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Improvements in the tropical ozone profile retrieval from GOME-UV/Vis nadir spectra

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Abstract

The Global Ozone Monitoring Experiment (GOME) is a nadir viewing grating spectrometer measuring radiances in the visible and ultraviolet spectral range. The analysis of sun-normalized nadir spectra from GOME enables us to retrieve height resolved ozone distributions. The retrieval is based upon the FURM algorithm (Full Retrieval Method) which uses the advanced optimal estimation scheme. The spectral data require accurate radiometric calibration with regard to the increasing degradation of the instrument with time. In this paper, a calibration and degradation correction will be presented which enables us to extend the spectral range to shorter wavelengths enhancing the stratospheric information content of the retrieved profiles. This helps to avoid non-physical profile structures often observed in the tropics, where the ozone maximum is sensitive to this spectral range. Results in the low latitude range are compared with experimental results from the HALogen Occultation Experiment (HALOE) and retrieval results from former versions of FURM and show generally much better agreement.

Keywords: GOME; Tropic ozone profile retrieval; Visible and ultraviolet spectra; Atmospheric ozone

1. Introduction

The Global Ozone Monitoring Experiment (GOME) was launched aboard ESA's 2nd European Remote Sensing Satellite (ERS-2) in April 1995 into a polar sun-synchronous orbit. GOME measures radiances in the visible and ultraviolet spectral range (240–790 nm) in nadir viewing geometry with a spectral resolution of 0.1–0.3 nm. The Hartley–Huggins ozone bands in the short wavelength range from GOME are used to retrieve the vertical ozone distribution. The FUll Retrieval Method (FURM) which is developed to derive ozone profiles is based on an iterative inversion scheme which uses the pseudo-spherical multiple scattering forward model GOMETRAN (Rozanov et al., 1997) to calculate the sun-normalized radiance and the so-called weighting functions for a given atmospheric state. The "ill-posed" inversion problem is solved by the so-called advanced optimal estimation scheme which combines the optimal estimation approach (Rodgers, 1976) with the information matrix method from Kozlov. A detailed description of FURM can be found in (Hoogen et al. (1999)).

The current version 19 of HALOE data is used to validate FURM profiles in this work (http://haloe-data.larc.nasa.gov/). The HALogen Occultation Experiment (HALOE) was launched in September 1991 on the Upper Atmosphere Research Satellite (UARS) spacecraft (Russell et al., 1993). The instrument uses solar occultation to retrieve the vertical distribution of ozone and other trace gases from thermal infrared regions between 9.22 and 10.42 μm.

2. Calibration corrections

An investigation of the residuals between the GOME measured reflectivity and the model reflectivity reveals a large increase below 290 nm. The filling-in of Fraunhofer lines due to rotational Raman scattering cannot

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explain this and it is regarded as an indicator for insufficient radiometric calibration and uncorrected stray light and dark current in this spectral range. In an *ideal* case the GOME measured reflectivity $\mathrm{Refl}_{\mathrm{meas}}(\lambda)$ would be directly proportional to the atmospheric reflectivity $R_{\mathrm{atm}}(\lambda)/\mathrm{Irr}(\lambda)$ calibrated only by the standard calibration function $\mathrm{SCF}(\lambda)$ of the instrument

$$\mathrm{Refl}_{\mathrm{meas}}(\lambda) = \frac{1}{\mathrm{SCF}(\lambda)} \frac{R_{\mathrm{atm}}(\lambda)}{\mathrm{Irr}(\lambda)}. \quad (1)$$

On the other hand, the *real* measurement is disturbed by instrument related artifacts influencing the retrieval as additive errors a and multiplicative errors $m(\lambda)$, the latter is wavelength dependent, as follows:

$$\mathrm{Refl}_{\mathrm{meas}}(\lambda) = \frac{1}{\mathrm{SCF}(\lambda)\mathrm{Irr}(\lambda)}(1 + m(\lambda))[R_{\mathrm{atm}}(\lambda) + a]. \quad (2)$$

Consequently, an accurate interpretation of the GOME measured spectra requires an detailed investigation of these effects. This will be done in two consecutive steps:

(a) Correction of additive errors a in the short wave range below 290 nm.
(b) Correction of multiplicative errors $m(\lambda)$ in three wavelength windows between 275 and 340 nm.

3. Additive corrections

The additive error is determined by neglecting multiplicative errors in the first step. With regard to our initial assumption, Eq. (2), this leads to an additive correction that is obviously proportional to the inverse irradiance $1/\mathrm{Irr}(\lambda)$

$$a \sim \frac{1}{\mathrm{Irr}(\lambda)}. \quad (3)$$

Fig. 1 shows the differential structure of a GOME reflectivity (radiance normalized by solar irradiance), the radiative transfer model (RTM) reflectivity including ring effect, and inverse irradiance that is used as a weighting function for the additive correction (add_wf(λ)). Strong peaks are observable at the position of two strong Fraunhofer lines at 280 and 285 nm. These

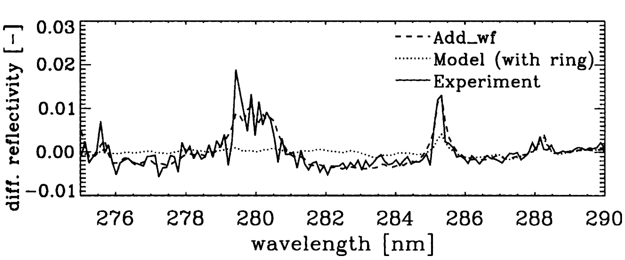

Fig. 1. Comparison between measured reflectivity, model reflectivity and inverse irradiance (after subtraction of a low order polynomial from each).

peaks result from incorrect stray light and dark current corrections which are additive and are removed by proper fitting of an additive constant.

This additive correction is retrieved in the spectral range between 275 and 290 nm by minimizing the differences between measurement and model reflectivity.

4. Multiplicative corrections

Besides the additive corrections, broadband multiplicative corrections are also taken into account. In a former version of FURM V5.0 two Chebychev polynomials are fitted along with the ozone profile in the spectral range between 290 nm and the end of channel 1 (314 nm) and in channel 2 between 314 and 340 nm.

By extending the spectral range to shorter wavelengths three polynomials are now taken into account in different spectral ranges as follows: (1) 275–300 nm, (2) 300–314 nm, (3) 314–340 nm. In order to avoid correlations between the fitted polynomial and the retrieved ozone eigenvectors showing very little differential structure, the multiplicative correction in the short wavelength range (275–300 nm) is done *before* the ozone retrieval.

5. Profile retrieval

After the applying the described multiplicative and additive correction, the ozone contribution is retrieved in the entire spectral range between 275 and 340 nm. Besides ozone eigenvectors, two remaining polynomials between 300 and 340 nm are fitted as described earlier. Other atmospheric species like albedo, temperature and Rayleigh scattering are taken into account as effective atmospheric fitting parameters. This new algorithm approach is now part of FURM Version 6.0

6. Results

Coincident measurements of GOME and HALOE are compared for the year 1998 in the latitude range between −30°N and +30°N. Two measurements are regarded as coincident if GOME and HALOE measurements are from the same day and have a maximum distance of 160 km between the center of the nearest GOME pixel and tangent point of the HALOE measurement. This assumption ensures in most cases that the HALOE measurement lies inside the GOME pixel (nominal size 320×40 km^2 (across track $\times$ along track)). Because of the large integration time of the GOME detectors in channel 1(a) eight ground pixels are co-added which leads to a ground pixel size of 960×100 km^2. The temperature and pressure a priori information is taken from the United Kingdom Meteorological Office (UKMO) assimilated data set (Swinbank and O'Neill, 1994) and the Fortuin and Kelder climatology (Fortuin and Kelder, 1998) is used as a priori ozone. Effective surface height and albedo derived from O_4 spectral range as described in (Tellmann et al., 2002) are used as first guess values. The retrieved profiles are in addition compared to profiles calculated with former Versions of FURM (see, Bramstedt et al., 2002).

Seventy-one equidistant height levels between 0 and 70 km are used in the profile retrieval, although the vertical resolution is 6 km and higher. Mean profiles for all four seasons are calculated in the low latitudes (January–March, April–June, July–September and October–December 1998) (Figs. 2 and 3). Also plotted are the results from the former version of FURM (FURM V5.0) calculated for the same data set. Also shown are the standard deviations of the mean differences to HALOE.

The altitude range is limited in the comparison to the height range between 15 and 40 km because HALOE cannot supply ozone information below 15 km and the information content of the GOME measurement is decreasing above 40 km. Besides the retrieved mean profiles with standard deviation of the differences here defined as (GOME–HALOE)/HALOE are shown. It can be clearly

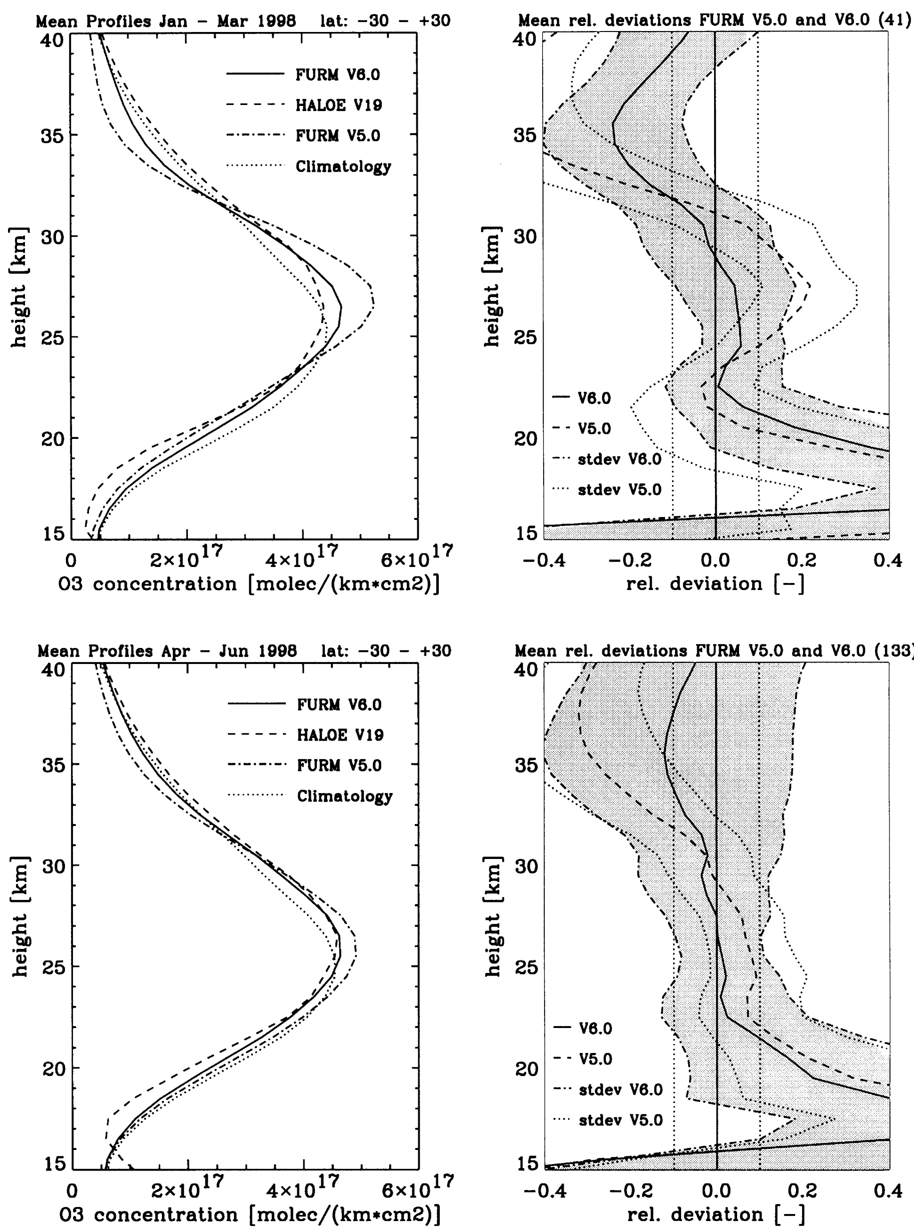

Fig. 2. Comparison of FURM profiles for January 1998–March 1998 (upper part) and April 1998–June 1998 (lower part). Left side: mean profiles from FURM V6.0 (solid line) and V5.0 (dashed line), HALOE and climatology. Right side: mean relative deviation between FURM and HALOE (FURM 6.0 (solid line) and FURM V5.0 (dashed line)); shaded area, standard deviation of mean relative deviation.

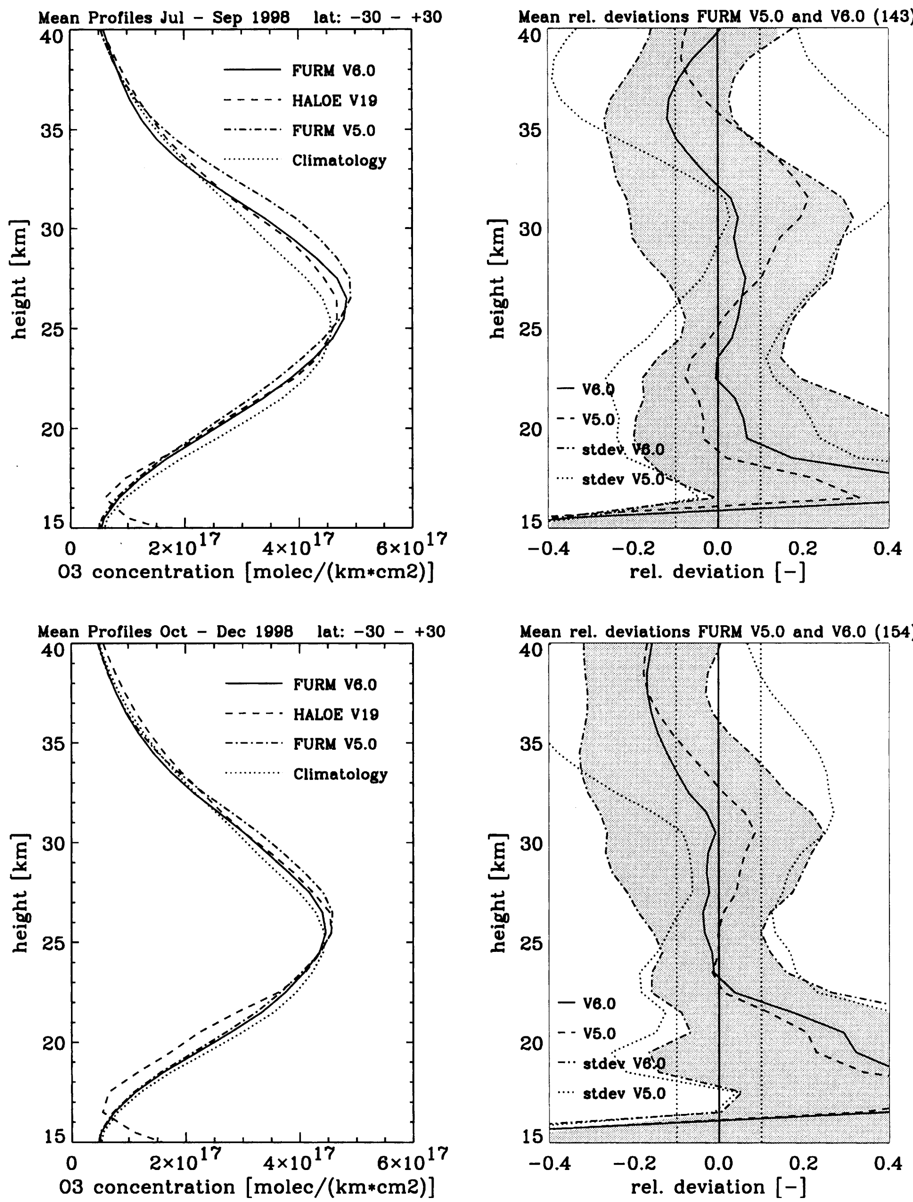

Fig. 3. Comparison of FURM profiles for July 1998–September 1998 (upper part) and October 1998–December 1998 (lower part). Left side: mean profiles from FURM V6.0 (solid line) and V5.0 (dashed line), HALOE and climatology. Right side: mean relative deviation between FURM and HALOE (FURM 6.0 (solid line) and FURM V5.0 (dashed line)); shaded area, standard deviation of mean relative deviation.

seen that the large deviations between the retrieval and the HALOE measurement in former versions of FURM is clearly reduced in the new retrieval. Particularly, the altitude of the ozone maxima are now well matched by GOME. The large deviations in the lower part of the height range may be resulting from the low information content of the HALOE measurement below 20 km.

7. Outlook

A new approach was developed to improve the FURM retrieval in the tropics. An extension to global ozone profile retrieval requires modifications of the new method to account for varying height ranges of ozone maxima and the different sensitivity of the retrieval to the selected spectral range. This adjustment and extension of this new algorithm to other latitude ranges is currently underway.

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References

Bramstedt, K., Eichmann, K.-U., Weber, M., et al. GOME ozone profiles: a global validation with HALOE measurements. Adv. Space Res. 29 (11), 1637–1642, 2002.

Fortuin, P., Kelder, H. An ozone climatology based on ozonesonde and satellite measurements. J. Geophys. Res. 103 (D24), 31709–31734, 1998.

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

Rodgers, C.D. Retrieval of atmospheric temperature and composition from remote measurements of thermal radiation. Rev. Geophys. Space Phys. 14 (4), 609–624, 1976.

Rozanov, V.V., Diebel, D., Spurr, R.J.D., et al. GOMETRAN: a radiative transfer model for the satellite project GOME, the plane-parallel version. J. Geophys. Res. 102 (D14), 16683–16695, 1997.

Russell, J.M., Gordley, L.L., Park, J.H., et al. The halogen occultation experiment. J. Geophys. Res. 98, 10777–10797, 1993.

Swinbank, R., O'Neill, A. A stratosphere–troposphere data assimilation system. Mon. Weather Review 122, 686–702, 1994.

Tellmann, S., Rozanov, V.V., Weber, M., et al. GOME satellite detection of ozone over a snow/ice covered surface in the presence of broken clouds, in: Schäfer, K., et al. (Eds.), Proceedings of SPIE. vol. 4539, ISBN 0-8194-4264-X, 2002.