OZONE DISTRIBUTIONS IN THE ARCTIC WINTER/SPRING 2002/2003 AS MEASURED BY THE THREE ATMOSPHERIC ENVISAT SATELLITE INSTRUMENTS GOMOS, MIPAS, AND SCIAMACHY

A. Bracher, K.-U. Eichmann, C. von Savigny, M. Weber, K. Bramstedt, J. P. Burrows

Institute of Environmental Physics (IUP), University of Bremen, P.O. Box 330440, D-28334 Bremen, Germany, Email: bracher@uni-bremen.de

ABSTRACT

GOMOS (Global Ozone Monitoring by Occultation of Stars), MIPAS (Michelson Interferometer for Passive Atmospheric Sounding) and SCIAMACHY (Scanning Imaging Spectrometer for Atmospheric Chartography) are the atmospheric scientific instruments aboard the Environmental Satellite (ENVISAT) of ESA which has been launched in March 2002. All three instruments are measuring stratospheric ozone profiles which complement each other: MIPAS measures during day- and night time while SCIAMACHY is only measuring during daytime and GOMOS only during night and

from the University Bremen SCIAMACHY ozone profile retrieval by C. von Savigny; GOMOS ozone profiles are from the ACRI prototype processor and MIPAS ozone profiles from the operational ESA processor. The information on arctic ozone distributions in the Arctic winter/spring 2002/03 of the three instruments is compared to each other and to ECWMF potential vorticity and temperature data. In addition, first estimates on total ozone loss calculations within the polar vortex using MIPAS ozone data are determined to be 9% for this winter. The three ENVISAT ozone profile retrievals agree within 20% (RMS <15%) between 18 and 36 km.

1 INTRODUCTION

Since the 1990s substantial chemical O_3 loss confined to lower stratosphere was observed in the Arctic polar vortex (by ground-based, balloon, air-borne, satellite techniques)- see e.g. [1]. The three ENVISAT instruments GOMOS (Global Ozone Monitoring by Occultation of Stars), MIPAS (Michelson Interferometer for Passive Atmospheric Sounding) and SCIAMACHY (Scanning Imaging Absorption Spectrometer for Atmospheric Chartography) measure globally 300-600 O_3 profiles per day. These measurements complement each other, because they measure with different vertical and horizontal resolution, during different times of the day: while MIPAS measures during day and night, SCIAMACHY measures besides some lunar occultation measurements only during daytime and from GOMOS so far only data from twilight and nighttime measurements are usable (further details in [2],[3],[4]).

SCIAMACHY measures in nadir, limb and occultation geometry solar and backscattered radiation from Earth in the UV-VIS-NIR range. In this study, we use the scientific ozone profiles derived by the retrieval from the Institute of Environmental Physics of the University of Bremen, further described in [5], from SCIAMACHY Level-0 data (version 1.6) between 15 and 40 km with 3 to 4 km resolution. SCIAMACHY O_3 profiles are at 18 to 40 km within 12% (RMS <15%) compared to collocated SAGE II (v6.2) measurements [6]. GOMOS measures ozone profiles besides other trace gases with stellar occultation between 17-22 km up to 80-100 km with 1 km resolution, more details in [4]. GOMOS profiles version GOPR 6.0a from the ACRI processor were used for this study which showed a small negative bias between 0 and 5% (RMS between 5-15%) at 21 to 52 km with collocated SAGE II (v6.2) measurements [6]. MIPAS measures the atmospheric limb emission spectra from 685-2410 cm^{-1} (14.5 to 4.1 µm) over the altitude range from 6 to 68 km. Besides other atmospheric constituents these spectra allow quantification of ozone concentration profiles (further details in [2]). MIPAS O_3 profiles are at 0.5 to 60 hPa within 5% (RMS <15%) compared to collocated SAGE II (v6.2) measurements [7].

The objectives of this paper is the start of a larger study calculating chemical ozone loss during winter 2002/2003 by using ENVISAT ozone data within the polar vortex and determining total ozone loss and diabatic heating rates. First results from total ozone loss rates from MIPAS data are presented. In addition, arctic ozone distributions using data from GOMOS, MIPAS and SCIAMACHY at different altitudes are compared to ECWMF PV and T at 475 K and GOME (because no SCIAMACHY data of the new version 5.1 were available) total ozone. A cross validation of arctic ozone profiles from GOMOS, MIPAS and SCIAMACHY is presented in order to elucidate how different data sets can be linked together. Before starting to work with the three ENVISAT ozone data sets, one has to bear in mind that in data of 2002-2003 indications for a slow drift in pointing to higher tangent heights (TH;~0.2 km/orbit) for SCIAMACHY [8] and to lower TH for

Proc. of the 2004 Envisat & ERS Symposium, Salzburg, Austria
6-10 September 2004 (ESA SP-572, April 2005)

MIPAS [9] and also for TH discontinuities up to 3 km due to a not accurate on-board orbit model have been found ([8],[9]); since Dec. 2003 a correction scheme based on engineering and orbit model updates is provided in the data sets starting from this date which lead to correct limb pointing data (a constant offset still appears to be present).

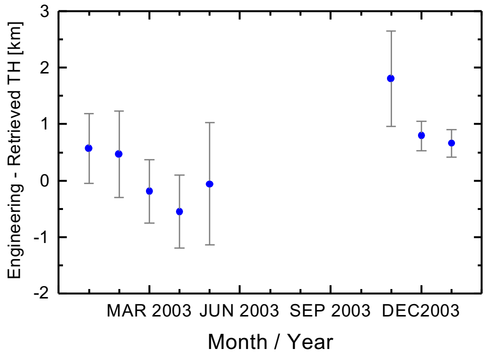

Fig. 1. Monthly average tangent height offsets in tropical SCIAMACHY limb profiles, picture taken from [10]

For MIPAS Offline data it is recommended to work instead on the altitude level rather on the pressure level which is correctly retrieved by the instrument itself (pers. com. by T. von Clarmann, IMK-FZK). For the scientific MIPAS Level-2 products from the IMK-FZK a simultaneous retrieval of temperature and and line of sight pointing is retrieved and the tangent heights are derived from this information. However, in this study operational MIPAS data are used. For SCIAMACHY so far two methods are used: The TRUE method where a tangent height retrieval is derived by the UV-B exploitation based on RTM SCIARAYS used for tropical measurements and then applied to all other measurements of one orbit (see further details in [8],[10] and Fig. 1) or an average correction by 1-2 km for a whole data set is applied. In this study SCIAMACHY data were shifted by 1 km up. Further improvements are expected when the reprocessing of the SCIAMACHY and MIPAS 2002/2003 data sets using corrected pointing information from ENVISAT has been applied (for further details see [11]).

2 OZONE LOSS WITHIN THE POLAR VORTEX DERIVED FROM MIPAS DATA

Corresponding to the method developed by [12] total ozone loss in the arctic winter 2002/03 within the polar vortex is determined from satellite ozone data: MIPAS O3 volume mixing ratios (VMR) from Nov. 2002 to March 2003 at the 475 K isentrope have been checked to be at this isentropic level within arctic polar vortex (criteria of PVU >38, using potential vorticity data from UK Meteorological Office). Fig. 2 shows averages with standard deviations of MIPAS values at 475 K of the winter 2002/03 within the arctic polar vortex.

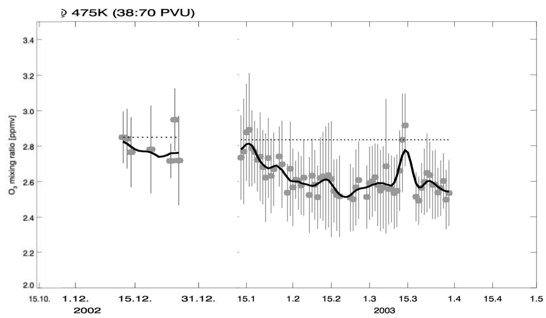

Fig. 2. Time series of MIPAS arctic vortex v4.61 daily averages [ppmv] (solid circles) and standard deviations at 475 K isentropic height for the winter/spring 2002/2003. The black line is a cubic spline interpolation through the five point running mean. The inner vortex is defined to be inside of the potential vorticity contour line of 38 PVU. Method according to [12]

As it can be seen by the first daily MIPAS ozone averages in the vortex in Figure 2, the arctic polar vortex formed in this year by early December 2002 due to extraordinary cold temperatures in the arctic stratosphere during November/December 2002 [13]. Values of MIPAS averages during this time start at 2.85 ppmv and are 10-15% below climatological means according to [14]. First PSCs in winter 2002-03 have been detected in MIPAS data on December 1 with top altitudes of around 24 km and continued to exist until December 29 at altitudes around 18 km [15]. We observe in Fig. 2 a continous decrease in ozone vmr at 475 K until this date, but then no data were available until Jan 14th 2002. In between this time, a rather strong minor warming in the end of December and a major warming occurred in mid January 2003 resulting the vortex to split into two centres over northern Europe and Canada. We observe a sudden increase of ozone vmr (> 2.95 +/- 0.2 ppmv), higher then at the beginning of the arctic winter 2002-03 when first ozone averages were measured witihn the polar vortex. But, by beginning of February the vortex was re-established and for a short period temperatures were again low enough for PSCs formation in the lower stratosphere [13]. Then a continous decrease until < 2.55 +/- 0.15 ppmv in ozone vmr at 475 K was observed, until the final warming started in the last days of March [13] and the ozone vmr started rising again. In the second half of April 2003 the polar vortex split and disappeared [13].
Overall, low total ozone loss was observed looking at the MIPAS data with about 12 ppbv loss per day. But, diabatic heating calculations according to [12] planned for the near future, will clarify if noticeable chemical ozone loss occurred in this arctic winter.

3 ENVISAT OZONE DISTRIBUTIONS ON MARCH 1ST, 2003

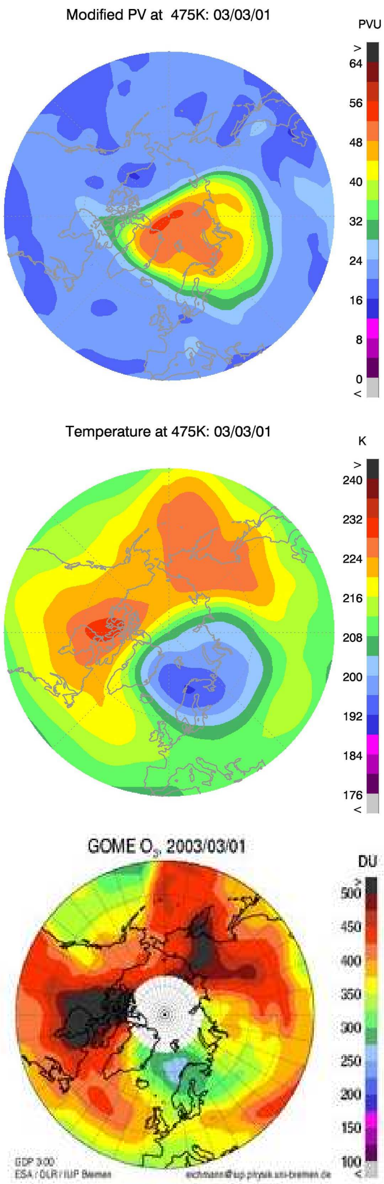

Fig. 3. Northern hemispheric distributions on March 1st, 2003 of modified potential vorticity (top) and temperature (middle), derived from ECMWF data, at the 475 K isentrope and total ozone (from GOME 3.0)

In this section, it was studied in which altitudes ozone distributions, measured by SCIAMACHY, GOMOS and MIPAS (Fig. 4) vary the most in comparison to total ozone distribution, measured here by GOME/ERS-2 (data version 3.0, Fig. 3 bottom), and potential vorticity (PV) and temperature data at the 475 K, derived from the UK Meteorological Office (Fig. 3 top and middle, respectively). As an example data from March 1st, 2003 are presented here. All ENVISAT ozone distributions have been derived from all measurements taken during that day and then extrapolated into 2.5° latitudinal x 5° longitudinal grids where measurements were available. To overcome the tangent height offset encountered in the MIPAS and SCIAMACHY data sets, SCIAMACHY data were shifted by 1.5 km up and MIPAS by 1.5 km down. For MIPAS in all grid points measurements were available, while ozone distributions for SCIAMACHY are limited to the area outside the polar night and to the availability of level-0 data during that day (which only comprise 10 out of 14 orbits), and for GOMOS to the dark measurements around the pole and twilight measurements in <45°.

In Fig. 3 the location of the polar vortex can be identified where PV values are above 40 PVU (PV units). Polar stratospheric clouds are expected to form where in addition to such high PV values also the temperature decreases below 195 K which is the case for the 475 K isentrope in the area reaching from northern Scandinavia and North-Sibiria over the North Pole to Greenland. This is in accordance with PSC occurrence derived from MIPAS spectral data, although mostly weak, in the Arctic for this area and time period by [16]. The highest gradient in northern hemispheric ozone distributions can be seen at 19 km (Fig. 4 upper panel), most pronounced in MIPAS data: lowest concentrations, but much weaker expressed in the SCIAMACHY data set, are found were the polar vortex formed and temperature values are lowest. This feature can be seen up to an altitude of 27 km in all three data sets.

4 COMPARISON OF ENVISAT OZONE DISTRIBUTIONS FROM ARCTIC WINTER 2003

In order to look how comparable different data sets can be linked together, we compared the arctic ozone data sets of the three ENVISAT instruments from January to March 2003 to each other. The coincidence criteria were that the tangent point of the GOMOS or MIPAS is within 500 km of SCIAMACHY or GOMOS and measurements were performed within 12 hours. In addition and according to the method by [17], only matches are compared where both are clearly within or outside the polar vortex, regarding to their PV value taken from UKMO data at the 475 K isentrope. Results of these comparisons are shown in Fig. 5: two examples of triple matches within the polar vortex (lower panel) show between ~20 and 40 km good agreement between SCIAMACHY and MIPAS. The GOMOS profile is with its maxima values close to the others, but shows an oscillating structure with really low values. Below 20 km deviations are much larger. The statistics outside the polar vortex, Fig. 5 upper panel, show a negative offset

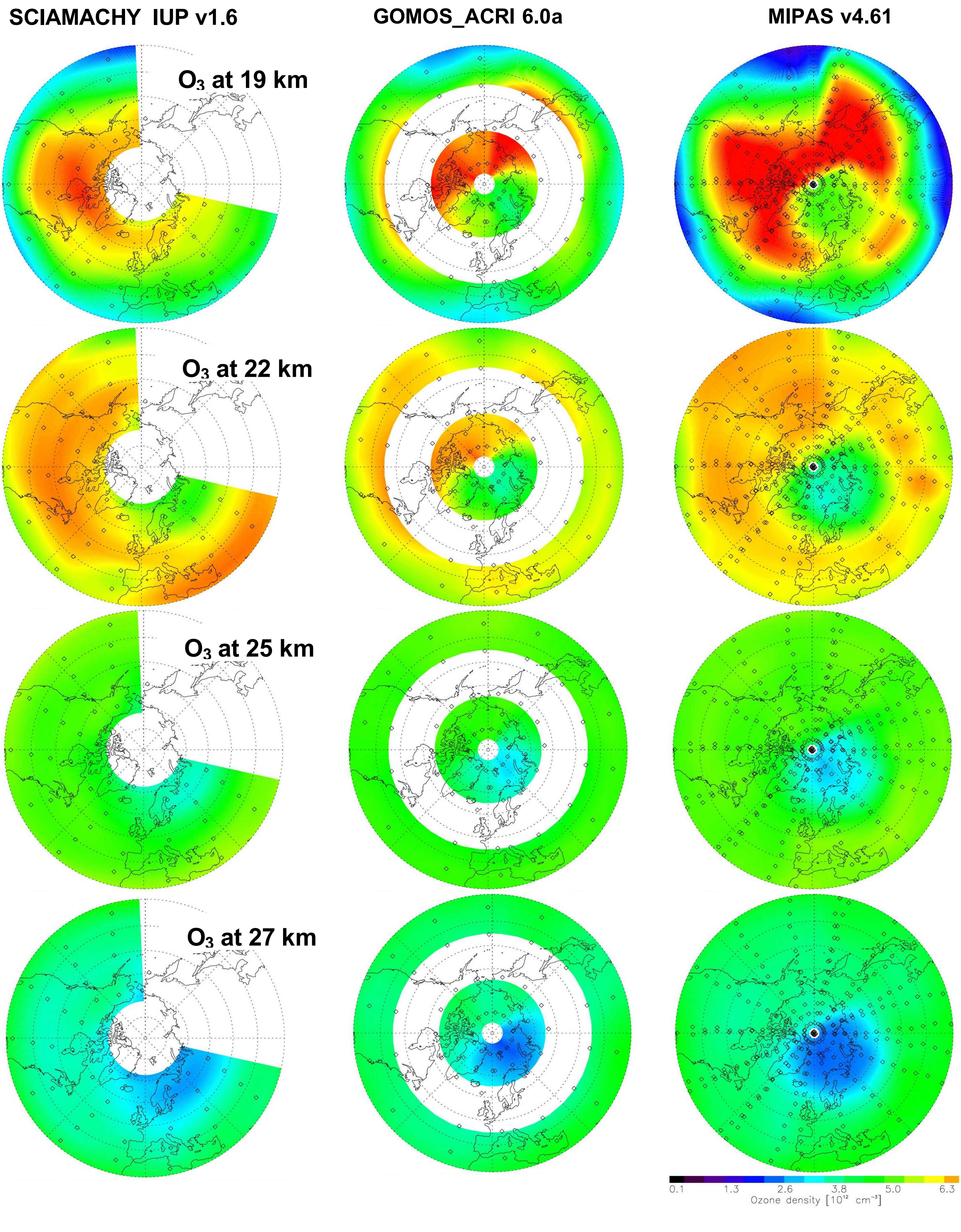

Fig. 4. Northern hemispheric O_3 distributions measured by SCIAMACHY_IUP v1.6, GOMOS ACRI 6.0a, and MIPAS v4.61 at 19, 22, 25, and 27 km

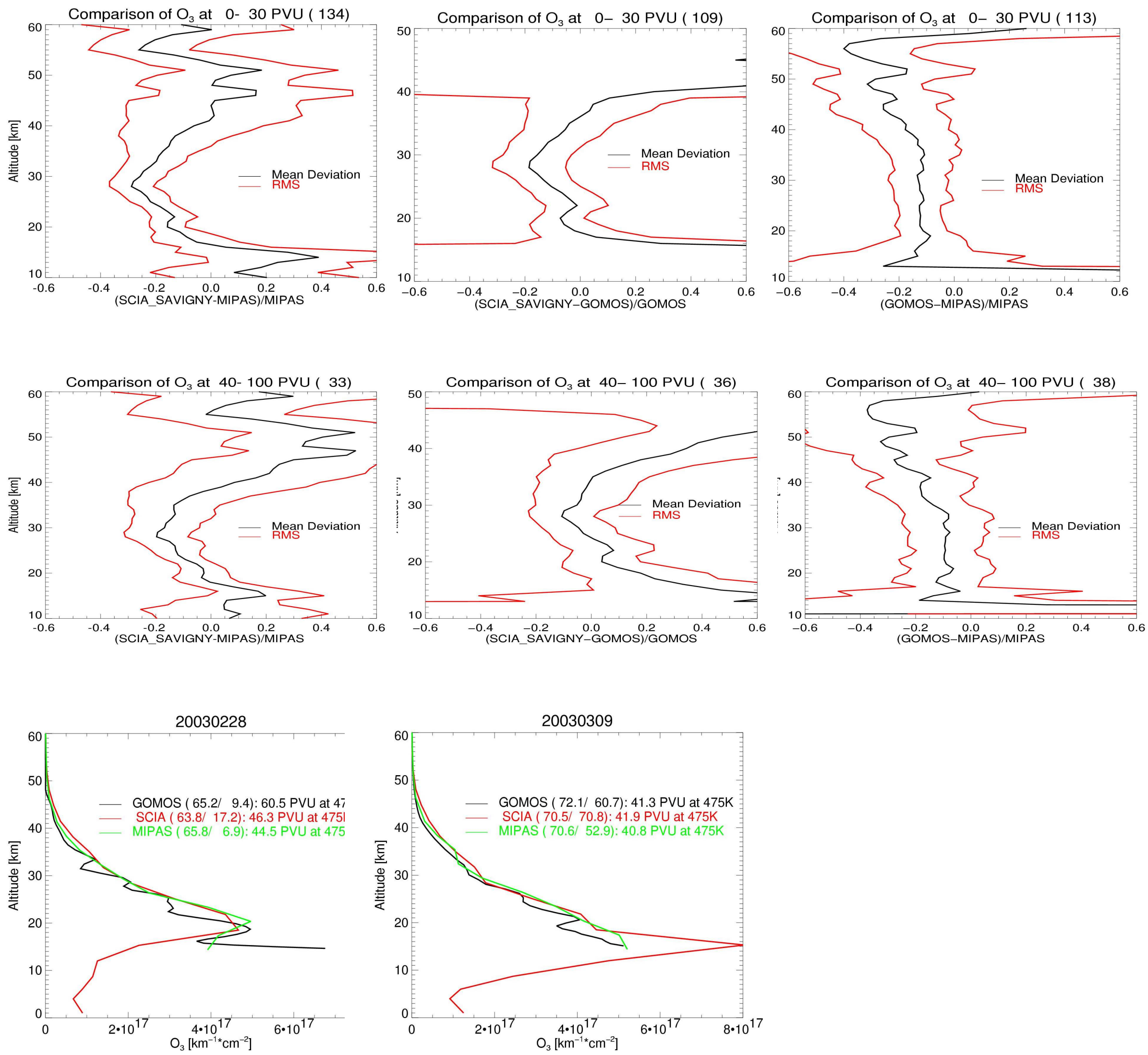

Fig. 5. Comparison of Arctic (latitudes >55°) O_3 profiles measured by SCIAMACHY_IUP v1.6, GOMOS ACRI 6.0a, and M IPAS v4.61. Upper panel: Mean relative deviation (black) and the standard deviation (RMS, red) of the mean relative deviation of collocated SCIAMACHY and MIPAS (left), SCIAMACHY and GOMOS (middle), and MIPAS and GOMOS (right) measurements outside the polar vortex (PV at 475 K <30 PVU). The number od collocation is given in the brackets. Middle panel: Mean relative deviation (black) and the standard deviation (RMS, red) of the mean relative deviation of collocated SCIAMACHY and MIPAS (left), SCIAMACHY and GOMOS (middle), and MIPAS and GOMOS (right) measurements inside the polar vortex (PV at 475 K >40 PVU). Lower panel: Examples of triple collocations within the polar vortex with GOMOS (black), SCIAMACHY (red), and MIPAS (green).

for SCIAMACHY to MIPAS of 5 to 25% (RMS 6-15%) between 17 to 36 km, for SCIAMACHY to GOMOS of 0 to 20% (RMS 8-15%) between 18 to 36 km and for GOMOS to MIPAS of 9 to 13% (RMS 7-15%) between 18 to 38km. Inside the polar vortex**,** Fig. 5 middle panel, we observe a negative offset for SCIAMACHY to MIPAS of 0 to 20% (RMS 8-15%) between 17 and 35 km and for GOMOS to MIPAS of 6 to 15% (RMS 6-15%) between 17 and 36 km. But, SCIAMACHY agrees now within 10% to GOMOS (RMS 12-20%) between 19 to 36 km.

5 CONCLUSIONS AND OUTLOOK

The ozone intercomparisons between the three ENVISAT instruments show an overall agreement within 20% at 18 to 36 km with RMS of 5 to 15% outside the polar vortex, but MIPAS data seem to be generally 5-20% higher than GOMOS and SCIAMACHY. Overall, the tangent height offset is observed to affect the SCIAMACHY data more severe than the MIPAS data.

Regarding the GOMOS, MIPAS and SCIAMACHY northern hemispheric ozone distributions on March 1st 2003, very low concentrations compared to other regions at the same latitudes have been found at 22 to 27 km where the polar vortex (>40 PVU and <200 K at 475 K isentrope) had formed. Despite the problem with the in the MIPAS and SCIAMACHY data encountered tangent height offset, a good agreement between ENVISAT instruments has been observed.

Our results show in MIPAS arctic ozone concentrations at the 475 K from winter 2002/03 a minimum at mid February 2003 and a maximum in mid January and after mid March (when air from outside is coming in and the vortex breaks apart). Overall a ozone decrease of ~ 9% or 12 ppbv/day could be calculated for this winter. Further calculations of diabatic heating rates to derive the chemical ozone loss and also an extension of the calculations to the 400 to 600K isentropic subcolumns are planned in the near future. After reprocessing of MIPAS and SCIAMACHY data with improved tangent height retrievals, we want to extend the ozone loss calculations to all three atmospheric ENVISAT instruments and to Arctic winter 2003/04.

ACKNOWLEDGEMENTS

We would like to thank ACRI France, DLR Oberpfaffenhofen and ESA for providing us with SCIAMACHY level-0, and MIPAS, GOMOS and GOME level-2 data. We thank the UK Meteorological Office and the European Centre for Medium-Range Weather Forecast for providing the meteorological data sets and T. von Clarmann (IMK) and G. Schwarz (DLR) for information on the MIPAS tangent height retrieval. This work is funded by the BMBF (FKZ 01 SF9994), the DLR-Bonn (50EE0025) and ESA (AO651).

6 REFERENCES

1. Manney, G. L., M. Froideaux, N. Santee, et al., Variability of ozone loss during Arctic winter (1991 to 2000) estimated from UARS Microwave Limb Sounder measurements, *J. Geophys. Res.*, 108, doi:10.1029/ 2001JD000482, 2002.

2. Stiller, G. P., N. Glatthor, S. Kellmann, E. Kimmich, A. Linden, M. Milz, H. Fischer, MIPAS on ENVISAT as an UT/LS Sounder, in *Current Problems in Atmospheric Radiation*, edited by W.L. Smith, Yu M. Timofeyev, pp. 839-842, A. Deepak Publishing, Hampton, Virginia, 2001.

3. Bovensmann, H., Burrows J. P., Buchwitz M., Frerick J., Noël S., Rozanov V. V., Chance K. V., and Goede A. H. P., SCIAMACHY - Mission Objectives and Measurement Modes, *J. Atmos Sci.*, Vol. 56, 125-150, 1999.

4. Bertaux J. L., Megie G., Widemann T., Chassefiere E., Pellinen R., Kyrölä E., Korpela S., and Simon P., Monitoring of Ozone Trend by Stellar Occultations: The Gomos Instrument, *Adv. Space Res.*, Vol. 11, 237-242, 1991.

5. von Savigny, C., A. Rozanov, H. Bovensmann, K.-U. Eichmann, J.W. Kaiser, S. Noël, V.V. Rozanov, B.-M. Sinnhuber, M. Weber, J.P. Burrows, The Ozone hole break-up in September 2002 as seen by SCIAMACHY on ENVISAT, *J. Atmosph. Sci.*, in press, 2004.

6. Bracher, A., K. Bramstedt, A. Richter, A. Rozanov, C. v. Savigny, M. Sinnhuber, M. Weber, J.P. Burrows, Validation of SCIAMACHY and GOMOS O3 and NO2 products with GOME, HALOE and SAGE II, *Procceedings of Second Workshop on the Atmospheric Chemistry Validation of ENVISAT (ACVE-2)*, 3-7 May 2004, 2004.

7. Bracher, A., K. Bramstedt, M. Sinnhuber, M. Weber, J.P. Burrows, Validation of MIPAS O3, NO2, H2O and CH4 profiles with HALOE and SAGE II, *Procceedings of Second Workshop on the Atmospheric Chemistry Validation of ENVISAT (ACVE-2)*, 3-7 May 2004, 2004.

8. Kaiser J.W., C. von Savigny, S. Noël, K.-U. Eichmann, H. Bovensmann, J. Frerick, J. P. Burrows, Pointing retrieval from limb scattering observations by SCIAMACHY, *Can. J. Phys.*, revised, 2004.

9. von Clarmann T., et al. Retrieval of temperature and tangent altitude pointing from limb emission spectra recorded from space by MIPAS, *J. Geophys. Res.*, revised, 2004.

10. von Savigny C,. et al., SCIAMACHY limb pointing retrieval report – improvement of pointing performance after December 2003 update. IUP, University Bremen, technical note: 2004.

11. Duesmann, B., R. Koopman, L. Ventimiglia, The Attitude of ENVISAT; the Past and Current Pointing Performance Observed by the Payload, Proceedings of the ENVISAT Symposium, Salzburg 6-10 Sept, 2004.

12. Eichmann K.-U., M. Weber, K. Bramstedt, J. P. Burrows: Ozone depletion in Northern Hemisphere winter/spring 1999/2000 as measured by the Global Ozone Monitoring Experiment on ERS-2. *J. Geophys. Res.*, 107, D20,8280, doi:10.1029/2001JD001148, 2002.

13. Naujokat, B.: The Northern Stratosphere in the 2002/03 Winter. Preliminary results from the first phase of VINTERSOL. European Ozone Research Coordinating Unit (eds.), June 2003, pp. 7, 2003.

14. European Ozone Research Coordinating Unit (eds.): The Northern Stratosphere in the 2002/03 Winter. Preliminary results from the first phase of VINTERSOL, June 2003, pp. 15, 2003.

15. Tilmes, S., et al.: Very early chlorine activation and ozone loss in the Arctic winter 2002/03. *Geophys. Res. Lett.*, Vol. 30, 2201, doi:10.1029/2003GL018079,2003.

16. Spang, R., J. J. Remedios, L. J. Kramer, et al., Polar stratospheric cloud observation by MIPAS on ENVISAT : Detection method, validation and analysis of the northern hemisphere winter 2002/3, Atmos. Phys. Chem., submitted, 2004.

17. Bracher, A., M. Weber, K. Bramstedt, S. Tellmann, J. P. Burrows, Long-term global measurements of ozone profiles by GOME validated with SAGE II considering atmospheric dynamics, *J. Geophys. Res.*, in press, 2004.