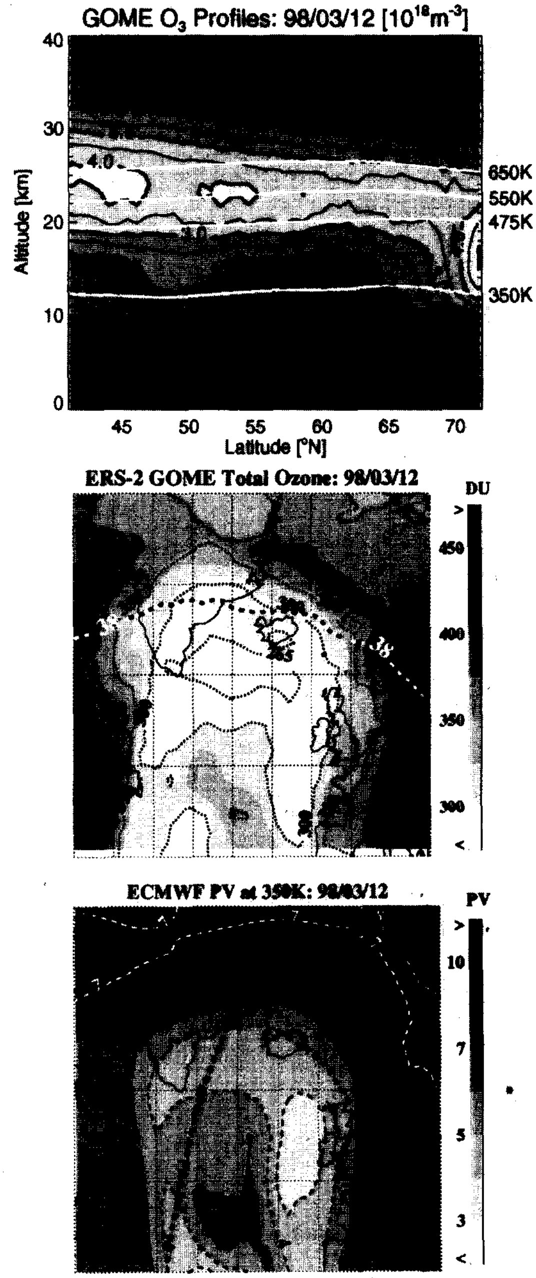

Fig. 4. GOME ozone height distribution along an orbit over the North Atlantic on 12 March 1998 (top). Total ozone field over the Northern atlantic from GOME Level-2 Version 2.3 data (middle). Potential vorticity in PVU at θ =350K derived from ECMWF analysis (bottom). The latitude and longitude scales for both maps are ranging from 40 to 80° N and from 70° W to 20° E. Otherwise the same features as in Fig. 2 were used.

UKMO 98/03/12 (65.0N, 35.0W)

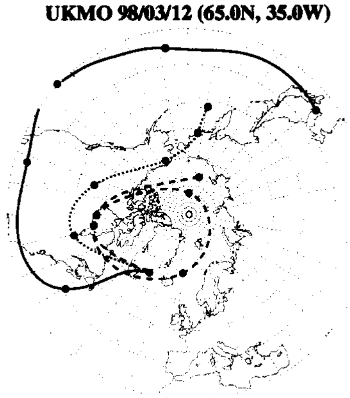

Fig. 5. Backward trajectories of air masses at potential temperature levels of 350K (solid line), 475K (dotted), and 550K (dashed). The start point is at the south-east coast of Greenland (65° N, 35° W). Data were taken from UKMO meteorological analyses.

the possible chemical and dynamical processes from GOME height-resolved ozone distributions will be prepared in the near future.

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