Response to anonymous referee #2

Lorena Moreira

June 30, 2017

We are very thankful to the anonymous Referee #2 for the evaluation of our manuscript and for the valuable comments that helped significantly to improve the quality of the paper. We have revised the manuscript by following each one of your suggestions. Below we try to answer each comment. The changes in the manuscript are shown in blue and the text simply removed is crossed out in red.

Specific comments

1. **Comments from the referee:** Pg. 1, Ln 13-15: This sentence presents a repetition that should be removed.

   Author's response:
   We agree on the referee's comment and the text has been modified according to it.

   Author's changes in the manuscript: Pg. 1, Ln 13-15: ~~On the other hand, the amplitude of the diurnal variation, night-to-day ratio (NDR), is not as strong as the observed one at higher latitudes, nevertheless we observe the winter anomaly of the night-to-day ratio.~~

2. **Comments from the referee:** Pg. 2, Ln 8-10: If GROMOS data have been validated in the past what is the need of an additional comparison with Aura MLS? Differently, if the comparison with MLS serves as a validation of the new retrieval version, then a comparison of the new version with previous versions should also be present.

   Author's response:
   We agree with the referee and we have performed a comparison between version 2021 and version 150 of the retrieval of GROMOS.

   Author's changes in the manuscript: Pg. 3, Ln 12: Recently, we have developed a new retrieval version (version 150) with the aim to optimise the averaging kernels. The differences with the former version (version 2021) are in the a priori covariance matrix, in the measurement error and in the integration time of the retrieval.
   In version 2021 the diagonal elements of the a priori covariance matrix are variable relative errors ranging from 35% at 100 hPa to 28% in the lower stratosphere and increasing with altitude from 35% in the upper stratosphere up to 70% in the mesosphere. Meanwhile, in version 150 the a priori covariance matrix has a constant value for the diagonal elements of 2 ppm. For both retrieval versions the

off-diagonal elements of the a priori covariance matrix exponentially decrease with a correlation length of 3 km.
Regarding the measurement noise, in version 2021 it is a constant error of 0.8 K whereas in version 150 we used a variable error depending on the tropospheric transmission:

$$\Delta T_b' = 0.5 + \frac{\Delta T_b}{e^{-\tau}} \tag{1}$$

the error of the measured brightness temperature, ΔT_b, is given by the radiometer equation:

$$\Delta T_b = \frac{T_b + T_{rec}}{\sqrt{\Delta f \cdot t_{int}}} \tag{2}$$

The radiometer equation gives the resolution of the radiation measured, which is determined by the bandwidth of the individual spectrometer channels (Δf), by the integration time (t_{int}) and by the total power measured by the spectrometer. A constant error of 0.5 K is considered as a systematic bias of the spectra, due to spectroscopic errors and the water vapour continuum. The error of the brightness temperature (ΔT_b) is of the order of a few Kelvins in the line centre and 0.5 K in the line wings of the spectrum. Therefore the measurement noise ($\Delta T_b'$) depends on the bandwidth of the spectrum and on the tropospheric transmittance. This is a more realistic approach for the retrieval than considering a constant measurement noise, resulting in an improvement in the retrieved ozone VMR in the lower stratosphere. The sampling time for version 150 is 1 hour and in case of version 2021 is 30 minutes. Longer integration time improves the retrieved ozone VMR at upper altitudes.

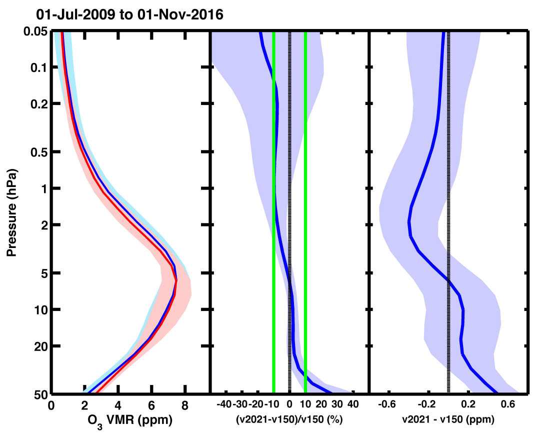


Figure 1: Mean ozone profiles retrieved by version 2021 (red line in the left panel) and by version 150 (blue line in the left panel) measured by GROMOS during the period from July 2009 to November 2016. The blue area (v150) and the red area (v2021) are the standard deviations of the ozone VMR. The mean relative difference profile (blue line) and the standard deviation of the differences (blue area) are represented in the middle panel, using the new version as reference. The green line delimits the ±10% area. In the right panel is shown the VMR difference profile along with its standard deviation

Pg. 4, Ln 1: In version 2021, the vertical resolution lies generally within 10–15 km in the stratosphere and increases with altitude to 20–25 km in the lower mesosphere. Between 20 to 52 km (50 to 0.5 hPa) the measurement response is higher than 0.8. For more details on version 2021 we refer to Moreira et al. (2015). Comparing the measurement response and the vertical resolution obtained by version 2021 and by version 150 we can conclude an improvement in the results retrieved by version 150. We assume that the changes performed in the a priori covariance matrix, in the measurement noise and in the integration time result in the improvement of the retrieval product, mainly observed in the lowermost and in the uppermost limit of the retrieved ozone VMR profile.

3. **Comments from the referee:** Pg. 2, Ln 23-24: Awkward sentence

   Author's response:
   No comments.

   Author's changes in the manuscript: Pg. 2, Ln 20-26: Marsh et al. (2001) interpreted the tertiary peak by considering that in the middle mesosphere during winter, with solar zenith angle close to 90°, the atmosphere becomes optically thick to UV radiation at wavelengths below 185 nm and, since photolysis of water vapour (Reaction 3) is the primary source of odd-hydrogen, reduced UV radiation results in less odd-hydrogen. The lack of odd-hydrogen needed for the catalytic depletion of odd-oxygen (Reactions 4, 5 and 6), in conjunction with an unchanged rate of odd oxygen production (Reaction 7), leads to an increase in odd-oxygen. This results in higher ozone concentration because atomic oxygen recombination (Reaction 8) remains as a significant source of ozone in the mesosphere. Additionally, Hartogh et al. (2004) extended the interpretation by considering the very slow decrease of the ozone dissociation (Reaction 9) rate with increasing solar zenith angle.

$$\mathrm{H_2O} + \mathrm{h}\nu(\lambda < 185nm) \longrightarrow \mathrm{OH} + \mathrm{O} \tag{3}$$

$$\mathrm{O} + \mathrm{OH} \longrightarrow \mathrm{O_2} + \mathrm{H} \tag{4}$$

$$\mathrm{H} + \mathrm{O_2} + \mathrm{M} \longrightarrow \mathrm{HO_2} + \mathrm{M} \tag{5}$$

$$\mathrm{O} + \mathrm{HO_2} \longrightarrow \mathrm{O_2} + \mathrm{OH} \tag{6}$$

$$\mathrm{O_2} + \mathrm{h}\nu(\lambda < 242nm) \longrightarrow \mathrm{O} + \mathrm{O} \tag{7}$$

$$\mathrm{O} + \mathrm{O_2} + \mathrm{M} \longrightarrow \mathrm{O_3} + \mathrm{M} \tag{8}$$

$$\mathrm{O_3} + \mathrm{h}\nu \longrightarrow \mathrm{O_2} + \mathrm{O} \tag{9}$$

4. **Comments from the referee:** Pg. 2, Ln 27: I would remove this sentence, or place it elsewhere.

   Author's response:
   No comments.

   Author's changes in the manuscript: Pg. 2, Ln 27: ~~This publication presents a new comparison between a ground-based instrument (GROMOS) and a spaced-based instrument (Aura/MLS).~~

5. **Comments from the referee:** Pg. 3, Ln 9: What a priori information are you referring to? Temperature and pressure profiles? What about the ozone a priori profile?

   Author's response:

   We agree on the referee's comment. The text has been modified according to it.

   Author's changes in the manuscript: Pg. 3, Ln 9: The a priori profile of O_3 VMR required for the retrieval is taken from a monthly varying climatology from ECMWF reanalysis until available (70 km) and extended above by an Aura MLS climatology (2004 to 2011). The line shape used in the retrieval is the representation of the Voigt line profile from Kuntz (1997). Spectroscopic parameters to calculate the ozone absorption coefficients were taken from the JPL catalogue (Pickett et al., 1998) and the HITRAN spectroscopic database (Rothman et al., 1998) The atmospheric temperature and pressure profiles are taken from the 6 hourly of the European Centre for Medium-Range Weather Forecast (ECMWF) operational analysis data and are extended above 80 km by monthly mean temperatures of the CIRA-86 Atmosphere Model (Fleming et al., 1990).

6. **Comments from the referee:** Pg. 3, Ln 18: Why do you have a systematic bias in the spectral measurements?

   Author's response:

   We do have systematic biases in the spectral measurements due to spectroscopic errors and the water vapour continuum.

   Author's changes in the manuscript: Pg. 3, Ln 18: In addition, a constant error of 0.5 K is considered as a systematic bias of the spectra, due to spectroscopic errors and the water vapour continuum.

7. **Comments from the referee:** Pg. 3, Ln 19: Even though the authors cite earlier papers describing in more details the technical aspects of the measurements, I think Figure 1 should still show an example of the spectrum measured and specify whether the 1-hour average spectrum is binned before deconvolving it. Are all channels binned in groups? Also those near the line center? This is critical for the high altitude comparison. Additionally, maybe a table similar to Table 1 of Moreira et al., 2015, would be a useful reminder of the main characteristics of GROMOS.

   Author's response:

   The referee is right to ask about an example of the spectrum measured and about a table of the GROMOS instrument specifications, yet we have not performed any instrumental change, therefore we can refer to Moreira et al. (2015) for these details.

   The fast Fourier transform spectrometer (FFTS) has around 32768 channels and after the binning in frequency the number of points in frequency are 54 with high frequency resolution in the line centre compare to the line wings.

   Author's changes in the manuscript: No changes.

8. **Comments from the referee:** Pg. 3, Ln 22: In figure 1, a priori and retrieved profiles are terribly close. I am aware that in the altitude region where the retrieval

algorithm is the most sensitive the a priori has a very small impact on the profile retrieved, yet it would be nice to see it. Most readers don't know and will wonder what's the point of the measurement if the climatology from other datasets already provides you with the true state.

Author's response:

In the middle panel of Figure 2 (former Figure 1) are shown the averaging kernels and the area of the averaging kernels, called measurement response. The averaging kernels are a key quantity for the characterisation of the retrieved profiles. It describes how the retrieval smoothes the true state and how sensitive it is to the a priori profile. The averaging kernel lines in the middle panel are shown in colour to help their interpretation, for instance, the green line shows the kernel line at 30 km and we can clearly see that the kernel actually peaks at 30 km. The measurement response is an indicator of the sensitive altitude range of the retrieved profile, it accounts for the amount of information from the true state of the retrieved profile at a given altitude. The measurement response (MR) is shown in red in the middle panel. It is considered a reliable altitude range of the retrieval when the true state dominates over the a priori information, i.e. where the measurement response is larger than 0.8 (an a priori contribution smaller than 20%). The measurement response shown in Figure 2 is around 1 from 18 to 70 km. Therefore, from this we can conclude the retrieved profile of GROMOS measurements is actually the true state of the atmosphere above Bern and not an a priori representation of the true state obtained from a climatology of other datasets.

Author's changes in the manuscript: No changes.

9. **Comments from the referee:** Pg. 4, Ln 1: How is this an improvement with respect to the older version? Again, a comparison with the previous retrieval version is necessary

Author's response:

As previously mentioned we have performed a comparison between version 2021 and version 150 of the retrieval of GROMOS. See comment 2 for details on the changes in the manuscript.

Author's changes in the manuscript: See **Comment from the referee 2** for details on the changes in the manuscript.

10. **Comments from the referee:** Pg. 4, Ln 19: Are these criteria consistent? The spatial requirement seems particularly generous compared to the temporal one. How far does a parcel of stratospheric air travel in one hour? A mesospheric one? Would a stricter spatial criterion improve your comparison results in the upper stratosphere/mesosphere? In other words, you should motivate your choices of coincident criteria.

Author's response:

In accordance with the referee wishes we have performed major changes in the comparison method. The criterion for spatial coincidence is now that horizontal distances between the sounding volumes of the satellite and the ground station have to be smaller than 1° in latitude and 8° in longitude. In addition, we have calculated the mean relative difference profile and the VMR difference profile separating daytime and nighttime values.

Author's changes in the manuscript: Pg. 1, Ln 10: On average, GROMOS and MLS comparisons show agreement generally over 20% in the lower stratosphere and within 2% in the middle and upper stratosphere for both daytime and nighttime, whereas in the mesosphere the mean relative difference is below 40% at daytime and below 15% at nighttime.

Pg. 4, Ln 17: The selected criterion for spatial coincidence is that horizontal distances between the sounding volumes of the satellite and the ground station have to be smaller than 1° in latitude and 8° in longitude. The present study extends over the period from July 2009 to November 2016 and covers the stratosphere and middle mesosphere from 50 to 0.05 hPa (from 21 to 70 km), and according to the spatial and temporal criteria, more than 2800 coincident profiles are available for the comparison. Figure 3a and Figure 3b show the mean ozone profiles of the collocated and coincident measurements of GROMOS (blue line), MLS convolved (red line) and MLS original (green line) at daytime and nighttime, respectively. The relative difference profile in percent given by $(\mathbf{x}_{\text{MLS,low}} - \mathbf{x}_{\text{GROMOS}})/\mathbf{x}_{\text{GROMOS}}$ is displayed in the middle panel of both Figure 3a and Figure 3b along with the standard deviation of the differences (blue area). The green line delimits the $\pm$ 10% area. The mean profile of the VMR differences is shown in the right panel of both Figure 3. The mean relative differences and the VMR differences at daytime (nighttime) are over 20% or 0.5 ppm (15% or 0.4 ppm) in the lower stratosphere and decreasing with altitude up to 0.7% or 0.02 ppm (2% or 0.06 ppm) at the stratopause and increasing with altitude up to 38% or 0.085 ppm (15% or 0.12 ppm) at 0.05 hPa (70 km). We conclude from Figure 3 that during nighttime GROMOS measures more O_3 VMR (ppm) than MLS except for the lower stratosphere, where MLS measures more O_3 VMR (ppm) than GROMOS, both at daytime and nighttime. Nevertheless in the mesosphere GROMOS measures more O_3 VMR (ppm) than MLS, both at daytime and nighttime.

Pg. 6, Ln 24: The agreement between measurements coincident in space and time for both data records is within 2% (0.06 ppm) between 30 and 50 km (15–0.7 hPa) increasing up to 20% (0.5 ppm) at 20 km (50 hPa), for both daytime and nighttime. In the mesosphere the difference increases up to 38% (0.085 ppm) at daytime and up to 15% (0.12 ppm) at nighttime at 70 km (0.05 hPa).

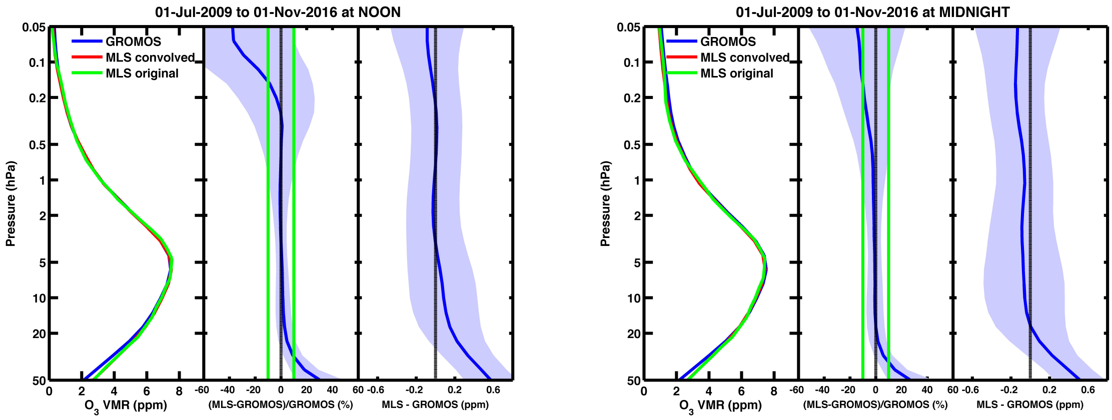
11. **Comments from the referee:** Pg. 4, Ln 21: I suggest "to" instead of "with the compliance of"

    Author's response:

    No comments.

    Author's changes in the manuscript: Pg. 4, Ln 21: ... and according to the spatial and ...

12. **Comments from the referee:** Pg. 5, Ln 1: I am not sure what this sentence implies. Are you suggesting that either the ground-based or the satellite-based data are inevitably faulty at high altitudes? Additionally, if I am not mistaken, the manuscripts you cite are either on SOMORA retrievals (which reach 55 km at the most) or GROMOS itself. Are you suggesting that the present relatively large



(a) Daytime (b) Nighttime

Figure 3: Mean ozone profiles recorded by GROMOS (blue line), MLS convolved (red line) and MLS original (green line) for the time interval between July 2009 and November 2016 are shown in the left panels of both daytime and nighttime Figures. The blue area (GROMOS) and the red area (MLS) are the standard deviations of the coincident measurements. The middle panels show the mean relative difference profile between data of both instruments, GROMOS as reference. The blue areas in the middle panels represent the standard deviation of the differences. The green lines in the middle panel delimit the ± 10% area. The mean VMR difference profile and its standard deviation (blue area) are displayed in the right panels of both daytime and nighttime, Figure 3a and Figure 3b, respectively

discrepancy in the GROMOS-MLS comparison at high altitude is likely to be due to GROMOS? If this is correct just say so.

Author's response:

We agree on the referee's comment and we have removed the sentence.

Author's changes in the manuscript: Pg. 5, Ln 1: ~~This result is in agreement with other comparisons performed between ground-based microwave radiometers and spaced-based instruments above Switzerland, where the bias among data sets relied within 5–10 % in the stratosphere and up to 50% towards the mesosphere (Studer et al., 2013; Barras et al., 2009; Hocke et al., 2007; Dumitru et al., 2006; Calisesi et al., 2005).~~

13. **Comments from the referee:** Pg. 5, Ln 4: I would write: "For an overview on the differences between coincident profiles, ..."

Author's response:

No comments.

Author's changes in the manuscript: Pg. 5, Ln 4: For an overview on the differences between coincident profiles, ...

14. **Comments from the referee:** Pg. 5, Ln 11: I would quantify the "almost perfect" with the slope of the linear fit. Second to last sentence in Section 3 : Could this be due to the spatial coincidence criterion? Last sentence in Section 3: I would suggest to postpone this last sentence to the conclusions section.

Author's response:

We agree on the referee's comment therefore we have changed line 11 and we have removed the last sentence of Section 3.

Author's changes in the manuscript:

Pg. 5, Ln1 1: The black lines, linear regression lines of the observations, are close to the green one to one lines, O_3(MLS)=O_3(GROMOS).

Pg. 5, Ln 17–19: ~~To sum up we can reiterate the fairly good agreement obtained for the comparison between ozone VMR profiles recorded by the ground-based instrument (GROMOS) and by the spaced-based instrument (Aura/MLS) during the time interval between July 2009 and November 2016 for the altitude range from 20 to 70 km.~~

15. **Comments from the referee:** Pg. 6, Ln 2: This needs to be better explained. Specifically, what part of your results agree with the work of Sonnemann 2007 and what doesn't. The fact that one dataset can peak at values that are twice as much as those of GROMOS seems an important difference. Do their data have a better vertical resolution? Retrievals that reach higher altitudes? Can you briefly address this difference?

Author's response:

Our results on the annual variation of mesospheric ozone at Bern are in agreement with the ones observed at Lindau by Sonnemann et al. (2007). The result disagrees in the amplitudes of the annual variation however according to Sonnemann et al. (2007), *the MMM is an effect occurring at high latitudes close to the polar night terminator around 72 km altitude during nighttime in the winter half of the year and extends into middle latitudes with decreasing amplitude.* Sonnemann et al. (2007) show nighttime ozone mixing ratio at Lindau up to 80 km. The upper altitude limit for the retrieval of ozone at 142 GHz measured by GROMOS is approximately 75 km, due to the fact that height-resolved information cannot be retrieved in the Doppler broadening domain since the line width does not depend on altitude. We set our altitude limit up to 70 km where the measurement response is ~ 1, therefore we do not have contribution from the a priori.

Author's changes in the manuscript: Pg. 6, Ln 1–2: Our results on the annual variation of mesospheric ozone at ...

Pg. 6, Ln 3: Disagreements appear in the amplitudes ...

16. **Comments from the referee:** Pg. 6, Ln 4-8: I would remove these two sentences as they were already stated in the introduction

Author's response:

No comments.

Author's changes in the manuscript: Pg. 6, Ln 4-8: ~~This maximum of mesospheric ozone during nighttime in winter is related to the middle mesospheric maximum of ozone (MMM) (e.g., Sonnemann et al., 2007; Hartogh et al., 2004) also known as the tertiary ozone maximum (e.g., Sofieva et al., 2009; Degenstein et al., 2005; Marsh et al., 2001). During winter, the photodissociation rate of water is reduced at high latitudes which leads to a decrease of catalytic ozone depletion by odd hydrogen.~~

17. **Comments from the referee:** Pg. 6, Ln 19: I would explicitly state what this anomaly is. Last two sentences in Section 4: It is not clear whether you ascribe the difference from Sonnemann et al. to the fact that Lindau is at higher latitudes. If this is the case, I would object that 5° latitude cannot make this large difference in mesospheric ozone values and that a latitude of 51.7 °N is not much higher than 47°N.

    Author's response:

    We acknowledge that "winter anomaly" is maybe not the best appellation so we have changed for "wintertime enhancement".

    According to Sonnemann et al. (2007), *the MMM is an effect occurring at high latitudes close to the polar night terminator around 72 km altitude during night-time in the winter half of the year and extends into middle latitudes with decreasing amplitude*. The observed sharp decrease of the amplitude of the MMM of ozone is due to the strong latitudinal gradient between high and middle latitudes. In fact, it is surprising that we can observe the effect of MMM at our latitude. Therefore, the difference in latitude between Lindau and Bern may have such impact in the amplitudes of the annual variability of mesospheric ozone due to the MMM. However it could also be due to some other effects like for example, differences in the retrieval algorithms between Bern and Lindau, different instruments used to perform the measurements, different calculation methods...

    Author's changes in the manuscript: Pg. 1, Ln 15: ~~On the other hand, the amplitude of the diurnal variation, night-to-day ratio (NDR), is not as strong as the observed one at higher latitudes, nevertheless we observe the winter anomaly of the night-to-day ratio.~~

    Pg. 6, Ln 19: ... the expected wintertime enhancement of the NDR

    Pg. 6, Ln 32: Moreover, the wintertime enhancement of nighttime ...

    Pg. 6, Ln 5: Nevertheless, our results are expected since this maximum of mesospheric ozone during nighttime in winter is related to the middle mesospheric maximum of ozone (MMM) and according to Sonnemann et al. (2007) its effect extends into midlatitudes with decreasing amplitude.

18. **Comments from the referee:** Pg. 6, Ln 27: Please, rephrase avoiding the repetition.

    Author's response:

    No comments.

    Author's changes in the manuscript: Pg. 6, Ln 27: the diurnal variability and its amplitude, the night-to-day ratio (NDR).

19. **Comments from the referee:** Pg. 6, Ln 29: Together with the relative difference I would quote here also the absolute one, which is less than 0.2 ppmv, on average (if I read correctly from figure 2). Last sentence: I would specify what the anomaly is also here in the conclusions

    Author's response:

    No comments.

    Author's changes in the manuscript: Pg. 6, Ln 29: The agreement between measurements coincident in space and time for both data records is within 2% (0.06 ppm) between 30 and 50 km (15–0.7 hPa) increasing up to 20% (0.5 ppm) at 20 km (50 hPa), for both daytime and nighttime. In the mesosphere the difference increases up to 38% (0.085 ppm) at daytime and up to 15% (0.12 ppm) at nighttime at 70 km (0.05 hPa).

Pg. 6, Ln 32: Moreover, the wintertime enhancement of nighttime ...

20. **Comments from the referee:** Figure 1:
    - I would add a panel with the GROMOS 1-hour spectrum.
    - I would enlarge, make it longer, the X-axis of the 3rd panel (maintaining the range 10-70 km).

    Author's response:

    As we highlighted previously, we have not performed any instrumental change, therefore we can refer to Moreira et al. (2015) for these details.

    With all due respect to the referee we do not understand the reason for enlarging the X-axis of the 3rd panel (maintaining the range 10-70 km).

    Author's changes in the manuscript: No changes.

21. **Comments from the referee:** Figure 2:
    - Would it be useful to show two separate averages, one for the daytime and one for the nighttime comparison?
    - I would reduce the range of the X-axis of the middle plot to be from -60% to 60%
    - I would use the same vertical unit (altitude or/and pressure) in all the figures or, even better, use both of them all the times. In figure 1 there's altitude, in figure 2 there's pressure.

    Author's response:

    We have calculated the mean relative difference profile and the VMR difference profile separating daytime and nighttime values.

    In Figure 2 (former Figure 1) we use altitude units in order to help in the interpretation of what it is shown.

    Author's changes in the manuscript: See the new Figure 3.

22. **Comments from the referee:** Figure 3:
    - I would make these plots much larger, removing one or two pressure levels if necessary.
    - Please specify in the caption the number of points involved in the moving average Figure 4

    Author's response:

    With all due respect to the referee we think that the plots are larger enough to be properly interpreted.

    Former Figure 3 is now Figure 4 and the number of points involved in the moving average is 7 points.

    Author's changes in the manuscript: Caption of Figure 4: Time series of averaged daytime and nighttime O_3 VMR measurements of GROMOS (blue line) and MLS (red line) for the period from July 2009 to November 2016 at different pressure levels. An averaging kernel smoothing has been applied to the series of the MLS measurements coincident in time and space with the GROMOS measurements. Both time series are smoothed over 7 points or 1 week in time by a moving average

23. **Comments from the referee:** Figure 4:
    - Same comment as for Figure 3: I would make these plots much larger, removing one or two pressure levels if necessary.
    - I would add the numbers m and q in the equation y=mx+q for each linear fit, or at least the slope m.
    - I am surprised by the relatively low correlation value at 0.617 hPa. By looking at figure 3 I was expecting a better result. Any comment?

    Author's response:

    With all due respect to the referee we think that the plots are large enough to be properly interpreted.

    In accordance with the referee wishes we add the slope of every linear fit in the titles of plots which form Figure 5 (former Figure 4).

    In our opinion this "low" correlation value can be expected from the time series at 0.617 hPa shown in Figure 5 (former Figure 4) since GROMOS measures more O_3 VMR (ppm) for most of the summers under assessment.

    Author's changes in the manuscript: Figure 5

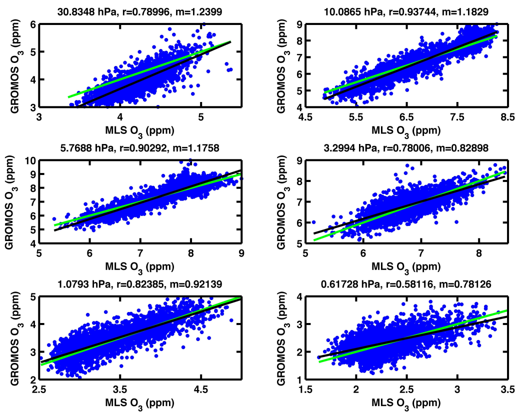


Figure 5: Scatter plots of coincident O_3 VMR measurements of GROMOS and MLS for the period from July 2009 to November 2016 at different pressure levels. The black line is the linear fit of both time series, and m the slope of the linear fit. The green line indicates the case of identity, O_3(MLS)=O_3(GROMOS). r values are correlation coefficients of the MLS and GROMOS time series

24. **Comments from the referee:** Figure 5:
    - It would be useful to see a comparison of averaged nighttime vertical profiles, not just level 0.05 hPa, in order to establish, for example, whether the MLS O_3 peak is at higher altitudes.
    - As a matter of fact, it would be useful to see a comparison of GROMOS mesospheric profiles also with the averaged MLS original (not weighted with

GROMOS AVK) nighttime profiles, in order to understand the capabilities of GROMOS to spot the MMM with the "correct" intensity at the "correct" altitude.

- It would be best if line colors in the various figures were consistent, e.g., MLS always in red, GROMOS always in blue, and so on. In particular, maybe colors in Figure 5 could be changed (GROMOS in blue and cyan, MLS in red and orange?)
- Again, please in the caption state how many points are included in the average
- In the bottom plot I would add the standard deviation of the mean for both GROMOS and MLS.

Author's response:

We have analysed the MMM at different altitudes, and for instance, at 0.1 hPa ($\sim$ 63 km) the results are pretty similar to the ones obtained at 0.05 hPa, although with smaller amplitudes.

In accordance with the referee wishes we have repeated the Figure. Former Figure 5 is now Figure 6.

With all due respect to the referee we think that our colours choice for this Figure 6 is rather intuitive.

Regarding, the addition of the standard deviation of the mean for both data records we think that this choice would make the Figure noisy. The standard deviation of the mean is $\sim$0.3 ppm for GROMOS, $\sim$0.2 ppm for MLS convolved and $\sim$0.5 ppm for MLS original.

Author's changes in the manuscript: Pg. 5, Ln 27: The first panel of Figure 6 displays the O_3 VMR measured at noon (GROMOS in red, MLS convolved in orange and MLS original in magenta) and at midnight (GROMOS in blue, MLS convolved in cyan and MLS original in black) at 0.05 hPa (70 km) for the already mentioned time period. The original MLS data, i.e. not weighted with GROMOS AVKs, is shown in order to provide an insight of the observability of the effect of MMM at northern midlatitudes by GROMOS.

25. **Comments from the referee:** Figure 6: Given that the daytime mesospheric ozone at 0.05 hPa is relatively constant, the night to day ratio provides more or less the same information already present in Figure 5. Maybe I am wrong, but then the authors should make an effort in discussing this figure a little more.

Author's response:

We acknowledge that the night-to-day ratio (NDR) just provides information about the amplitude of the diurnal and seasonal variability of mesospheric ozone, nevertheless we want to keep it in the manuscript in order to be comparable with the study of Sonnemann et al. (2007).

Author's changes in the manuscript: No changes.

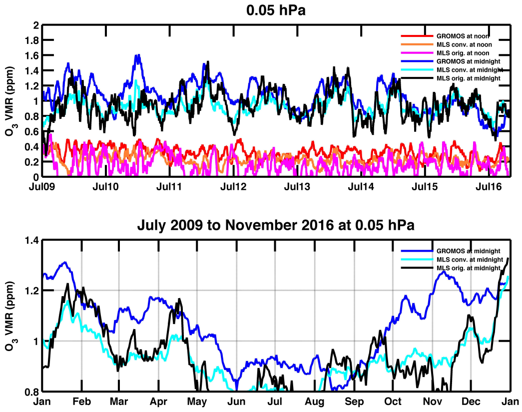


Figure 6: The first panel shows the diurnal variation of O_3 VMR measured at noon (GROMOS in red, MLS convolved in orange and MLS original in magenta) and at midnight (GROMOS in blue, MLS convolved in cyan and MLS original in black) at 0.05 hPa (70 km) and the second panel shows its evolution throughout the year averaged for the time interval under assessment (July 2009–November 2016). All time series are smoothed in time by a moving average over 15 points (1 week)