Ground-Based Millimeter Wave Observations of Stratospheric Ozone at the Alpine Station Zugspitze in 2003

G. Kopp, J. Groß, G. Hochschild, and R. Lehm

Institut f. Meteorologie und Klimaforschung, Forschungszentrum und Universität Karlsruhe, Germany

Abstract. From February to July 2003 the ground-based millimeter wave radiometer MIRA2 was operated at the Environmental Research Station Schneefernerhaus (Umwelt Forschungsstation Schneefernerhaus, UFS), situated on the south slope of the Zugspitze summit (47.4°N, 11°E, 2650 m a.s.l.). This high altitude site was chosen because of its low tropospheric opacity during long seasonal periods. From the measurements a nearly continuous time series of ozone profiles in the vertical range 15-55 km was retrieved. The location was well outside the polar vortex for most of the period, except around March 20 when this site was in the vortex edge region. The result was a decrease of the maximum mixing ratios of ozone. No significant growth in the stratospheric columns has been observed during this event which might be due to some ozone loss in the vortex edge region. From winter to summer an increasing altitude of the isopleths in the lower stratosphere due to the upwelling and decreasing stratospheric columns were observed.

Introduction

The ground-based millimeter wave radiometer MIRA2 was developed by the Forschungszentrum Karlsruhe and is designed to measure ozone, ClO, N_2O, and HNO_3 in the frequency range 268-281 GHz. A detailed description of the system is given in Berg et al. [1998]. For data analysis a modified Optimal Estimation Method [Rodgers, 1976] is used to retrieve vmr profiles of the stratospheric constituents in the vertical range 15-55 km. The vertical resolution of the retrieved ozone profiles is at best 7 km and for the minor constituents the vertical resolution is at best between 10-12 km [Kopp et al., 2002].

From 12 February to 28 July 2003 the radiometer MIRA2 was operated at the Environmental Research Station Schneefernerhaus (Umwelt Forschungsstation Schneefernerhaus, UFS) on the Zugspitze (47.4°N, 11°E, 2650 m a.s.l.). Because of its altitude this site has a high tropospheric transmission and is therefore well suited for ground-based microwave observations. At the end of February the tropospheric transmission reached maximum values of more than 90%. From the measured spectra nearly continuous time series of the stratospheric constituents were retrieved.

Results

The results of the measurements for ozone and N_2O are presented in Figure 1. For comparison the potential vorticity and temperature at 475 K isentropic level over the Zugspitze (ECMWF data) are shown in the lower panel of the same figure. The inner, outer, and mean vortex edge were calculated using the equivalent latitudes as suggested by Nash et al., [1996]. The mean vortex edge is given by the steepest gradient of the PV plottet against the equivalent latitude, and the inner and outer edge by the strongest curvature.

As can be seen in this graph the Zugspitze was outside the polar vortex for most of the time. But around March 20 the Zugspitze was in the vortex edge region resulting in increasing PV values and decreasing temperatures.

Ozone The topmost panel of Figure 1 shows the time series of ozone vmr profiles from 18 February to 16 July. During some periods no measurements were taken due to technical problems. Single days of missing data were interpolated for this graph. The second panel shows the corresponding ozone columns above an altitude of 10 km.

During the first two weeks the vertical ozone distribution over the Zugspitze stayed nearly unchanged. Then the maximum mixing rations decreased significantly when this site was in the vortex edge region. The ozone columns show no significant increase as one would expect if no ozone depletion took place inside the polar vortex. Therefore the nearly constant stratospheric columns during this event are an evidence of chemical ozone depletion inside the vortex and the vortex edge region. This corresponds to the results of Odin measurements [Urban et al., 2004] and to measurements in Kiruna (67.8°N, 20.4°E, 425 m a.s.l.) using a radiometer system similar to MIRA2 [Raffalski et al., 2004].

In the course of spring to summer the time series of ozone profiles shows increasing altitudes of the isopleths as a result of the buoyancy in the atmosphere. During the same time span the ozone columns decrease due to the buoyancy in the atmosphere and the breakdown of the Brewer-Dobson circulation which transports ozone rich air from the tropics to higher latitudes during winter.

N_2O The third panel of Figure 1 shows the time series of N_2O vmr profiles between 15 March and 16 July. As for the ozone time series single days of missing data were interpolated for this graph. N_2O is widely used as a long-lived tracer to investigate dynamical effects in the stratosphere.

During the time span in March when the Zugspitze was in the vortex edge region the N_2O isopleths show decreasing altitudes. This is the result of the diabatic subsidence inside the polar vortex. Close inspection reveals that the diabatic subsidence increases with altitude. The altitude difference between the vortex edge values and the N_2O profiles outside the vortex amounts to over 6 km for the 0.05 ppmv isopleth.

From spring to summer the isopleths show increasing altitudes due to the buoyancy in the stratosphere. The difference in altitude between spring and summer amounts to about 6 km for the isopleths between 0.05 and 0.3 ppmv N_2O.

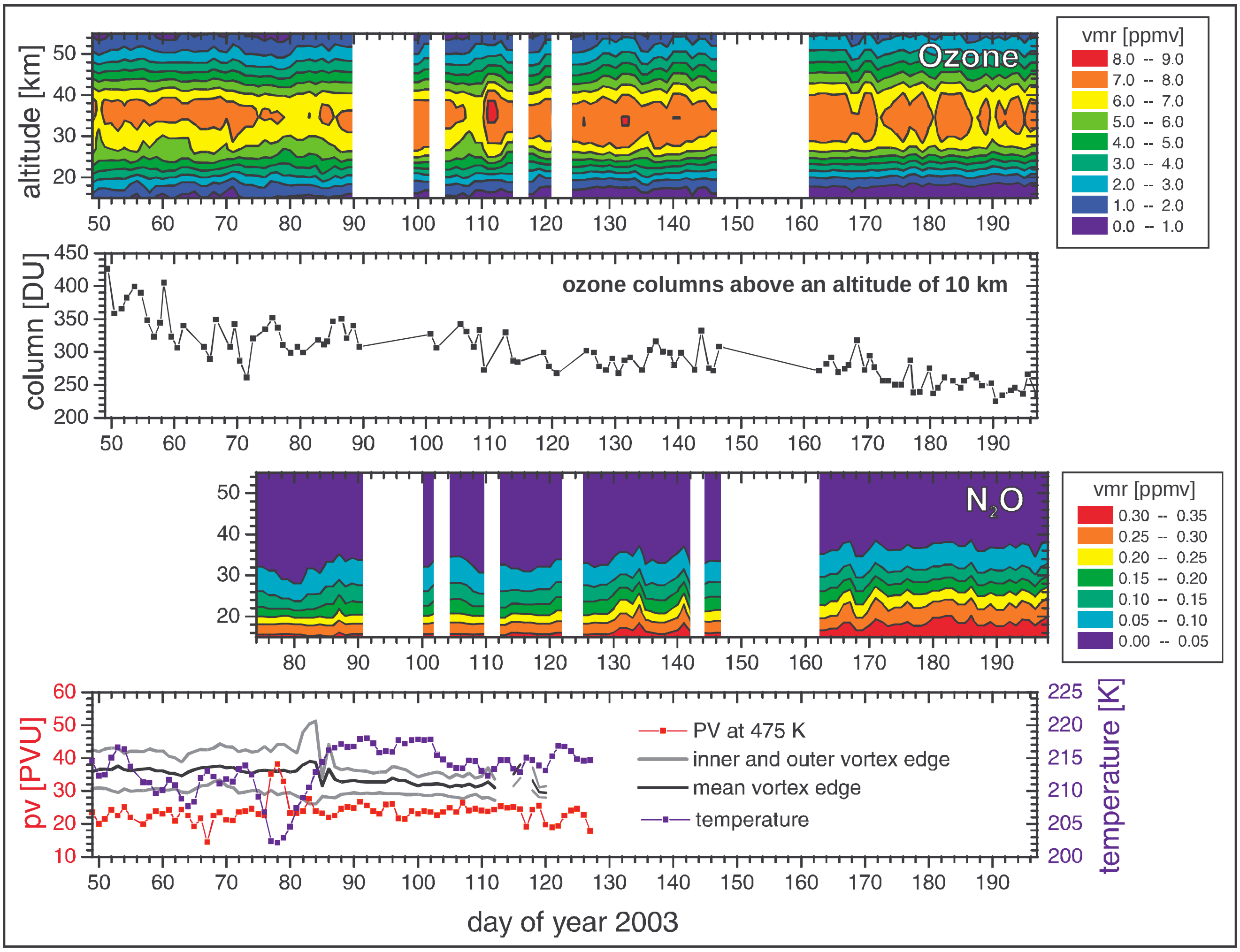

Figure 1. Ozone and N_2O as measured by the microwave radiometer MIRA2 on the Zugspitze in 2003 and the corresponding PV and temperature at 475 K isentropic level (ECMWF data).

Acknowledgments We would like to thank the stuff of the Schneefernerhaus for their kind support during our measurement campaign. We are grateful to ECMWF and NILU for providing the PV and temperature data. The authors also thank NCEP for providing temperature and pressure data used for the retrievals via the Goddard automailer system. This project was funded by BMBF/DLR under the contract FKZ 50EE0011.

References

Berg, H., R. Krupa, G. Hochschild, G. Kopp, M. Kuntz, Millimeter wave radiometer with adjustable internal calibration load for high resolution measurements of stratospheric constituents, *Proceedings of 2nd ESA Workshop on Millimetre Wave Technology and Applications: Antennas, Circuits and Systems*, 372-377, Espoo, 1998.

Kopp, G., et al., Evolution of ozone and ozone related species over Kiruna during the THESEO 2000 - SOLVE campaign retrieved from ground-based millimeter wave and infrared observations, *J. Geophys. Res.*, Vol. 107, 8308, doi:10.1029/2001JD001064, 2002. [printed 108(D5), 2003]

Nash, E. R., P. A. Newman, J. E. Rosenfield, and M. R. Schoeberl, An objective determination of the polar vortex using Ertel's potential vorticity, *J. Geophys. Res.*, 101, 9471 – 9478, 1996.

Rodgers, C.D., Retrieval of Atmospheric Temperature and Composition from Remote Measurements of Thermal Radiation, *Reviews of Geophysics and Space Physics*, 14, 609-624, 1976.

Raffalski, U., G. Hochschild, G. Kopp, J. Urban, Evolution of stratospheric ozone during winter 2002/2003 as observed by a ground based millimetre wave radiometer at Kiruna, Sweden, submitted to *Atmospheric Chemistry and Physics*, 2004.

Urban, J., et. al, The Northern Hemisphere Stratospheric Vortex during the 2002-03 Winter: Subsidence, Chlorine Activation and Ozone Loss observed by the Odin Sub-Millimetre Radiometer, *Geophysical Research Letters*, accepted, 2003.

E-mail: `gerhard.kopp@imk.fzk.de`
www: `www.fzk.de/imk/asf/mira`