Height resolved ozone hole structure as observed by the Global Ozone Monitoring Experiment-2

J.C.A. van Peet[1], R.J. van der A[1], A.T.J. de Laat[1], O.N.E. Tuinder[1], G. König-Langlo[2], and J. Wittig[2]

[1]*Royal Netherlands Meteorological Institute, De Bilt, The Netherlands*
[2]*Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany*

ABSTRACT

We present GOME-2 ozone profiles that were operationally retrieved with the KNMI OPERA algorithm for the period September-December 2008. It is shown that for the first time it is possible to accurately measure the vertical distribution of stratospheric ozone for Antarctic ozone hole conditions from spectra measured at ultraviolet and visible wavelengths. Comparisons with ozone sonde observations from the Neumayer station at the Antarctic coast show an excellent agreement for various ozone profile shapes representing different phases of the annual ozone hole cycle. A time series analysis shows the development and recovery of the ozone hole in great detail. Around the time of maximum ozone depletion in the middle of October we plotted latitudinal and longitudinal cross sections of the atmosphere centered on the Neumayer station. These cross sections give a clear view of the extent of the ozone hole in both North-South and East-West direction and it's dynamics. A preliminary analysis of the three-dimensional structure of the ozone hole shows for example that at the vortex edges ozone rich mid-latitude middle and upper stratospheric layers are superimposed over ozone depleted lower stratospheric 'ozone hole' layers. These Antarctic ozone profile observations combined with the daily global coverage of GOME-2 enables the monitoring of the three-dimensional structure of the ozone hole on a daily basis.

1. INTRODUCTION

The launch of the Global Ozone Monitoring Experiment (GOME) on board of the European Remote Sensing 2 satellite in April 1995 started a new era of measuring earth-reflected solar radiation with relatively high spectral resolution for UltraViolet and VISible wavelengths (UV-VIS). A number of studies have shown that it is possible to retrieve ozone profiles from these UV-VIS spectral observations [e.g. 2, 4].

A typical problem with UV-VIS profiles is their limited vertical reolution, and as a consequence, small scale vertical ozone features cannot be observed. This is also true for the ozone hole, since the thickness of the depleted layers is typically about 5 km. In addition, the difference between snow/ice surfaces and middle/high level clouds can cause errors in the retrieved ozone profiles. It is expected that instruments like GOME-2 will be less influenced by these drawbacks and will improve our knowledge obout the vertical distribution of ozone in the ozone hole.

The GOME-2 instrument [1], launched on 19 October 2006 onboard Metop-A, flies in a sun-synchronous polar orbit with an equator crossing time of 09:30 hrs (local solar time). GOME-2 is a nadir looking cross-track scanning spectrometer. The instrument measures backscattered solar light from the Earth's atmosphere between 240-790 nm in four channels with a relatively high spectral resolution (0.2-0.4 nm). In its normal mode, the instrument has an almost global daily coverage with a cross-track swath width of 1920 km which is split up in ground pixels with a horizontal resolution of 80×40 km between 307-790 nm and with 640×40 km below 307 nm due to much weaker signals. The operational retrieval algorithm for GOME-2 ozone profiles is the Ozone ProfilE Retrieval Algorithm (OPERA) algorithm [6, 7], which will be described in the next section.

We have investigated how well the ozone profile retrievals from GOME-2 UV-VIS measurements can capture the vertical distribution of ozone during Antarctic ozone hole conditions and discuss the use of these observations for monitoring the 3-D structure of the Antarctic ozone hole on a daily basis.

2. OPERA

OPERA is an algorithm that solves the profile retrieval problem using the optimal estimation method [e.g. 5], which requires *a priori* information (including error covariance) for the state vector elements and the derivatives of the measurement to the state. The apriori information is taken from the ozone climatology of [3]. The derivatives of the measurement to the state vector (i.e. weighting functions) are calculated with the radiative transfer model LidortA [8].

The optimal estimation method is applied iteratively until convergence is reached. The convergence criteria for the retrieval are based on the magnitude of the state update and the deviation between measured and simulated radiances. The retrieval of ozone profiles is currently done using ground pixels of 640×40 km.

© Proceedings of the 8th International Symposium on Tropospheric Profiling, ISBN 978-90-6960-233-2
Delft, The Netherlands, October 2009. Editors, A. Apituley, H.W.J. Russchenberg, W.A.A. Monna

3. INTERCOMPARISON OF OZONE PROFILES

For validation of the GOME-2 ozone profiles we use data from the ozone balloon sounding program conducted at the Antartic research station Neumayer (8.26°W and 70.65°S) which has been operational since 1992, with ozone profiles obtained weekly. During the development of the ozone hole, the sounding frequency is increased to three times a week.

We only compare ozone sonde data and satellite data when the following three criteria have been fullfilled. First, the Neumayer Station should be located inside the satellite footprint. Second, within a footprint, the distance between Neumayer and the pixel centre should not exceed 300 km, the typical length scale of lower stratospheric ozone variations. Third, the launch of the sonde and the overpass of the satellite should be within 12 hours of each other. In total 37 collocations were found for the period September - December 2008, some of which are collocations of one sonde with multiple GOME-2 overpasses.

The sonde profile is convolved with the averaging kernel according to the equation $\hat{\mathbf{x}} = \mathbf{x_a} + \mathbf{A}(\mathbf{x} - \mathbf{x_a}) + \epsilon$. Replacing $\mathbf{x}$ by the sonde observation, $\hat{\mathbf{x}}$ gives us the retrieved sonde profile.

We have gridded the data to $1° \times 1°$ using an area weighted averaging. The gridded dataset is used in constructing plots of time series and cross-cutting views of the atmosphere (see Results).

4. RESULTS

In figure 1 we show a comparison between sonde and satellite profiles representing various stages in the ozone hole life cycle. A time series (September - December 2008) of the gridded dataset over the Neumayer Station is plotted in figure 2 which shows the development and breakup of the ozone hole. To get a better impression of the global behavior of the ozone concentration around the time of maximum ozone depletion, we made longitudinal and latitudinal cross sections of the atmosphere centered on Neumayer (see figure 3).

5. CONCLUSION

The first GOME-2 ozone profiles for Antarctic ozone hole conditions are presented. The algorithm OPERA is capable of retrieving the ozone profile in good agreement with ozone sonde measurements in this region. The time series shows that we are capable of monitoring the three dimensional structure of the ozone hole on a day-to-day basis. One interesting observation is the presence of ozone depleted laminae below the ozone maximum at the edge of the Antarctic vortex.

Since the GOME-2 instrument series will continue flying until about 2020, the expected recovery of the ozone hole can be monitored. In addition, the daily three dimensional coverage of the ozone hole opens new exciting possibilities to study Antarctic vortex dynamics, transport processes and evaluating climate models that include stratospheric chemistry.

For for more detailed information, see [9].

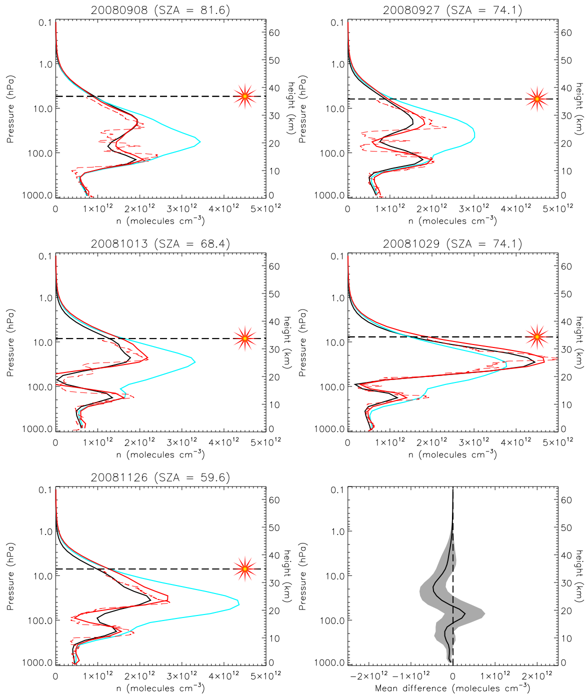

Figure 1. 5 ozone profiles (number density n in molecules cm^{-3}) using original, non-gridded data. The black line is the GOME-2 profile, the solid red line is the convolved sonde profile, the dotted red line is the original sonde profile and the blue line is the a priori profile. The bottom right plot shows the mean difference (GOME-2 - sonde) of all collocations in the period September - December 2008 (black line) and the 1 sigma error (grey area).

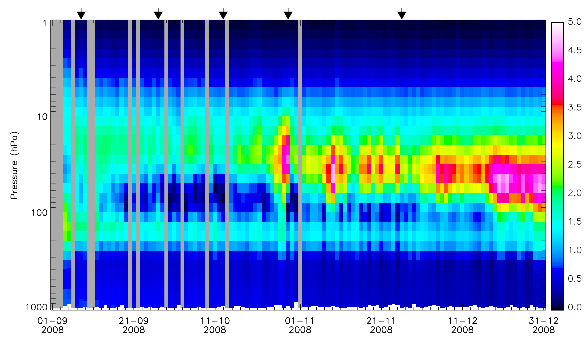

*Figure 2. Time series of the ozone concentration over the Neumayer Station. Arrows along the top indicate the locations of the profiles in figure **A**. Grey areas indicate missing data. Concentrations are given in 10^{12} molecules cm^{-3}.*

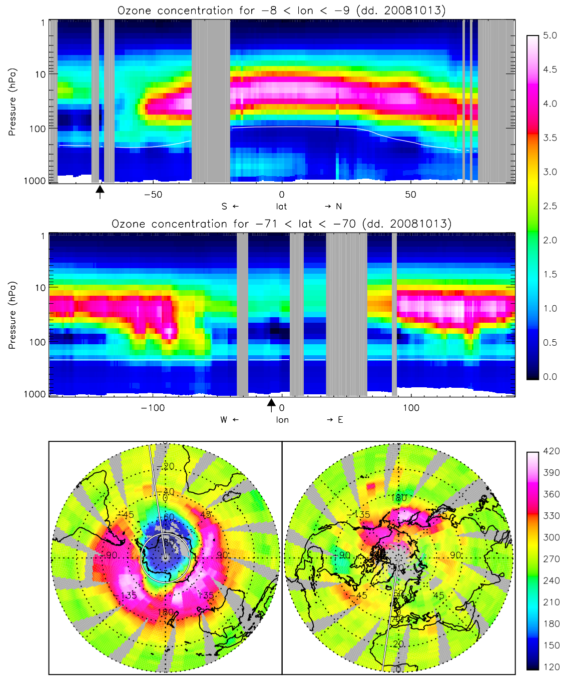

Figure 3. Longitudinal (top) and latitudinal (middle) cross sections of the atmosphere for 13 October 2008 centered on Neumayer. The bottom plots show GOME-2 total ozone columns integrated from the profiles (in DU) for the Southern (left) and Northern Hemisphere (right).

REFERENCES

[1] Callies, J., E. Corpaccioli, M. Eisinger, A. Hahne, and A. Lefebvre (2000), Gome-2 metops second-generation sensor for operational ozone monitoring, *ESA bulletin*, *102*, 28–36.

[2] Chance, K., J. Burrows, D. Perner, and W. Schneider (1997), Satellite measurements of atmospheric ozone profiles, including tropospheric ozone, from ultraviolet/visible measurements in the nadir geometry : a potential method to retrieve tropospheric ozone, *Journal of Quantitative Spectroscopy and Radiative Transfer*, *47*, 467–476.

[3] McPeters, R., G. Labow, and J. Logan (2007), Ozone climatological profiles for satellite retrieval algorithms, *Journal of Geophysical Research*, *112*, D05308, doi:10.1029/2005JD006823.

[4] Munro, R., R. Siddans, W. Reburn, and B. Kerridge (1998), Direct measurements of tropospheric ozone distributions from space, *Nature*, *392*, 168–171, doi:10.1038/32392.

[5] Rodgers, C. (2000), *Inverse methods for atmospheric sounding*, 238 pp., World Scientific Publishing.

[6] van der A, R., R. van Oss, A. Piters, J. Fortuin, Y. Meijer, and H. Kelder (2002), Ozone profile retrieval from recalibrated global ozone monitoring experiment data, *Journal of Geophysical Research*, *107(D15)*, 4239, doi:10.1029/2001JD0000696.

[7] van Oss, R., and J. de Haan (2004), Algorithm theoretical basis document for OPERA, issue 1.1, CHEOPS/KNMI/ATBD/001/17-20.

[8] van Oss, R., and R. J. D. Spurr (2002), Fast and accurate 4 and 6 stream linearized discrete ordinate radiative transfer models for ozone profile retrieval, *Journal of Quantitative Spectroscopy and Radiative Transfer*, *75*(2), 177–220, doi:10.1016/S0022-4073(01)00246-1.

[9] van Peet, J. C. A., R. J. van der A, A. T. J. de Laat, O. N. E. Tuinder, G. König-Langlo, and J. Wittig (2009), Height resolved ozone hole structure as observed by the global ozone monitoring experiment-2, *Geophysical Research Letters*, *36*, doi:10.1029/2009GL038603.