

Editor comments:

I. 185: It should be clarified if the retrieval uses forward calculations with and without clouds, using the cloud fraction as weights for partially cloudy scenes.

Author reply: Yes, this is the way it is computed internally in the radiative transfer code (DISAMAR software) used for the forward model calculations.

Manuscript update: The following phrase has been added: "The computations are performed with and without clouds, using the cloud fraction as a weight for partially clouded scenes." And other minor changes in the paragraph to improve the readability.

I. 198: "along the total ozone axis" sounds awkward, maybe say "in both ranges the median from all profiles for a given total ozone value is used.

Author reply: We agree that the expression might not be clear; therefore we have accordingly updated the manuscript.

Manuscript update: On line 195: we have replaced the phrase "with the median of all the values along the total ozone axis" with "with the median ozone profiles for a given total ozone value."

I. 369: do not use the term "sub-columns". Mention panel numbers instead. You may say "the panels on the left and right sides".

Author reply: We agree that the phrasing on sub-columns (here of ozone, not of the Figure) can be confusing.

Manuscript update: On line 363 (in the numbering of the new version), "sub-column" has been replaced by "panel".

Fig. 2: Replace orbit numbers with a time axis, e.g. years (or add a second time axis). Technically, each individual plot needs a separate panel number.

Author reply: The authors agree with the suggestion.

Manuscript update: A secondary time axis has been added on the left panel, while in the right panel the orbits in the legend have been replaced with the years of the mission. The figure caption has also been modified in accordance to the new numbering of each individual plot.

Fig. 5: use larger fonts in the maps

Manuscript update: A new figure has been updated to the manuscript, with increased fonts and each panel having a label.

Fig. 6: each plot needs a panel number

Manuscript update: The figure is updated, with each panel having a label.

Fig. 11: use a lighter grey colour in the plot (too dark). Add panel numbers for each plot (three) and mention the ground-based measurement type in each panel. Explain what X (χ) is.

Author reply: These suggestions have been taken into account upon recreating the plots. The mathematical formulation for chi square - as used in the plot - has been added to the figure caption for clarity, but it has not been further explained, as this would then be required for all plotted quantities.

Manuscript update: Figures 11 and A4 have been horizontally stretched to increase readability, and horizontal scales of absolute and relative differences have been updated accordingly (larger range hence showing more white background). The reference instrument type has been added to the title text. A lighter shade of grey has been used for the individual line plots (only applicable to Figure 4). Panel numbers have been added for referencing in the respective captions. The mathematical formulation for chi square - as used in the plot - has been added to the figure caption for clarity.

Fig. 14: Make the fonts larger in each map. In the figure caption, explain the panels in the right order (now: you start with c and then a, b). Alternatively, you can reorder the maps to match the order in the figure caption.

Author reply: The suggestion is taken into account and the text and the figure have been accordingly updated (Fig. 13 in the new file).

Manuscript update: The figure caption has been replaced to match the order of the panels.

Fig. A4: see comments to Fig. 11.

Author reply: see reply to comments on Fig. 11.

The appendix should be separated from the paper and be available as a supplement. Then, the numbering should be S1 instead of A1, and so on.

Author reply: This had actually been our first intention, but upon checking the AMT Supplements guidelines, this did not seem to be the best approach (<https://www.atmospheric-measurement-techniques.net/submission.html>): "Supplementary material is reserved for items that cannot reasonably be included in the main text or as appendices. These may include short videos, very large images, maps, CIF files, as well as short computer codes such as Matlab or Python script." Especially for the reference station lists, an Appendix with direct access to detailed information seems more appropriate to expert readers. We will however comply with the eventual publication instructions of the Copernicus / Latex editor.

Manuscript update: TBD with the Copernicus editor upon manuscript acceptance.

Referee comments:

Referee report to the revised version of the “Five years of Sentinel-5p TROPOMI operational ozone profiling and geophysical validation using ozonesonde and lidar ground-based networks” manuscript by Arno Keppens et al. The manuscript has been significantly improved with respect to the presentation quality. Most of my comments were addressed in a satisfactory way. However, some issues are still needed to be dealt with. The manuscript can be accepted for the publication in AMT after a minor revision. My detailed comments are provided below.

Detailed comments:

- Lines 13-14: “vertical sensitivity” - it is not a common notation and should be defined before using.

Author reply: This term is explained between brackets in the manuscript update.

Manuscript update: “(i.e., the fraction of the information that originates from the measurement)” has been added right after “vertical sensitivity”.

- Line 20: “meridian dependence of its bias” - Whose bias is meant here, that of the sensitivity or of the tropospheric ozone?

Author reply: The authors agree that this phrasing is confusing.

Manuscript update: “its” has been replaced by “the”.

- Line 66: “The same combination of TROPOMI UV and CrIS IR retrieval wavelengths has been exploited by ...” - “A similar” instead of “the same” would be more correct, as the wavelength ranges used by these two retrievals are quite different.

Author reply: The authors agree that the rephrasing is more correct.

Manuscript update: The update has been implemented as suggested.

- Line 160: “Additionally, the CAMS ozone profiles are scaled to match the total ozone column derived from the OMPS total column data (Jaross, 2017).” - I am wondering why you do not use the total ozone column from TROPOMI instead (just for curiosity, not as a requirement to change).

Author reply: This is for historic reasons. In the beginning of the mission, we did not have a well validated total ozone L3 product available, and the procedure has not been changed to allow for consistency. In the future, when we reprocess the soft calibration data, this could be updated to use TROPOMI total column data.

Manuscript update: None

- Line 267: Could you please comment on the value of 200 for the cost function threshold. How did you come to this value?

Author reply: This value has been determined from sensitivity studies in order to have an indication for the users on how to remove data with poor fitting quality. As explained in the PRF (Product

Readme File) of the Ozone Profile product, this value is used as a diagnostic information for the ground pixels showing reduced quality of the fit.

Manuscript update: on line 264, "(value determined from sensitivity studies)".

- Lines 341-342: "... resolution and altitude registration that differs from the retrieval grid ..." - what does "altitude registration" mean here? You probably want to highlight that the AK peaks are not at nominal altitudes but this formulation seems quite confusing to me.

Author reply: The authors agree that this phrasing may sound unnecessarily complex. It has now been simplified in agreement with Section 4.3.

Manuscript update: "an effective vertical resolution and altitude registration" has been replaced by "an effective vertical position and resolution" for "each retrieved ozone value".

- Line 382: "... the a-priori is smoothed by the measurements" - this statement sounds extremely confusing. I am sure you agree, measurements cannot affect a priori in any way. Please reword.

Author reply: The authors agree with the rephrasing suggestion. It was not meant that the measurements affect the a-priori but more how the measurement combines with the a-priori values to give the result visible in the retrieval panel, which does not show the same steps visible in the ozone layer in the a-priori panel.

Manuscript update: The phrase has been replaced with "how the measurements combine with the a-priori values in a smoother retrieved ozone layer at the top panel." The caption of the figure has also been modified according to the new numbering.

- Line 473: "... an increase of the DFS ..." - Fig. A3 does not show any DFS, I suppose you refer to Fig. A2 here. From the sentence, it is not clear if you refer to the 6-12 km column when talking about DFS increase with SZA. Looking at Fig. A2 I see a much larger increase of DFS with SZA for the 12-18 km column (the third row from the bottom) than for the 6 - 12 km one.

- Line 473: "... an increase of the ... bias for the 6-12 km column with SZA" - In Fig. A3 I do not see any increase of the bias with SZA for any of the columns.

- Lines 473 - 475: "This correlation seems to be somewhat compensated for in the lowest column by increased atmospheric penetration of the sunlight at low solar zenith angles (0 to about 30°)." - I cannot understand which correlation you are talking about here and where you see it compensated.

- Lines 475 - 477: "Additionally, the bias is clearly negatively correlated with the surface albedo for the 6-12 km subcolumn, despite the latter's apparently slightly positive correlation with the retrieval DFS." - a similar correlation for the differences is seen for the 0-6 km column and a bit reduced for the 12 - 18 km column. DFS for the 0-6 km column does not seem to show any correlation with albedo while this correlation for the 12-18 km is largest. In general, this sentence does not seem to overview the full picture.

Author reply: These comments are all on the same paragraph, and have therefore been addressed combinedly. All subcolumns of relevance for the ozonesonde comparisons (i.e., below 32 km) were

confusingly indicated as “lowest subcolumns”. This has now been corrected for, and the abstract and conclusions have been minimally updated accordingly.

Manuscript update: This paragraph has been rewritten as follows: “An optical path length dependence of the TROPOMI bias is observed for the subcolumns, which also translates into a seasonal and meridian dependence of the bias, as seen in Figure 10. Scatter plots in the Appendix show the dependence of the subcolumn DFS (Figure A2) and bias (Figure A3) on SZA, VZA (both related to path length), cloud fraction, and surface albedo. The bias is clearly negatively correlated with the surface albedo for the lowest three subcolumns, despite the albedo’s apparently slightly positive correlation with the retrieval DFS. The meridian dependence of the full profile bias with respect to ozonesondes is shown in Figure A4 for five latitude bands, where increased tropospheric biases are observed for high solar zenith angles in the mid to high latitudes. As a result, increased tropospheric biases are found for high-SZA observations above highly reflective scenes, like is the case for Antarctic (sea) ice. On the other hand, when the deviation from the prior profile becomes too strong, these observations are flagged by the check in Eq. (2).”

- Lines 481 - 482: “... while a negative drift is observed for the two sub-columns above (18-32 km).” - I see a negative drift only for 18 - 24 km but not for 24-32 km (numbers in the plot), are you still discussing Fig 10?

Author reply: Thanks for noticing this error. The 18-24 km column drift was just negative in the first version, and just positive with the ozonesonde data updates for the second version of the plots, while the text had not been updated accordingly. As the drift for this column is negligible, the text now focuses on the significant drifts above and below.

Manuscript update: The quoted text has been corrected as follows: “...and a negative drift of similar size for the 24-32 km subcolumn, while the drift is negligible for the subcolumn in between (18-24 km).”

- By the way, in the caption of Fig. 10 it is not explicitly indicated which column belongs to which row. I understand it is the same as for Fig 9 but this still should be mentioned explicitly.

Author reply: The column ranges that are in the caption of Figure 9 were not repeated for Figure 10 because the latter’s y-labels contain this information.

Manuscript update: For completeness, the column ranges have now been added in the caption of Figure 10 as well.

- Lines 519 - 520: “This can be seen from Figure 10, with the black lines (average differences) being within the grey areas (SRD requirements).” - This is not really visible in the plot, especially in the right column.

Author reply: The black lines are not fully visible in the subplots on the right, but are constant within each row and hence can be interpreted from the middle plots. This has been specified in the updated text.

Manuscript update: “black lines (average differences)” is updated to “thick horizontal black lines (average differences that are constant for each row)”.

- Line 527: “The vertical retrieval grid is sampled at a resolution of 6 km or higher...” and Table 2: “Partially, as the vertical grid complies...” - I do not think it is correct to rate a sufficient sampling of the vertical grid as a partial compliance with respect to the vertical resolution. I agree it is required to have a vertical grid with sufficient sampling but it has nothing to do with the measurement/retrieval capabilities.

Author reply: The authors agree with the reviewer’s concern. However, as the requirements do not differentiate between ‘sampling’ resolution’ and ‘effective’ resolution, we have attempted to appropriately address both at the same time. As such, we have tried to find a middle ground between an expert versus non-expert user perspective on this matter.

Manuscript update: None.

- Line 536: “... observed in the western ocean out of South Africa ...” - Do you mean “in the Atlantic ocean western of South Africa”?

Author reply: Yes.

Manuscript update: Rephrase has been implemented.

- Figure 9: suboptimal position of the text boxes in the lower right plots: the boxes strongly cover the plot contents. 50 % quantile lines are often difficult to distinguish, another color, e.g. green, might help.

Author reply: The authors agree on the suboptimal position of the legends. Where appropriate, these have been moved to the upper right corner of the panel. In order not to introduce yet another colour in this figure, a different plotting thickness has been used to clearly distinguish between the median and other quantile lines (also for Figures 10, A2, and A3).

Manuscript update: The trend line legends in the lowest three panel rows have been moved to the upper right corner of the panel. A different plotting thickness has been used for the median versus other quantile lines. The figure caption has been updated accordingly (also for Figures 10, A2, and A3).

- Figure 11: The figure is still difficult to read. It should be stretched to occupy the full page width. Horizontal space between the sub-plots would be useful.

- Figure A4: same as for Fig. 11.

Author reply: The reviewer suggestions have been taken into account upon recreating the plots.

Manuscript update: Figures 11 and A4 have been horizontally stretched to increase readability, and horizontal scales of absolute and relative differences have been updated accordingly (larger range hence showing more white background).

Technical corrections:

- Line 19: “The vertical sensitivity of the TROPOMI tropospheric ozone amount” - This sounds a bit weird to me. Maybe you should exchange “of” by “to” or “for”, or talk about sensitivity of the retrieval and not that of ozone amount...

Author reply: The authors agree that this phrasing is confusing.

Manuscript update: “amount” has been replaced by “retrieval”.

- Line 268: “...for all 33 levels I combined...” - should “I” be separated by commas?

Author reply: This seems to depend on the stress you want to give. For clarity, “I” has been put between brackets, in agreement with the number density symbols in the same line.

Manuscript update: “(denoted I)” has been added to the text for clarity.

- Line 302: “...of up to 5 %, and except in the tropical upper troposphere...” – should there be a comma after “and”?

Author reply: Adding a comma would indeed make the phrasing more correct, but we have opted to split the sentence for readability instead.

Manuscript update: “...of up to 5 %. Except for the tropical upper troposphere...”