

Interactive comment on “Sensitivity of the OMI ozone profile retrieval (OMO3PR) to a priori assumptions” by T. Mielonen et al.

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Replies to the comments by Referee 1 concerning the manuscript “Sensitivity of the OMI ozone profile retrieval (OMO3PR) to a priori assumptions”

We thank the Referee 1 for the constructive comments which we have taken into account to improve the manuscript. Our replies to the general and specific comments are given below and the manuscript has been revised accordingly.

The paper is well written in general and mostly clear in the text. However, captions and legends of the figures need to be more explicit and better explained for sake of clarity.

- We have revised the captions and legends in order to improve intelligibility.

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The general approach is interesting and the assumptions that are tested (radiance corrections, surface albedo, a priori profiles, constraint matrix) sequentially are indeed very important for the quality of the ozone retrievals. However, the improvement of the modified scheme is only commented in relative terms with respect to the operational approach and in average for all pixels. The comparison with ozone sondes is only briefly explained in the text and reader needs to see the paper by Kroon et al (2011) for understanding the biases as a function of altitude that are intended to be reduced.

- We had tried to summarize the validation results by Kroon et al. (2011) in the Table 1 of the submitted manuscript. However, as the referee points out, the table did not provide information as a function of altitude, thus we added it. Moreover, we added a section (4.2) where we compared the different versions of the retrieval with ozonesondes over North America.

Additionally, the comparison with IASI retrievals is an interesting approach for verifying the regional consistency of the retrieval, although explanations and figures lack of important information for a complete understanding of the comparison.

- We have extended the comparison with IASI retrievals according to the detailed comments by the referee.

In order to be publishable, my main recommendations for the paper are the following: (1) In the current paper, clearly show as a function of altitude the results of the comparison of the operational ozone retrievals against ozone sondes from Kroon et al (2011), and compare them with the results of the new modified scheme. I suggest doing this in a detailed dedicated table or if possible, in a panel of a new figure that would also show in another panel the comparison between ozone retrievals of the operational and the new modified schemes.

- We agree with the referee that additional comparisons would improve the paper and, therefore, the revised manuscript includes a new section (4.2) where we have compared the operational and modified retrievals with ozonesondes over North America.

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The following text was added to the manuscript: "Figure 15 presents the absolute and relative differences between the ozonesondes and two versions of the OMO3PR algorithm. Figures 15a and 15b show the relative and absolute differences for the operational OMO3PR retrieval, respectively, while 15c and 15d show them for the modified version (Trop alb covar 10). When compared with the values in Table 1 (ECC sondes at mid-latitude), the operational retrieval in our study agrees slightly better with ozonesondes. As these plots show, the modification of the OMO3PR algorithm improves the agreement with ozonesondes at the lowest two layers and at altitudes over 20 km. In the upper troposphere/lower stratosphere (UTLS) the operational retrieval performs better. The reason for this is the significantly larger climatological ozone values and a priori errors used in the modified algorithm at these altitudes. Although the modified algorithm is not able to improve the performance of the retrieval for the whole atmosphere, it improves the correspondence with ozonesondes in the troposphere which was the main goal of this research."

(2) Comparison with IASI retrievals: the differences between the IASI and OMI ozone retrievals in terms of sensitivity as a function of altitude should be clearly presented. I recommend adding new figures showing the differences in terms of degrees of freedom in the lower troposphere and the altitude of maximum sensitivity within this layer. In the comments of these results, it should be clearly stated whether the improvement of the results from OMI are obtained only in the background values of ozone or it corresponds to regional differences (with ozone plumes or lower ozone abundances) and the link with the modifications in the OMI scheme. Moreover, I suggest commenting these regional/background differences by showing explicit figures with the lower troposphere ozone distribution over Europe (not only differences) from IASI and OMI (at least from the modified version). Another aspect that should be mentioned in the comparison is the difference between IASI and OMI in the overpass local time and how this would affect the lower tropospheric ozone abundances.

- We agree with the referee that the recommended figures would improve the compari-

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son. We have added a figure showing the tropospheric ozone distribution retrieved with IASI and with two versions of the OMO3PR algorithm and the following discussion on the effect of the time difference between the measurements to the manuscript. "Finally, we compared the absolute tropospheric ozone abundances from two versions of the OMO3PR algorithm and IASI. Figure 14 shows that the operational version (Fig. 14a) does not match the IASI results (Fig. 14c) at all, whereas the modified version (Trop alb covar 10, Fig. 14b) is able to capture the ozone plume in Eastern Europe (48-56N, 20-30E) better. Nevertheless, as Fig. 13d showed, the difference are still quite large there. One reason for this is probably the time difference between the measurements. The IASI measurements are taken around 9:30 local time whereas OMI measures around 13:30 local time. This means that the air masses and the ozone plume have had plenty of time to move between the overpasses. Moreover, due to the diurnal cycle of ozone it is expected that there would be more ozone in the troposphere during the OMI overpass. This could partly explain the overestimation in the OMI retrievals. However, the photochemical production of ozone that causes the diurnal cycle takes place near the ground level and OMI (or IASI) is not very sensitive there. "

Comparison of the degrees of freedom is a good idea but the new version of OMI has a slightly different pressure grid than the operational version and consequently the first three layers go slightly higher up in the atmosphere (about 400hPa in the operational and about 315 hPa in the new version). Therefore, we are not able to compare degrees of freedom from the exactly same pressure level/altitude range. The new version includes a slightly larger part of the atmosphere and that also increases the degrees of freedom. Thus, it is difficult to say if the increased degrees of freedom in the new version are caused by the improvements in the retrieval or just by the fact that the layers reach slightly higher altitudes. Regarding the altitude of maximum sensitivity, we did the suggested comparison and found out that the altitude of maximum sensitivity in the OMI retrievals is always the at the third layer (highest layer considered in the analysis). Therefore, we will not include a figure showing this in the revised manuscript but we will discuss it in the text as follows: "Regarding the sensitivity of the instruments,

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the altitudes of maximum sensitivity of the OMI retrievals are always at the highest layer in the troposphere, while for the IASI retrievals the altitudes vary between 1-7 km."

(3) Clarity of figures and captions: a significant effort is to be done in order to complete the captions of the figures clarifying the datasets that are used, the units and what is the quantity that is shown. Each figure with its caption is to be clear and explicit by itself with no need to read the main text to understand it. In many figures (1, 2, 4 and 6) the legend included "mod" and "orig" is used, which is not clear for the reader. I suggest using clearer terms and not generic ones, and clearly indicate in the caption what they are. This applies as well to the term "differences in O3" used in many other figures. Which unit is used for O3 concentration? Differences from what with respect to what? In many cases (figures 3, 5 and 8), much more curves are shown that are not detailed in the legend, thus they are difficult to understand. All curves should be included in the legend.

- The figures and captions have been clarified according to the referees comments.

(4) Sensitivity to the surface albedo: Since it depends on surface properties, I recommend showing this sensitivity test as a function of latitude/altitude. As comments are already given in the text, figures should show these regional differences.

- We have added a figure showing the sensitivity as a function of latitude/altitude. Now, we mention in the text that "As Figure 3b shows the largest decrease in ozone levels were found (over 20

(5) The previous remark also applies for the sensitivity test with respect to the ozone climatology. Regional and latitude-dependent changes are also expected when changing the ozone climatology. I suggest adding a new figure comparing the operational and the modified version (the best one) as a function of latitude/altitude.

- We have added a figure showing the sensitivity as a function of latitude/altitude. Now, we mention in the text that "For this case, as Figure 5c shows, the highest altitudes

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do not change much. This is also evident from Figure 6 which shows the averaged differences for six latitude bands. For most of the selected latitude bands the amount of tropospheric ozone is decreased close to the surface but increased higher up. " and "Furthermore, Figure 6b shows that for most of the selected latitude bands the amount of tropospheric ozone is decreased, except for the lowest layers, where half of the latitude bands show increase in ozone abundance."

Other detailed aspects are the following: (6) Page 1836, Line 15: I suggest adding "AS EXPECTED, we found that the a priori covariance . . ."

- Done.

(7) Page 1836, Lines 17-19: Please clarify "equally". What about mean biases of the retrieval? Do they depend only on the assumed a priori errors?

- Equally means that in each version of the algorithm the relative difference between the posterior errors and the a priori errors were in the same range. Biases between the different retrievals were different and they depend also on other a priori assumptions. We revised the text as follows: "Moreover, the relative difference between the posterior and a priori errors were in the same range for all the studied versions of the OMO3PR algorithm."

(8) Page 1836, Line 26: please clarify at which altitudes tropospheric ozone is a greenhouse gas and where it acts as a pollutant.

- We now mention in the manuscript: "Tropospheric ozone, on the other hand, is a greenhouse gas that warms the atmosphere at all altitudes (deF Forster and Shine, 1997). Moreover, at the ground level it is a pollutant that causes respiratory problems in humans and damages crops."

(9) Page 1837, Line 2: indicate the typical lifetime of ozone

- We now mention in the manuscript: "It is a short-lived species when compared with transport times (22 days in the troposphere), and therefore, inhomogeneously mixed."

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(10) Page 1837, Lines 7-23: *The capability of TIR sensors (IASI and TES) for retrieving ozone and tropospheric ozone should be introduced in this section.* (11) Page 1837, Line 15: *The statement on the fine horizontal resolution applied also, for IASI, whose pixels are comparable to those of OMI.*

- Infrared measurements were already mentioned in the introduction, thus, we only added the information regarding the fine horizontal resolution of the infrared instruments: "Microwave measurements are not affected by clouds and they can be done during night and day (like thermal infrared measurements, TIR) whereas ultraviolet measurements are limited to daytime. However, nadir UV (and TIR) measurements have much better horizontal resolution than the other methods

(12) Page 1838, Lines 15-18: *Other validation papers of this IASI ozone retrieval should be cited: Keim et al., 2009 ACP and Dufour et al., 2012, AMT.*

- The text has been revised as follows: "In their work, Eremenko et al. (2008) used ozone profiles retrieved from the Infrared Atmospheric Sounding Interferometer (IASI; Clerbaux et al., 2009) data. IASI ozone profiles have been thoroughly validated for example by Keim et al. (2009) and Dufour et al. (2012). "

(13) Page 1839, lines 29: *the consequences of not modeling clouds in the retrieval should be explained. What is the loss of precision for partially cloudy pixels? Are cloud fractions used in the retrieval? How? From which source?*

- The text regarding clouds in the retrieval was poorly formulated. The clouds are modeled and cloud fractions are used in the retrieval. The cloud fractions are taken from the OMI product OMCLDO2.

We studied how precision is affected by cloud fraction and did not see any clear signal. Overall, the precision values were in the same range for all cloud fractions. However, their variability is higher for clear pixels than for cloudy pixels.

We revised the text as follows: "Surface albedo is also fitted in the retrieval and the

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OMI surface albedo climatology (Kleipool et al., 2008) is used as an initial value for the surface underneath the atmosphere. If the cloud fraction taken from the OMCLDO2 product (Acarreta et al., 2004) is lower than 0.2, surface albedos are fitted. Otherwise, cloud albedo values are fitted. The wavelength dependence of the albedo in both UV1 and UV2 channels is described with a second order polynomial. Surface albedo is fitted for all wavelengths (although the shortest ones do not "see" the surface) to partly account for the presence of aerosols which are not known or modeled specifically in the retrieval. Clouds are taken into account with a simple Lambertian cloud model. The vertical location (cloud pressure) and the effective cloud fraction are taken from the OMCLDO2 product and a fixed a priori albedo is used."

(14) Page 1840, lines 12-17: *Please better explain, fitting is done between what and what? What is done within the ozone retrieval scheme?*

- This part was clarified as follows: "Regarding the ozone profile retrieval, correction for stray light is done in two steps. The first correction is done during the production of the L1B spectra (OML1BRUG; van der Oord et al., 2006). In this correction, specific wavelength ranges are used to define so-called source and target regions. For the source regions averaged signals are calculated using the information over the whole swath. Then these signals are multiplied by a polynomial that distributes the stray light over the target regions. Finally, the signals are subtracted from all the pixels in the corresponding target areas. The second stray light correction is part of the optimal estimation in the OMO3PR algorithm. There, stray light is described with 2nd order polynomials for both UV channels separately. "

(15) Page 1843, lines 18-19: *Please, explain why there is an improvement for ozone precision with a linear fit of albedo with respect to a second order polynomial fit.*

- Even though the precision profiles look different, the averaged precision values for these profiles are almost identical: 10.9

(16) Page 1848, line 1: *"shows shows", Please correct.*

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- Done.

(17) Page 1848, lines 17-18: Please, justify this modification with minimum a priori errors of 10 climatological values?

- We now mention in the manuscript: "The minimum a priori error of 20

(18) Page 1849, line 11: The formula is not clear, please correct.

- The formula is written according to the guidelines of the journal, thus, we did not change it.

(19) Page 1849, lines 25-27: It does not seem very clear, please clarify.

- This part was clarified as follows: "The modified version of the algorithm uses a different pressure grid than the operational one, thus we had to interpolate the profiles in order to compare values for the exactly same altitude range. This was done by calculating a cumulative ozone profile in Dobson units from the surface to the top of the atmosphere. Then, the cumulative profile could be interpolated without changing the total ozone amount in the column. Finally, the tropospheric ozone abundance was taken from the 400 hPa level which corresponds to the altitude of 6 km used in the analysis by Eremenko et al. (2008). "

(20) Page 1850, lines 21 and elsewhere in this section: Please better identify the regions that are mentioned (e.g. where is the Bay of Biscay? which outskirts of Europe?)

- The text was clarified by adding latitude and longitude ranges for the discussed regions.

(21) Section 4: The location of pixels with partial cloud cover should also be considered in the analysis. Please add a corresponding figure of cloud cover that might explain differences in ozone abundances.

- A figure presenting the cloud fractions used in the OMI retrieval was added to the manuscript. The referee was right, cloud cover explains some of the differences and

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we modified the text as follows: "The usage of a linear albedo at the UV2 channel does not have as large effect as the climatology (Fig. 11b). However, decrease in ozone abundance can be seen in Northern Europe (above 54N). The changes are mainly connected to cloud cover, as Figure 12 shows. In Fig. 12, cloud fraction data from OMCLDO2 are shown for the studied day. When compared with the tropospheric ozone differences (Fig. 11b) it is clear that the modified albedo has the largest effect on partly cloudy pixels."

(22) Figure 9: Squared structures (of 5x5 or 6x6 degrees in latitude and longitude) are evident in the differences of the ozone retrieved by the differences schemes. Please, clarify why these structures is present.

- The squared structures in Figure 9 originate from the calculated tropopause heights. The heights are calculated with 1 km vertical resolution from ECMWF data which have a spatial resolution of 1 x 1 degrees. The coarse vertical resolution combined with the spatial resolution of the ECMWF data causes large areas to have the same tropopause height and the transition from one a priori profile to another can cause artificial structures that are visible in the difference plots. This information was added to the text.

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