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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Simultaneous Retrievals of Polar Mesospheric Clouds (PMCs) with Ozone from OMI UV measurements" *by* J. Bak et al.

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We thank the reviewer for providing the detailed and very useful comments on our paper.

General comments:

The manuscript discusses the ozone profile retrieval algorithm improvements as applied to Ozone Monitoring Instrument (OMI). The authors introduce a methodology for fitting simultaneously ozone profile and PMC parameterization to the OMI retrieval using UV wavelengths. Presently PMCs are not considered in the retrieval, which causes negative bias at altitudes above 2 hPa, with largest effect around 0.2 hPa compared to MLS ozone profiles. The manuscript shows that the biases can be reduced if the novel

retrieval method is used. The topic of the manuscript is interesting and techniques to diminish systematic biases in ozone observations are important. The results of the paper are, in particular, interesting for OMI type of nadir observations of atmospheric ozone profiles. While mainly concentrating on the effects on ozone retrievals, the manuscript does not discuss, characterize or validate further the PMC observations. The manuscript is generally well written and clear. I appreciate that the manuscript is kept rather short. The main focus of the paper is in improving the retrieval algorithm in specific (however important) conditions rather than demonstrating the geophysical implications or novel observations. Therefore, a more methodological journal (like Atmospheric Measurement Techniques) might be more suitable forum for this work. The title of the paper seems also somewhat misleading and I would suggest changing it to something like "Improving OMI ozone profile retrieval by simultaneously fitting PMCs". Alternative, the authors should consider deepening strongly the discussion about the PMC retrievals and the data quality and usefulness, including validation and data characterization, etc. In general, I would also like to suggest that more attention is put to formulating the algorithm as it plays an important role in the manuscript. Some important references are missing: - General references for OMI, MLS and Aura should be given - Spurr references are mentioned but not given - Optimal estimation references are missing

Response to General Comments:

As the referee mentioned, the main goal of this paper is not to retrieve/validate the PMC optical depth, but to improve the ozone profile retrievals in the upper atmosphere by removing the positive radiance biases due to the PMC scattering. We demonstrated the usefulness of our strategy through validating the improved OMI ozone profile retrievals with MLS data. Therefore, we have decided to change the title of paper to "Improvement of OMI ozone profile retrievals by simultaneously fitting Polar Mesospheric Clouds" according to the referee. Lastly, we have included the indicated references.

Detailed comments

Comment #1: It would be good to note that there are several ozone products available for OMI. Also, it would be nice to have some idea how PMCs in general affect also the other OMI ozone products (total ozone DOAS and TOMS algorithms, and KNMI ozone profile product). Are PMCs taken into account in these algorithms?

Response #1: We have inserted one sentence to note the operational OMI ozone products in Sect 2.1 OMI and MLS ozone measurements, "The OMI science teams provide two standard total ozone products, OMTO3 (Bhartia and Wellemeyer, 2002) and OMDOAO3 (Veefkind et al., 2006), and one ozone profile product, OMO3PR (Kroon et al., 2011)". All these algorithms do not take into the PMC scattering for ozone retrievals. The effect of the PMC scattering could be important for ozone profile retrievals using UV measurements below 300 nm such as OMI as well as SBUV, GOME, OMPS Nadir Profiler, which is noted in the revised manuscript.

-Revised Text (Page 3, Line 69-77). On the other hand, the detectability of the signal of PMCs from UV wavelengths below 300 nm in the ozone Hartley bands implies that failure to account for PMCs in ozone profile retrievals using these wavelengths might affect the determination of ozone and its trends in the upper atmosphere from nadir-viewing UV instruments such as SBUV, SBUV/2, OMI, Global Ozone Monitoring Experiment (GOME) (ESA, 1995), SCIAMACHY, GOME-2 (Munro et al., 2006), and Ozone Mapping and Profiler Suite (OMPS) Nadir Profiler instruments (Flynn et al., 2014). However, the impact of PMCs on ozone retrievals has not been taken into account for any ozone algorithm or even thoroughly investigated with sufficient statistical data.

-Revised Text (Page 11, Line 266-269): Despite being optically thin, PMCs can significantly affect the UV radiances at shorter wavelengths where the signal is weak, implying that the effect of PMC scattering may be not negligible for the stratospheric ozone retrievals from OMI as well as the SBUV, SBUV/2, GOME, GOME-2, SCIAMACHY, and OMPS Nadir Profiler instruments.

-Revised Text (page 15, line 368-371): This study indicates that the impact of PMC scattering is likely not negligible for the stratospheric ozone retrievals from OMI as well as SBUV, SBUV/2, GOME, GOME-2, SCIAMACHY, and OMPS Nadir Profiler as the effects of PMCs have not been taken into account in any of the operational ozone profile algorithms.

Comment #2: Please, include an image of the angles discussed VZA, SZA, AZA as they play important role in the modelling. Alternatively, the authors can give a reference to a figure where the angles are given. Is azimuth zenith angle generally known concept?

Response #2: Yes, these angles are known/basic concepts in radiative transfer so we feel that it is not necessary to add a figure to illustrate them. Azimuth Zenith Angle was misnamed. We have corrected them to relative AZimuth Angle (AZA), i.e., the difference between solar azimuthal angle and viewing azimuthal angle. We have included the discussions on the typical OMI angles where there are PMCs.

-Added Text (page 7, line 161-165) : The PMC are typically observed at latitudes above 55° from OMI where Solar Zenith Angle (SZA)s are above ∼35°, Viewing Zenith Angle (VZA)s are below ∼ 70°, relative AZimuth Angle (AZA)s range from ∼ 40° to ∼80° (right side of the nadir swath) and from ∼ 110° and ∼ 130° (left side of the nadir swath), depending on the cross-track position.

Comment #3: All figures are given in relative values. It would be good to have at least one figure where the ozone profiles are plotted with error bars so that the differences found with different retrieval techniques and their significance can better be understood.

Response #3: In Figure 1, we have added the OMI ozone and solution error profiles (DU) averaged for PMC and non-PMC pixels. Despite the large relative biases, the bias in absolute magnitude in DU is very small because the ozone values at upper layers are too small. It indicated that the effect of PMCs on total ozone retrieval is very small. We have added this point in the revised manuscript.

-Added text (page 9, line 219-222) : Despite the large relative biases ($\sim$ -20 % at 0.5 hPa) due to the presence of PMCs, the absolute bias is very small ($\sim$-0.05 DU at 0.5 hPa) because the ozone values in upper layers are quite small (Figure 1 c and d). It implies that the effect of PMCs on total ozone retrievals is negligible.

Comment # 4: Around P 25909: It is mentioned that limb observations of PMCs are useful. It would be good to give a bit more information on that, which instruments can be used and which parameters can be retrieved (several Envisat instruments e.g.). How does OMI PMC detection compare with these?

Response #4: According to both reviewers, we have revised the introduction section to include more previous studies on PMCs from OMI and other sensors on page 2 and 3 in the revised manuscript.

Comment #5: P 25909 L 18: one could add here: ... when nadir observations are used.

Response #5: We have revised the associated sentence as follows, "On the other hand, the detectability of the signal of PMCs from UV wavelengths below 300 nm in the ozone Hartley bands implies that failure to account for PMCs in ozone profile retrievals using these wavelengths might affect the determination of ozone and its trends in the upper atmosphere from nadir-viewing UV instruments such as SBUV, SBUV/2, OMI, Global Ozone Monitoring Experiment (GOME) (ESA, 1995), SCIAMACHY, GOME-2 (Munro et al., 2006), and Ozone Mapping and Profiler Suite (OMPS) Nadir Profiler instruments (Flynn et al., 2014)."

Comment #6: Around: P 25909: How do the ozone trends of nadir observations and the limb observations agree in upper stratosphere?

Response #6: We think it is irrelevant to discuss the agreement between limb and nadir observation in this paper because the goal of this study is to identify the UV nadir-viewing ozone retrieval errors due to the presence of the PMC scatterings and

improve them.

Comment #7: P25910 The OE solution could be opened a bit more. I think it is important to mention that it is an iterative optimization algorithm. I would prefer saying that Bayesian a posteriori solution is searched using EO optimization algorithm - or something like this.

Response #7: Our OE-based algorithm has been described in detail in Liu et al. (2010). For more clarification, we have revised the manuscript.

-Revised text (Page 5, line 108-111): This algorithm retrieves partial column ozone at 24 layers (surface to $\sim$ 65 km) from OMI measurements with the fitting window of 270-330 nm, based on the well-known optimal estimation (OE) technique (Rodgers, 2000). The iterative solution of the nonlinear problem is given as:

Comment #8: P25910 Please, open what is meant by weighting function matrix.

Response #8: We have added the notation, ∂R/∂X_i for weighting function matrix.

Comment #9: P. 25911 L3: is -> has?

Response #9: We have corrected "is" to "converges".

Comment #10: P. 25911 Please, define what is meant by norm: || . || _2

Response #10: it denotes the sum of each element squared. This definition is inserted after the equation 2.

Comment #11: The prior is based on McPeters & Labow climatology which is based on using MLS data. Also here the comparison is done with MLS data – it would be good to comment this and speculate how it impacts/does not impact the results.

Response #11: There is no important impact on the results. We also performed this study using the previous version of the ML climatology, which is mostly based on the SAGE stratospheric ozone profile measurements, as a priori. The main conclusion on

the improvements of OMI ozone retrievals with the PMC fitting is unchanged. We have added some information on ML climatology in Sect 2.3.

Comment #12: P25912 line 19, notation i=0, . . ., 23 would be more clear.

Response # 12: We have revised the associated sentence for more clarity in lines 168-170 on page 7.

Comment #13: P25913 line 20 – something missing here?

Response #13: Yes, we missed the value of the POD a priori state (zero), which is inserted in the revised manuscript.

Comment #14: Fig 8b) The interpretation of the figure is somewhat unclear to me. I get the impression from the figure that in all cases (non-PMC and PMC) cases the retrieval with PMC fit results in somewhat lower ozone values, being typically between 0-5% when no PMCs are detected and larger up to 15% when PMCs are detected. However, at SZA 57 – 67 it seems that the results are similar, so that the difference is also larger in case there are no PMCs detected.

Response #15: The retrieved ozone values at upper atmosphere tend to be higher if the PMC fitting is considered because of slight anitcorrelation between POD and ozone parameters in the upper atmosphere. The classification of PMC and non-PMC pixels is based on the work of DeLand et al. (2010). As we mentioned in Section 3.1, there are pixels that are "dark" based on the OMI PMC detection threshold may still have enough PMC contamination to bias OMI ozone retrievals. Figure 8. (a) shows that the retrieved POD value is typically higher for a brighter pixel, but there are non-PMC pixels where a larger POD value is retrieved. It is possible that some PMC pixels are not detected at SZA 57ËŽ – 67ËŽ and are classified as non-PMC pixels. We have revised the manuscript to include this discussion.

-Revised text (page 13, line 316-323): It illustrates that the retrieved ozone values tend to be larger if the PODs are simultaneously retrieved because of slight anticorrelation

between POD and ozone parameters in the upper atmosphere. The ozone column differences are larger for PMC pixels than for non-PMC pixels, indicating that the simultaneously retrieved POD could correct the negative biases in OMI ozone retrievals. However, there are non-PMC pixels that show the significant correlation between the POD and ozone parameters at SZAs 57°-67°, indicating that some PMC pixels are not detected from OMI.

Comment #15: P 25916 L24 This could be opened a bit more: which figure specifically is meant.

Response #15: We have corrected "Fig.4" to "Fig.4. a and b"

Comment #16: Fig 7 and elsewhere. The terminology a priori error value is used many places. I suggest being more specific on this: std or variance? Also term "solution error" is used – std?

Response #16: The terminologies of "a priori error, solution error" are particular for the retrievals using the optimal estimation. A priori error means the range (1σ) that a variable is allowed to vary. The solution error is the retrieval error (1σ) for a retrieved variable. Although there is some similarity with std, we think that they should not be replaced with std or variance. We have revised the manuscript to provide some description on them.

-Added Text (page 5, 119-120): Ozone a priori information is generally taken from climatological mean values and standard deviations of long-term measurements data, respectively.

-Added Text (page 5, 124-125): The quality of the retrievals could be characterized by the solution error, defined as the root square sum of the random noise error and smoothing error.

Please also note the supplement to this comment:

http://www.atmos-chem-phys-discuss.net/15/C11444/2016/acpd-15-C11444-2016-supplement.pdf

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Interactive comment on Atmos. Chem. Phys. Discuss., 15, 25907, 2015.