GOMOS bright limb ozone data set by S. Tukiainen et al.

Answers to refere comments, Refere #3 (RC C170).

The authors would like to thank Referee #3 for reviewing the manuscript.

General comments

The Referee criticizes that we have not stated clearly where the GBL data is useful and where it is not. The Referee argues that more parameters (than latitude, altitude, and solar zenith angle), that possibly affect the product quality, should be investigated.

We agree that these are valid comments. To make sure that we are not missing any important correlations we have investigated the following parameters:

Season

The season is strongly correlated with the solar zenith angle (Fig. 1). If we investigate solar zenith angles 40-50, i.e. measurements that we have during all seasons, we do not observe any distinct patterns (Fig. 2). Thus we are confidient that the season has no significant effect on the quality of the GBL data.



Figure 1: GBL solar zenith angle as function of time

Albedo

The bias in the GBL data is not correlated with the albedo (Fig. 3). We studied the year 2004 using the data from the latitudes 40S-40N (with the solar zenith angle less than 60).



Figure 2: Difference of GBL and GOMOS night occultations as a function of season (2002–2012, 20–60N, solar zenith angles 40–50).

Scattering angle

The bias in the GBL data is also not correlated with the (single) scattering angle (Fig. 4), at least not very clearly. We studied the year 2004 using the data from the latitudes 40S–40N (with the solar zenith angle less than 60).

Conclusions

According to the results shown here in Figs. 1–4, and in the paper itself, it is quite clear that the most significant variables affecting the quality of the GBL data are the solar zenith angle and altitude. We decided not to add Figs. 1–4 to the manuscript (because they do not bring in much new information) but instead added the following discussion in the conclusions:

In this work, we showed the accuracy of the GBL data as a function of latitude, altitude, and solar zenith angle (Figs. 7–9)¹. These are the most important variables affecting the overall quality of the profiles. Besides these variables, we have also studied the effect of season, scattering angle, albedo, and time, but they do not seem to correlate substantially with the bias. The quality of the GBL data could be summared as follows. The accuracy of the GBL data is better than than 10 % between 20 and 35 km. There is a negative bias at 35–45 km, that has a consistent shape with all studied observation conditions. Because of the regular shape, this bias is straightforward to correct if the data is used, for example, in time series studies. Above 45 km, the data is valid with the solar zenith angles less that 75 ° when the accuracy is approximately up to 15 %.

¹Figs. 6–8 in the discussion paper. We will add one figure to the manuscript.



Figure 3: Difference of GBL and GOMOS night occultations as a function of albedo (2004, 40S–40N, solar zenith angles 0–60).



Figure 4: Difference of GBL and GOMOS night occultations as a function of scattering angle (2004, 40S–40N, solar zenith angles 0–60).

Minor points

• 1) Paragraph between lines 25-35 - more about the Taha results We added more text about the Taha work:

In their study, Taha et al. (2008) used an optimal estimation based method to retrieve ozone from the limb scatter radiances and reported up to 10-15% agreement with the reference data between 25-53 km. The authors retrieved separate ozone profiles from both bands (upper/lower) and obtained consistent results.

• 2) Upper/lower band in the introduction and the stray light removal Added:

We also tested the sensitivity of the retrieval method to the selected spectral band and decided to use the lower band radiance to process the GBL data set. Another important decision is the choice of the stray light removal method (GOMOS daytime radiances are badly contaminated by stray light). In this work we adapted a simple method that estimates the average stray light from the high tangent altitude GOMOS spectra.

- 3) Why show daytime occultations? We think it is worth showing the general quality of the daytime occultations. It is the motivation for another GOMOS retrieval in the first place. In addition, readers might wonder how good or bad the GOMOS daytime occultations really are because the night time occultations are so accurate. This figure should illustrate that.
- 4) "heights" and not "tangent heights" It is true that "tangent height" should be used when talking about the (radiance) measurement and "altitude" when talking about the retrieved, and possibly interpolated/regularized, profile. We try to follow this practice in the manuscript now.
- 5) Typo Corrected.
- 6) Two sentences need to be reworded It should be better now:

In this work, we have used two different OSIRIS ozone profile products. The University of Saskatchewan's OSIRIS ozone product is retrieved from OSIRIS data using the SaskMART Multiplicative Algebraic Reconstruction Technique (Degenstein et al., 2009). The product has been the target in several validation studies (e.g. Adams et al., 2012, Adams et al., 2013). In this study we use the version 5.07 of these data. The Finnish Meteorological Institute's OSIRIS ozone product is retrieved using the Modified Onion Peeling method (Tukiainen et al., 2008), which is similar to the method used in this work. The present version is 3.2. The two available OSIRIS ozone products agree with each other within a couple of percents.

7) More text about not smoothing We explain the decision not to smooth: The vertical resolution of GBL is determined by the field of view of GOMOS and the movement of the satellite during the measurement. These lead to around ~ 2 km theoretical resolution in the GBL product, which is further lowered to ~2-3 km due to the retrieval method, according to our estimate. In the GOMOS occultation retrieval, the resolution is fixed to 2-3 km (depending on the altitude) using the Tikhonov regularization and target resolution technique (Tamminen et al., 2010). The vertical resolutions of the OSIRIS and MLS ozone products are very close to the GOMOS resolutions and the marginal resolution differences do not seem to cause any notable issues in the comparisons. The NDACC ozone sounding profiles, which have significantly better vertical resolution, were smoothed to the approximately same resolution with the satellite products using a Gaussian filter.

- 8) Use height/altitude instead of tangent height See the answer to the comment 4) above.
- 9) How is the error estimate done? We explain it now in the text and added a figure: The error covariance matrix of the retrieved densities is estimated at the minimum assuming Gaussian posteriors:

$$\boldsymbol{C}_r = (\boldsymbol{J}'\boldsymbol{J})^{-1} \frac{\chi^2}{(n-p)} \tag{1}$$

where \mathbf{J} is the Jacobian, n is the number of spectral points in the fit, and p is the number of retrieved gases. The error estimates of the retrieved densities are the square roots of the diagonal elements of C_r . An example of the ozone profile errors is shown in the left panel of Fig. 1.² The relative error (error/density×100 [%]) is 2–15 [%] depending on the altitude, which are quite typical error values for stratospheric ozone profiles. Scaling the covariance matrix with the reduced χ^2 in Eq. (1) leads to more realistic error bars for the profiles. In theory, the reduced χ^2 should be unity but the average χ^2 of GBL is around 0.5 between 20–45 km and the scaling is needed (Fig. 1, right panel). The GBL χ^2 values less than unity indicate some issue in the measurement error characterization.



Figure 5: Interquartile range of the relative error (left) and reduced χ^2 (right). Data from the tropics, 2004.

 $^{^{2}}$ It is Fig. 1 in the manuscript, Fig. 5 here.