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 ERS-2 during the Arctic spring 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 ozone mini-hole condition 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; Newman et al., 1997). Record low northern polar total ozone amounts inside the vortex has been observed (Newman et al., 1997; Santee et al., 1997) in 1995/96. Despite the large dynamic ozone variability observed in the northern hemisphere, chemical ozone loss due to heterogeneous chemical processes similar to that observed in the Antarctic have been recently 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 in late March (Coy et al., 1997). PSCs drive the heterogeneous reactions, which activates 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 1997/98 was warmer than in the previous years and less ozone depletion was observed by GOME in the Arctic. The Full Retrieval Method FURM, which derive ozone profile from GOME satellite data have been for the first time applied to derive NH vertical ozone distributions. Results for selected days during the Arctic spring in 1997 and 1998 are presented and discussed.

Low ozone can be also frequently observed in northern mid-latitude region outside the vortex and are termed ozone mini-holes (Hood, 1997; Newman et al., 1988). During such events exchange of ozone-poor airmasses from the sub-tropics and the polar vortex occur, which leads to further adiabatic cooling and possible PSC formation (Grewe and Dameris, 1997). During March 1998 GOME ozone profiles inside an ozone mini-hole have been observed for the first time.

2 GOME Ozone Retrieval

Global Ozone Monitoring Experiment (GOME) (Burrows et al., 1997) measures the backscattered and reflected solar radiation from the Earth's atmosphere and surface. The primary objective of GOME is the determination of the global distribution of total ozone, total column amounts of relevant atmospheric trace constituents, for instance, O_3, BrO, OClO, NO_2, HCHO, and SO_2. Column amounts are 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 (ESA95, 1995).

From the broad spectral range (240 - 790 nm) at moderate spectral resolution (0.2 - 0.4 nm), height-resolved ozone information can be derived from the Hartley-Huggins ozone band in the shortwave region of GOME. The Full Retrieval Method (FURM) (Hoogen et al., 1998), which derives ozone profiles from the GOME sun normalized spectra, consists of two parts: a forward model, which is a pseudo-spherical multiple scattering radiative transfer model (RTM) GOME-

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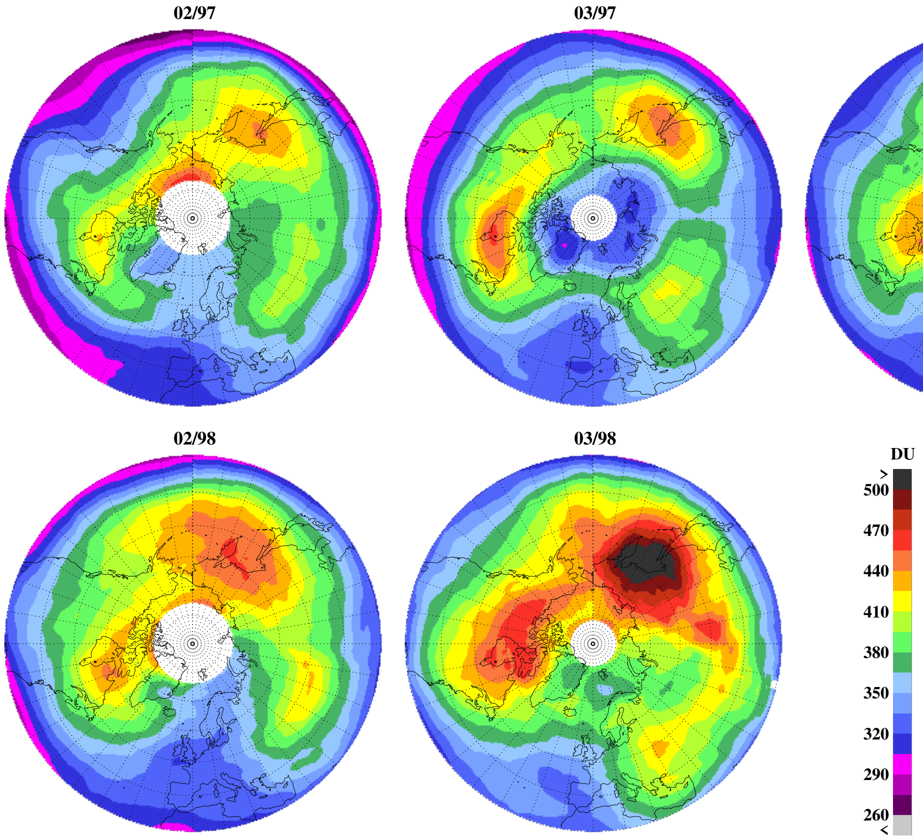

Fig. 1. GOME total ozone monthly means for February, March and April 1997 (upper panel) and February and March 1998 (lower panel). The stereographic projection extends from the North Pole to 40° N. GOME level-2 data Version 2.0 were used to derive the monthly means for 1997 and Version 3.0 for 1998.

TRAN (Rozanov et al., 1997) calculating the top of atmosphere (TOA) radiance for a given state of the atmosphere as defined by the ozone vertical distribution, trace gas distribution, surface albedo, aerosol scenario among others, and 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 as provided by GOMETRAN. A detailed account on the retrieval methodology applied to GOME is given in the companion paper by Hoogen et al. (1998).

3 Results

GOME measurements from the last three winter/spring seasons 1995/1996, 1996/1997, and 1997/1998 are available. Selected monthly total ozone means for the two recent winter/spring seasons, which were derived from the GOME level-2 Version 2.0 ozone data, are shown in Fig. 1, which reveals the high year-to-year variability in the dynamics of the total ozone in the northern hemisphere. The typical winter/spring ozone maximum expected for high northern latitude is exemplified by the values of more than 400 DU observed above the Sea of Ohkotsk (Far East) and above Hudson Bay (Canada), which is 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 the previous years, which agrees with the generally higher observed stratospheric temperatures at the 50hPa pressure level which were closer to the longterm mean and higher than in the previous three years (L. McCoy, NASA, private communications).

3.1 Arctic Winter/Spring Observation in 1996/1997

In 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 50hPa 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). For instance, low total ozone columns (TOZ) of below 280 DU were observed inside the polar vortex on 2 April 1997 (see Fig. 2, middle).

An altitude-latitude chart of ozone concentrations along part of a selected GOME orbit, which started at mid-latitudes and crosses the vortex boundary region into the polar vortex, is depicted in Fig. 2. The polar vortex edge runs across Northern Scandinavia (Fig. 2, middle and bottom). At about 65° latitude ozone concentration are strongly enhanced in the lower stratosphere (11–21km altitude with a pronounced maximum at a height of 18km, which may be caused by sub-

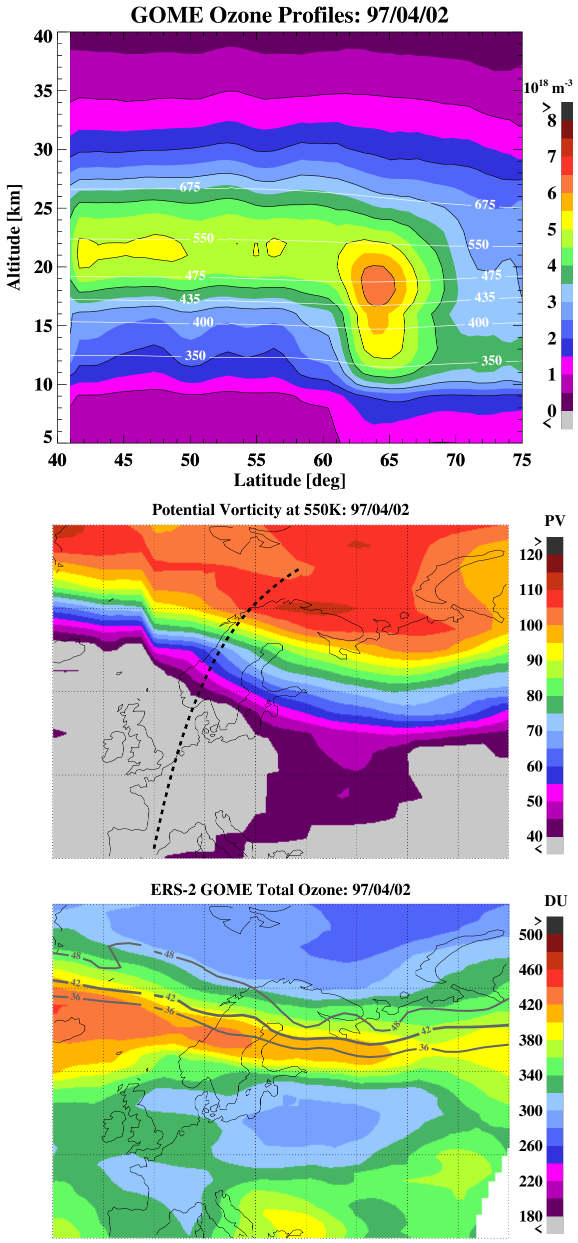

Fig. 2. Top: Ozone height distribution along the GOME orbit Nr. 10197. White contour lines indicate the various potential temperature levels. Middle: Potential vorticity in units of 10^{18}m^3 at θ =550K in Northern Europe derived from ECMWF analysis. The latitude and longitude scales for both maps are ranging from 40 to 80° N and from 20° W to 70° E. The subsatellite points of the GOME orbit Nr. 10197 is indicated by the dashed line. Bottom: Total ozone field derived from the GOME Level-2 Version 2.0 data in the same region as shown in the middle plot. PV contour lines in units of 36–48 10^{18}m^3 at θ =475K define the polar vortex edge.

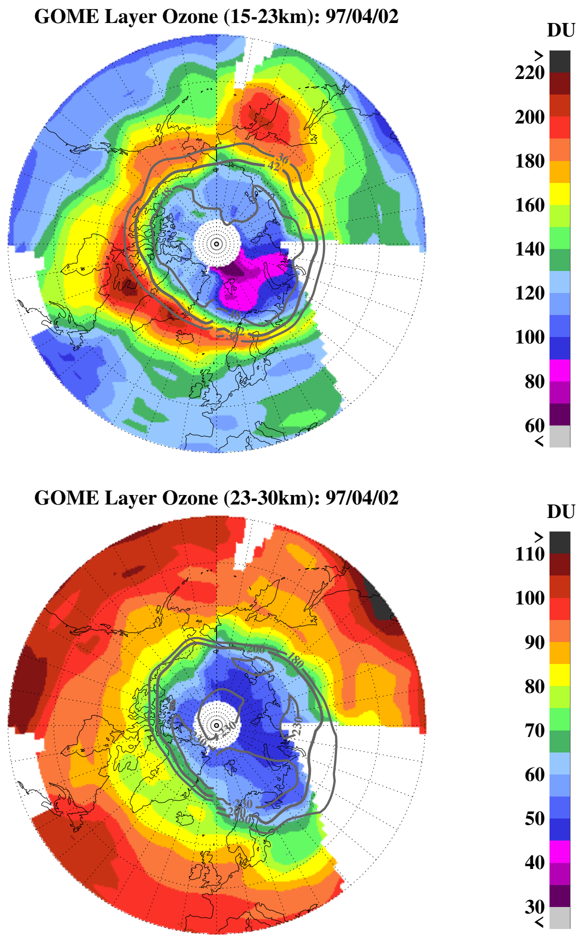

Fig. 3. Ozone column distribution in the altitude ranges 15-23 km (upper panel) and 23-30 km (lower panel) on 2 April 1997.

sidence of ozone rich air masses as it gets colder across the vortex edge (see also the small dip in the lower θ-levels of the potential temperatures). 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 total ozone data as shown in the middle section of Fig. 2.

From the analysis of all 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., 1998), and is about 8km in the lower stratosphere. A significant reduction of ozone levels of roughly 50% is observed in both altitude regions.

3.2 GOME observation of an ozone mini-hole event in March 1998

Stratospheric temperatures were on average warmer during spring 1998 than in the previous years and the polar vor-

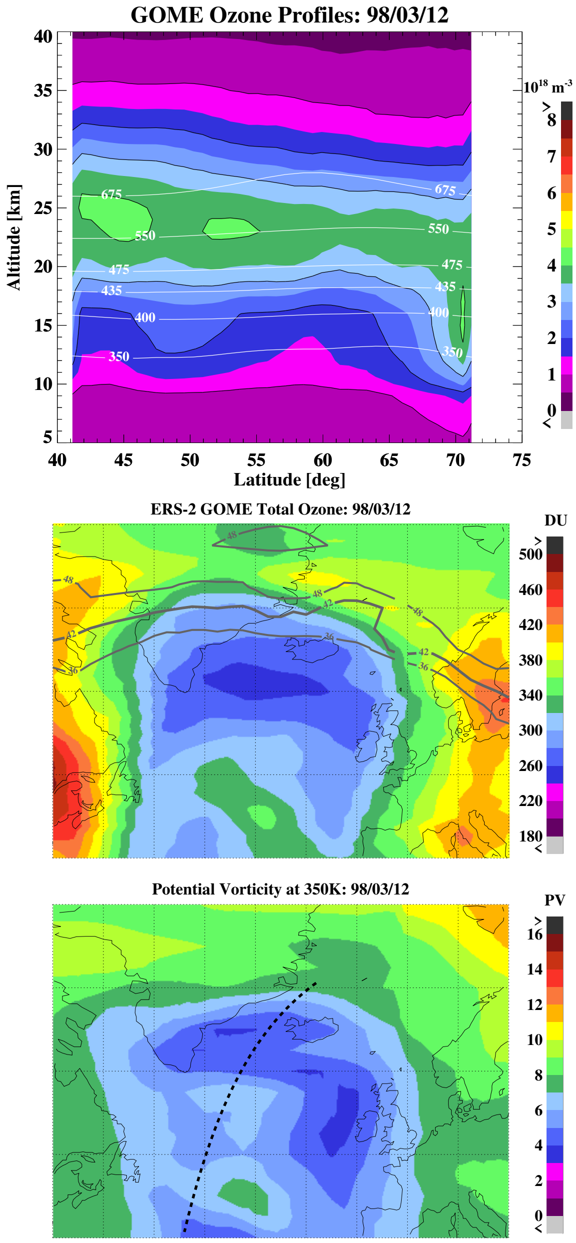

Fig. 4. Top: Ozone height distribution along the North Atlantic GOME. White contour lines indicate the various potential temperature levels. Middle: Potential vorticity in units of $10^{18}\mathrm{m}^3$ at θ =550K in Northern Europe derived from ECMWF analysis. The latitude and longitude scales for both maps are ranging from 40 to 80° N and from 70° W to 20° E. The subsatellite points of the North atlantic GOME orbit is indicated by the dashed line. Bottom: Total ozone field derived from the GOME Level-2 Version 3.0 data in the same region as shown in the middle plot. PV contour lines in units of 36–48 $10^{18}\mathrm{m}^3$ at θ =475K define the polar vortex edge.

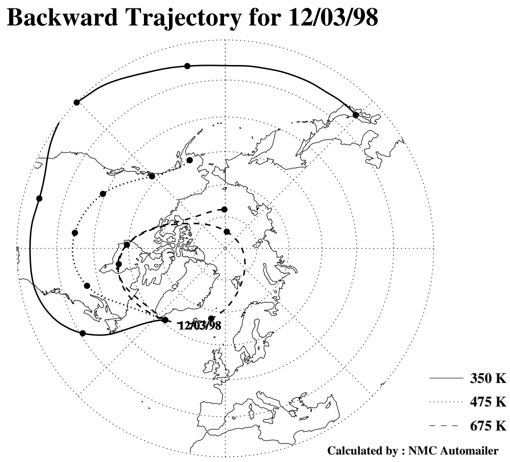

Fig. 5. Backward trajectories of air masses at the potential temperature levels 350K, 475K and 675K (Data taken from NASA GSFC automailer).

tex was rather weak and displaced most of the time towards Northern Europe and the North Atlantic. 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 are termed ozone mini-holes (Newman et al., 1988).

An ozone mini-hole event was observed by GOME over the Northern Atlantic on 12 March 1998 (top, Fig. 4). Subtropical air was advected to the North raising the tropopause, as indicated by the low PV (4-6 PVU) at 350 K in the Northern Atlantic region between the east coast of Greenland and the British isles (top, Fig. 4). Lifting of the tropopause 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) 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 675 K (dashed) is displayed in Fig. 5. The start time for the backwards trajectory is 12:00 UTC. Each circle stands for one day backwards. The lowermost air (350 K) is clearly identified coming from the subtropical region near 30° N. At 475 K the air is just outside of the vortex and remains close to the vortex edge, while at 675 K the air is inside the vortex. This effect can be seen in the lower panel of Fig. 4. A thinning of the ozone concentrations in the layers above 350K is clearly detectable in the GOME altitude-latitude chart near 60° (top, Fig. 4) and are responsible for the reduced TOZ (top, Fig. 4).

4 Conclusions

Using the FURM 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 by GOME inside the polar vortex during spring 1997. GOME ozone profiles have been successfully analyzed to identify an ozone mini-hole event in early March 1998. Investigations to quantify the possible chemical and dynamical loss processes from the GOME height-resolved ozone distribution will be prepared.

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