GOME satellite observation of chemical ozone loss in the lower stratosphere in 1999/2000 and comparisons to earlier winters

UNIVERSITÄT BREMEN

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K.–U. Eichmann, M. Weber, K. Bramstedt, J. P. Burrows, A. Lee[1], B.-M. Sinnhuber[2], G. Braathen[3]

Institute of Environmental Physics, Univ. Bremen, Bremen; [1] Univ. Cambridge, Cambridge; [2]School of the Environment, Univ. Leeds, Leeds;

[3] Norwegian Institute of Air Research (NILU), Kjeller; contact: mark.weber@iup.physik.uni-bremen.de

Abstract

GOME ozone volume mixing ratios inside the polar vortex at the 475 K and 550 K altitude level are compared with results ftom ozone sondes and the SLIMCAT 3D CTM model. Mean chemical ozone loss rates inside the Arctic vortex were derived from the vertical ozone distribution measured by GOME during the winter/spring seasons 1996/97–1999/2000. The accumulated chemical ozone loss in late winter and early spring are compared with results from the 3D SLIMCAT chemical transport model.

Data sources

- **GOME total ozone** GDP Version 2.7 (Burrows *et al.*, 1999, DLR/DFD 1996)
- **GOME ozone profiles**: FURM Version 5.0 (Hoogen *et al.*, 1999, Bramstedt et al. 1999)
- **GOME ozone sonde profiles**: see Poster, G. Braathen *et al.*

Analysis: Chemical Loss Rates

A) GOME Analysis

- Conversion of number density into volume mixing ratios (vmr) at θ potential temperature level using UKMO Met data.
- Calculation of daily Arctic vortex mean as defined by the area with potential vorticity > 38 MPVU (Lait 1994).
- Determination of daily diabatic heating rates using broadband RTM from Shine (1991) using GOME ozone profiles as input.
- Estimation of diabatic ozone changes from the mean vortex heating rate Q and ozone derivative (Braathen et al. 1994)

$$\partial O_3/\partial t = Q(p_o/p)^\kappa\, \partial O_3/\partial\theta$$

and subtract from vmr time series before estimating chemical loss rates.

B) 3D CTM SLIMCAT

- Seasonal run ($2.5°\times3.75°$) starts in November using multi-annual run (begin in October 1991) for initialization (Chipperfield 1999)
- Met field from UKMO UARS analysis
- Passive ozone tracer starts in December
- Chemical ozone loss provided by the difference between passive tracer and modeled ozone

Summary and Conclusion

- **Cold winter/spring seasons 1996/1997 and 1999/2000**
  - → The absolute values of the mean Arctic vortex ozone vmr differ in late winter by up to 20% in 1996/97, while in 1999/00 good agreement was found at both θ-levels
  - → Good agreement between model and observation in the chemical ozone loss rates at 475 K in 1999/2000, but in 1996/97 the observed chemical loss is underestimated by the model $\Longrightarrow$ large scale denitrification only realized in the most recent winter (Sinnhuber et al. 2000)?
  - → After mid-March 2000 agreement between GOME and sondes as well as SLIMCAT less satsisfactory $\Longrightarrow$ insufficient vertical resolution of GOME profiles, chemical loss confined to a narrow altitude range
  - → In 1996/97 chemical loss continued well into early May, although stratospheric temperatures started to increase after late March $\Longrightarrow$ "summertime" NO_x chemistry inside a well isolated airmass (Hansen et al. 1999)
- **Warm winter/spring seasons 1997/1998 and 1998/1999**
  - → SLIMCAT underestimates observed ozone vmr by up to 20%
  - $\longrightarrow$ too much chlorine activation in SLIMCAT(?)
  - $\longrightarrow$ diabatic descent underestimated (?)
- **Uncertainties**
  - → Uncertainties in modeled diabatic descent (and ozone changes) in both SLIMCAT and GOME analysis
  - → insufficient characterization of leewave activity in SLIMCAT model
  - → limited vortex coverage by GOME in early to mid February (SZA)
  - → limited height resolution of GOME vertical profiles

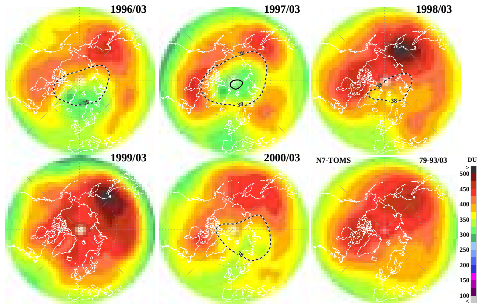

Fig. 1. *Mean March GOME total ozone distribution 1996–2000 and TOMS Nimbus 7 average for the period 1979–1993. Dashed contour shows the mean position of the vortex edge (38 PVU @ 475 K) and the solid lines the maximum temperature required for possible PSC formation (195 K @ 475 K).* At the end of a cold stratospheric winter, like 1995/96, 1996/97 and 1999/2000 total ozone levels are generally lower in the mid- to high latitudes, while in warm winters like in 1997/98 and 1998/99 the total ozone levels are higher than the climatological mean. In warm winters diabatic descent is generally stronger (Chipperfield and Jones 1998). The TOMS image shows the climatological average of the 80s. In each of the cold winters including the most recent one, total ozone values were well below 400 DU inside the Arctic vortex.

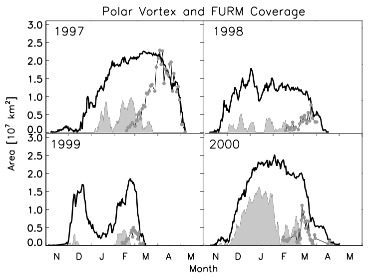

Fig. 2. *Time series of the total area of the Arctic vortex as defined by the area with >38 PVU at 475 K isentropic level (solid line) and vortex coverage by GOME ozone profile observations (grey solid line). Area of possible PSC existence are indicated by the shaded area as defined by temperatures below 195 K at 475 K isentropic level.* In 1996/97 an 1999/2000 Arctic vortex area reached more than 20 million square km. In January 2000 the area of possible PSC existence reached record size. The other winters are characterized by a smaller vortex area and rather sporadic PSC events. In January 1999 a major stratospheric warming event occured, the first event in almost ten years. The GOME observations are limited to the sunlit portion of the vortex. Due to changes in integration times at solar zenith angles larger than 75°, the profile retreival from GOME is limited to smaller SZA. Thus, GOME coverage improves as the sun returns into the Arctic during late winter and spring. Nevertheless, vortex coverage by GOME is much better because of the airmasses moving in and out from the dark region.

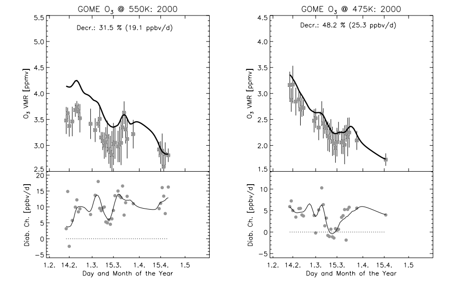

Fig. 3. *Top: GOME ozone volume mixing ratios (vmr) as a function of time in late winter 1999/2000 (grey solid points). Error bars indicate 1σ standard deviations from averaging. Solid line is the adiabatic ozone vmr by adding diabatic ozone changes (bottom part of each figure) accumulatively backward from the last ozone vmr. Top: Isentropic level of 550 K (∼22 km altitude). Bottom: Isentropic level of 475 K (∼19 km) altitude.* From the slope of the adiabtic ozone vmr time series the chemical loss rate is estimated.

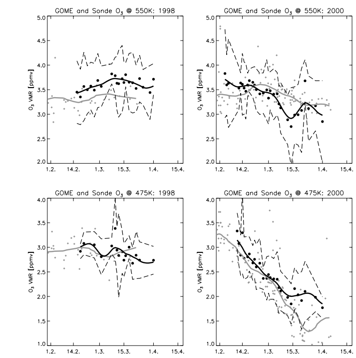

Fig. 4. *Top: GOME vortex average O_3 vmr and 2σ standard deviation (solid points and dashed line, respectively) compared with individual sonde measurements inside the Arctic vortege (grey points). The sonde and the GOME time series has been smoothed with two successive 7-point boxcars (grey and black solid lines, respectively). Top: 550 K isentropic level, bottom: 475 K isentropic level, left: winter 1997/98, right: winter 1999/2000. Only data with PV values larger than 42 MPVU were included.* Agreement between vortex mean sondes and GOME vmr is reasonable at both isentropic levels. After mid March in 2000 we see the effect of the differing vertical resolution between GOME (∼6 km) and sondes (∼0.2 km). In this winter the chemical ozone loss was well confined within a narrow altitude range (see Poster, M. Rex et al.), thus GOME should observe higher vmr at 475 K than the sondes.

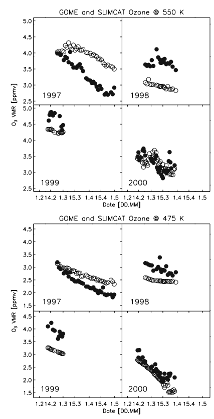

Fig. 5. *Comparison of GOME vortex average ozone vmr (solid points) with SLIMCAT CTM results (light points) during the four most recent winters. Vortex edge position of 38 MPVU was assumed. Top: 550 K isentropic level, Bottom: 475 K isentropic level.* In warm winters (1997/98 and 1998/99) SLIMCAT seems to generally underestimate the observations. In 1996/97 GOME values are lower, while in 1999/2000 agreement is best at both isentropic level.

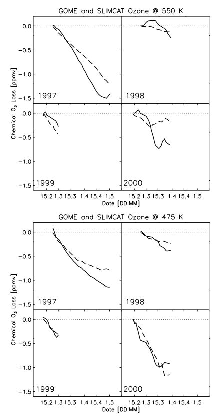

Fig. 6. *Accumulated chemical ozone loss in ppmv: GOME (solid line) and SLIMCAT (dashed line) during the four most recent winters.* In 1996/97 chemical ozone loss in late winter and early spring was large (about 1.5 ppmv and 1.2 ppmv at 475 K and 550 K, respectively). In 1999/2000 the chemical loss rates are higher but losses stopped earlier than in 1997. Until mid-March GOME and SLIMCAT agree well at 475 K. In 1996/97 SLIMCAT underestimates GOME observed ozone losses. Fairly good agreement in the accumulated chemical losses with GOME are achieved by SLIMCAT in the warmer winters.

Table 1. *Chemical Ozone loss rates: GOME and SLIMCAT*

Chemical Ozone Depletion at 475 K, PV Boundary at 38 PVU							
		GOME			SLIMCAT CTM		
season	Period	starting value (ppmv)	loss rate (ppbv/d)	accumulated loss	starting value (ppmv)	loss rate (ppbv/d)	accumulated loss
1996/97	02-20 to 05-02	3.3	20	43%	3.1	11	26%
1997/98	02-20 to 04-01	3.3	12	14%	2.6	6	10%
1998/99	02-10 to 03-01	4.1	15	7%	3.3	16	10%
1999/00	02-12 to 03-27	3.3	27	37%	2.8	26	42%

Chemical Ozone Depletion at 550 K							
		GOME			SLIMCAT CTM		
season	Period	starting value (ppmv)	loss rate (ppbv/d)	accumulated loss	starting value (ppmv)	loss rate (ppbv/d)	accumulated loss
1996/97	02-18 to 05-02	4.0	19	32%	4.0	17	30%
1997/98	02-20 to 03-30	3.1	8	8%	3.1	3	4%
1998/99	02-10 to 02-28	4.6	9	4%	4.3	24	10%
1999/00	02-12 to 03-27	3.5	15	17%	3.4	4	6%

References

Braathen, G.O., et al., Temporal development of ozone within the Arctic vortex during the winter of 1991/92, Geophys. Res. Let. 21, 1407-1410, 1994.

Burrows, J.P., M. Weber, et al., The Global Ozone Monitoring Experiment (GOME): Mission Concept and First Scientific Results, J. Atmos. Sci. 56, 151–171, 1999.

Chipperfield, M.P., Multiannual simulations with a threedimensional chemical transport model, J. Geophys. Res., 104, 1781–1805, 1999.

Chipperfield, M.P., and R.L. Jones, Relative influence of atmospheric chemistry and transport on Arctic ozone trends, Nature, 400, 551–554, 1998.

DLR/DFD, Product Specification Document of the GOME Data Processor, Document ER-PS-DLR-GO-0016, Iss./Rev. 3/C, DLR German Remote Sensing Data Center, Oberpfaffenhofen 1996.

Eichmann, K.-U., K. Bramstedt, M. Weber, V.V. Rozanov, R. Hoogen and J.P. Burrows, O3 profiles from GOME satellite data - II: Observations in the Arctic spring 1997 and 1998, Physics and Chemistry of the Earth 24, 453-457, 1999.

Hansen, G, Chipperfield, M.P., Ozone depletion at the edge of the Arctic vortex 1996/1997, J. Geophys. Res., 104, 1837–1845, 1999

Hoogen, R., V.V. Rozanov, J.P. Burrows, Ozone profiles from GOME satellite data: Algorithm description and first validation, J. Geophys. Res. 104, 8263–8280, 1999.

Shine, K.P.: On the cause of the relative greenhouse strength of gases such as the halocarbons, J. Atmos. Sci., 1513–1581, 48, 1991.

Sinnhuber B.-M., et al., Large loss of total ozone during the Arctic winter of 1999/2000, Geophys. Res. Let. (in press), 2000.

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