

Referee #1

General comments: The paper discusses about the GOMOS ozone profile validation using ground-based and balloon sonde measurements. The paper is a continuation of the work by Meijer et al. in JGR (2004). The paper is well written but it has some quite serious deficiencies. The following specific questions should be addressed before the paper can be accepted for publication.

Specific comments:

C1 page 8519-21, Sec. 1.2: I find the list of earlier validation studies missing some essential papers:

* Large satellite validation including GOMOS: Dupuy (2009) mentioned elsewhere in the paper C1505 ACPD 10, C1505–C1509, 2010

* Envisat instrument inter-comparison: Bracher et al, Adv. Space Res. 36, 855, 2005

* Comparison to balloon measurements: J-B. Renard, J. Geophys. Res., 113, A02302, 2008

* Comparison to Fortuin-Kelder: Kyrölä, E., et al, J. Geophys. Res., 111, D24306, 2006

Find GOMOS validation references, for example, by http://adsabs.harvard.edu/abstract_service.html.

Reply

Additional references to GOMOS validation studies have been included.

C2 pages 8521-22: Sec. 2.1. Add a short description how GOMOS measurement accuracy (individual profiles) depends on star temperature and visual magnitude.

Reply

A paragraph describing the influence of star characteristics has been added to the manuscript.

C3 pages 8521-23, Sec 2.1-2.1.1: I am (very) surprised that there is no reference to the official ESA document about the GOMOS data quality, i.e. GOMOS disclaimer (http://envisat.esa.int/handbooks/availability/disclaimers/GOM_NL_2p_Disclaimers.pdf).

I would like to think that this document is a starting point for any validation work on GOMOS! Including a co-author from the GOMOS team would also have brought some hands on knowledge on GOMOS instrument and data to the present validation work.

Reply

References to the handbook and the disclaimer have been added.

C4 page 8522, line 4: Are you removing individual measurements or the whole profile when you apply 20% filter? Please, clarify.

Reply

We remove the individual measurement points when the reported error exceeds 20%. This has been clarified in the text.

C4 page 8523, lines 1-5: Below 1 hPa GOMOS uses ECMWF, above 1 hPa GOMOS uses MSIS90. Please, correct the text.

Reply

The text has been updated.

C5 page 8523, lines 6-13: The aerosol coefficients are parameters determined from data. They are also function of altitude. Please, modify the text.

Reply

The text has been updated.

C6 p.8523, lines 9-12: Notice that second order polynomial allows a more realistic description of the aerosol effective cross section than 1/lambda law.

Reply

This has been added to the text to correspond to the other papers published in the special issue.

C7 page 8523, lines 13-10: The large ozone profile differences (100%) coming from the changing the cross sections in Liu et al (2007) are probably peculiarity of the used nadir measurements and applied retrieval methods. In the recent GOMOS work (see a recent work by Kyrölä presented in the WMO ACSO workshop http://igaco3.fmi.fi/ACSO/otm_2010.html) the differences between various cross sections lead to about 1% profile differences. Also, it is difficult to say definitely that one specific cross section is the best i.e. nearest the one used by physical processes in the atmosphere. please, comment these.

Reply

We have removed the discussion of the ozone cross sections and refer the readers to the GOMOS handbook and the paper by Bertaux et al. in this special issue describing the retrieval algorithm in more detail.

C8 page 8524, Sec. 2.2: Could you discuss briefly how well are the validating instruments used (lidar, sonde and microwave) agreeing with each other?

Reply

For the particular datasets, no direct intercomparison can be carried out for all instruments. However, the used validation instruments have been validated previously. Intercomparison campaigns are also carried out, often supported by initiatives such as the network for the detection of atmospheric composition change (NDACC).

C9 page 8524, 2.2.1: Lidar data: please, discuss briefly: ozone cross sections used, typical precision/bias and vertical resolution/sampling. Mention also how lidars are validated especially above the ozone sonde range.

Reply

We have added the requested information on the data quality to the text. In short, the lidar network can be considered to be homogeneous within about 2 percent and, on average, precision of the ozone measurements is around 1% up to 30 km, 2 to 5% at 40 km and 5 to 25% at 50 km (Keckhut et al., 2004). On average, resolutions range between 1 and 2 km at low altitudes (below 20 km) increasing to 3 - 5 km at 40 km (Godin et al., 1999).

An effort is being made by the NDACC lidar working group to standardise the used cross sections used as well as the used terminology (e.g. reported error terms, resolutions). Most groups use Bass and Paur. Compared to using the Brion, Daumont and Malicet cross section, this resulted in relative differences up to 1.8% at 45 km in the tropics (Godin-Beekmann and Nair, 2010).

Above sonde altitudes, lidar data are validated using a travelling standard (lidar), by algorithm intercomparisons and can also be validated by satellite measurements and to some extent microwave radiometer data.

C10 page 8525, lines 3-4: Why do you allow more uncertainty for lidar data than to GOMOS data?

Reply

Allowed uncertainty ranges are chosen to match those used in Meijer et al. (2004).

C11 page 8525, 2.2.2: Sonde data. please, discuss briefly: typical precision/bias and vertical resolution/sampling. Are we sure that sonde data provides the final truth about ozone profiles below 30 km?

Reply

Given the long history of intercomparisons and calibrations /validation efforts, it should be reasonable to assume that the retrieval algorithms converge towards the truth. Ozone profiles derived from sonde measurements have a precision of about 5% (Smit and Kley, 1998;Thompson et al., 2003). The section in the main document has been updated.

C12 page 8525, lines 23-26: When you average sonde data, are you using the GOMOS averaging kernel?

Reply

Sonde data have been averaged using a running mean.

C13 page 8526, 2.2.3: Microwave data. please, discuss briefly: typical precision/bias and vertical resolution/sampling. How are these measurements validated above sonde altitudes

Reply

The microwave radiometer's vertical resolution (defined as the full width to half maximum of the averaging kernels) is in the range 6 to 10 km between 20 and 50 km and about 13 km at 64 km (Boyd et al., 2007;Hocke et al., 2007). Precision is typically about 5% between 20 and 55 km and increases above (7% at 64 km). Compared to the ozone profiles provided by AURA microwave limb sounder (version 2.2), agreement with two NDACC microwave radiometers was within 5% (Boyd et al., 2007). This has been added to the text of the main manuscript.

Microwave radiometers can be validated above sonde altitudes with lidar and satellite measurements.

C14 page 8526, lines 3-4: Why do you allow more uncertainty for microwave data than to GOMOS data?

Reply

Allowed uncertainty ranges are chosen to match those used in Meijer et al. (2004).

C15 page 8527, lines 1-2: please, clarify: "... and the daylight condition have to be the same,..." Do you mean local hours must be at most TBD hours different?

Reply

The solar zenith angles at the time of observations have to be in the same class (see Table 1 in the ACPD document for ranges of the three groups) and the time span in between of measurements 5 hours at most.

C16 page 8528, Sec. 3.1: Fig. 1. An important figure but differences are difficult to see and the validating sets are not identical Why did you not compare the two versions directly against each other? This kind of comparison would show more clearly the differences.

Reply

The two datasets used in Figure 1 a and b are identical, except for the results of the filtering based on the provided errors as the error calculation has changed. The difference between the two versions can be deduced from the differences

between the two validation results, whereas a direct comparison of the two versions would omit to show the differences to the validation reference, providing an indication of the precision of the two datasets.

C17 pages 8528-9, Sec. 3.1: Figs. 1 and 2. The mesospheric differences may result from local hour differences between microwave instrument and GOMOS (see comment page 8527, line 1-2 above). Can you comment?

Reply

As the observations are done under the same daylight conditions, this should not be a source of differences. Unfortunately here are too few measurements available to limit the collocations to a very short time difference.

C18 page 8529, lines 14-15: You are removing profiles exceeding $10+13$ mols/cm³. Do you mean that the whole profile is ignored or only that portion exceeding the threshold? Removing big profiles creates easily bias in averages. How do you avoid this trap? Does not the error filter 20% remove already these measurements?

Reply

Only the points in the profile outside the allowed ozone range are removed from the analysis dataset. The error filter of 20% does not remove these spurious retrievals (see Figure 1). Median difference profiles, which are used to describe the biases in most figures, are virtually the same (compare Fig.1 with Fig. 2), so this trap is avoided.

C19 page 8530, Sec. 3.2.1: There is no comparison of stray light profiles?

Reply

Profiles flagged to have straylight contamination are included in the figures. When considering them separately, results are very similar to the fully dark cases.

C20 page 8530, lines 19-20: The important spectral region for the ozone retrieval depends on altitude. At high altitudes, the retrieval is based on UV wavelengths and at low altitudes on visible wavelengths. Therefore, the accuracy of the ozone retrieval depends not only on the star magnitude but also on the shape of the stellar spectrum i.e. star effective temperature. Looking at available stellar spectra we can theoretically conclude that GOMOS faces difficulties when it is using cool and weak stars at high altitudes. And real measurements agree with theory. This aspect has been elaborated in the aforementioned JGR-paper by Kyrölä. The comparisons in the present paper show distinctions using temperature and magnitude separately. The trouble causing stars (cool and weak) are a subset of the cool stars set but their contribution can be masked by cool and strong stars. As explained in the paper by Kyrölä the separation magnitude is about 1.9 and temperature 7000K. If this "feature" is not understood, it is easy to contaminate unnecessarily comparisons with these troublemaker stars ($m > 1.9$ and $T < 7000K$). Can you comment on these aspects?

Reply

We have split the cool stars into the cool+bright stars and cool+weak stars categories. Although it seems counter-intuitive, no cool+strong stars collocations are available above 50 km, so all the data shown in the mesosphere are for the combination cool+weak stars. As the quality of these measurements is lower, the reported error is higher, which is reflected in the strongly reduced number of collocated pairs. We have tried to make it clearer in the text that the quality of the measurements is affected by the star characteristics, but that validation results also depend on applied error filtering.

C21 All figures except 3: Please provide comments on the following questions: 1) How does the natural variation affect the results and your conclusions? 2) Do you have a view to the large discrepancies in the mesosphere?

Reply

1. Given the results presented in Fig. 9 (effects of time and distance criteria used in the collocation procedure), no effects induced by natural variation are expected.
2. We believe that part of the discrepancies in the mesosphere originate from the increasing uncertainties in the microwave data at high altitudes. Additionally, there may be increasing straylight contamination. Comparison with other instruments is therefore recommended.

C22 Technical corrections:

page 8529, line6: ...the with...

Reply

Corrected.

Referee #2

C1 Numerous minor corrections to the English are needed. I strongly suggest that the paper be edited by a native English speaker, for example by one of the co-authors.

Reply

Done.

C2 page. 8523, lines 13-15: The comment about the ozone cross sections is misleading and should be deleted. Nadir sounders are different from limb sounders and the comment seems to imply (incorrectly) that a relatively small change in the cross sections could have a big impact on GOMOS retrievals.

Reply

This section has been altered to refer to the GOMOS handbook and the paper from Bertaux et al. in this special issue.

C3 page. 8325, line 10: Delete the irrelevant comment about the hydrostatic equilibrium.

Reply

This has been rephrased.

C4 page 8527, line 4: ‘linear spline’ is misleading as splines are generally piecewise cubic polynomials. Perhaps ‘linear interpolation’ is meant.

Reply

The applied interpolation is a spline, but it is almost linear. The text has been updated to ‘a nearly linear spline’.

C5 page 8527, line 10: I disagree about the statement about using averaging kernels. The resolution of a microwave radiometer is considerably less than that of GOMOS and needs to be taken into account. If the authors do not like averaging kernels then simply smoothing the GOMOS data to roughly match the vertical resolution of the radiometer is adequate. Contrary to the statement at the end of the paragraph, biases resulting from different vertical resolutions do not average to zero.

Reply

We agree with the reviewer that the difference in resolution should best be taken into account. We have tested smoothing the GOMOS data when collocated with microwave radiometer measurements over 4, 8, 10 and 12 km, but no significant improvements were seen (see Fig. 1 for a comparison between non-smoothed and 12-km smoothed GOMOS data for the microwave collocations). Nevertheless, we have decided to update all figures to include a 10-km (corresponding to a typical resolution for microwave radiometer ozone profiles at 50 km – the middle of the range used for the comparison) smoothing of the GOMOS data for the collocations with microwave radiometer.

C6 page 8527, line 17: Again I disagree strongly: measurements without some sort of error estimates are meaningless. Some sort of error estimates must be provided even if they are just ‘typical values’. Lines 24-26 are misleading in this respect because using large numbers of profiles does not eliminate systematic errors.

Reply

GOMOS:

The retrieval error (precision) of the GOMOS version 6.0 (note that we use 5.0 here) night time measurements in the stratosphere is typically 0.5–4% (Tamminen et al., 2010). See the answers to the first reviewer for typical accuracies found for the validation instruments; we have updated all sections in the main manuscript accordingly. Systematic errors are minimised thanks to a long history of intercomparison and validation activities.

C7 page 8528. I do not think it is valid to lump all of the validation data together because they come from such different sources. Clearly ozonesonde, lidar and microwave radiometer data have different statistical and systematic errors. The validation data sources need to be compared separately first. In particular, typical altitudes, vertical resolutions, precision of measurements and systematic errors for each of the three validation sources needs to be given in section 2. After individual comparisons, some sort of overall comparison is then fine.

Reply

It is not possible to carry out a direct comparison of the validation data used here. Many instrument intercomparisons have been held in the past (Steinbrecht et al., 2009; Dumitru et al., 2006; Fioletov et al., 2006). We have updated section 2 to discuss the typical instrument characteristics.

References

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