Reply to Robert Roland Nelson

We thank the referee for his time and effort in critically reading and reviewing our manuscript. Below we reproduce the questions/comments in bold and address them in plain text. Changes in the manuscript are marked in different colors. In response to the overall reviews, we have expanded the manuscript to include

- joint retrieval results in which we adopt the MAP-band concept (section 7), and
- discussion on the retrieved aerosol properties in Appendix B.

General comments:

The manuscript entitled, "Anthropogenic CO_2 monitoring satellite mission: the need for multi-angle polarimetric observations" presents an analysis of the value of adding a multi-angle polarimeter (MAP) to the Copernicus anthropogenic CO_2 monitoring (CO2M) mission. Using synthetic observations, they assessed the precision and accuracy of the CO2M XCO2 estimates from a 3-band spectrometer with and without the addition of auxiliary MAP information and found that MAP reduced the errors to below the mission requirements. They also assess the specific technical properties of the desired MAP instrument via linear error analysis. The manuscript is thorough, clear, and very well-written and I recommend publication in AMT after the authors address minor comments below.

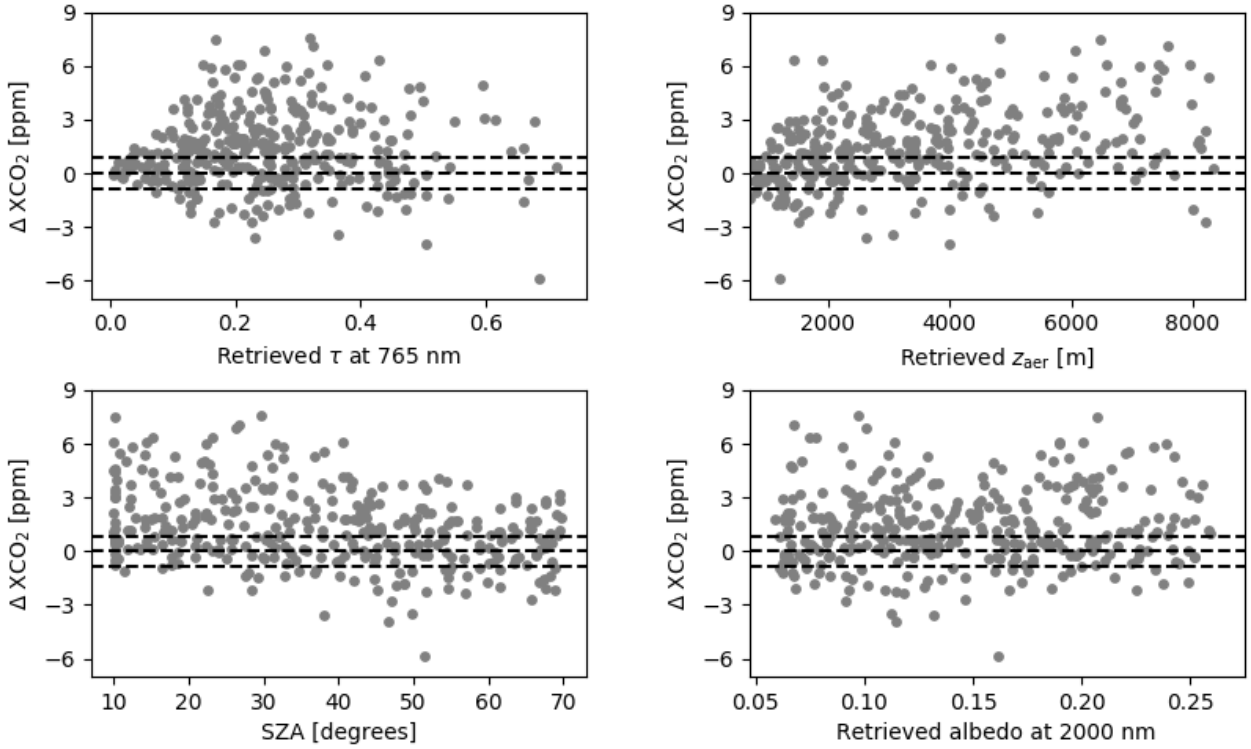
Thank you for your positive remarks and careful reading.

Specific comments:

[1] In Section 5, did you compare ΔXCO2 to the retrieved state vector elements (e.g. retrieved AOD)? This can be informative.

In Figure 1 in section 5, we show ΔXCO2 as a function of true AOD, aerosol height, albedo, and SZA. Below we show the same kind of plots, but as a function of the retrieved AOT, aerosol height, and albedo for your comparison. Please note that spectrometer-only retrieval considers only one mode of aerosols so a fair comparison between the retrieved z_{aer} and the true $z_{aer,coarse}$ is difficult. Retrieved AOD tends to cluster at smaller values than the truth (as also seen in Figure B1 in appendix B). Other than that, we believe that the retrieved values present no additional information. The scatter and the overall trend are similar to the true AOD - ΔXCO2 plot in Fig. 1, which is also the case for the albedo plot.

A statement about this has been added to the manuscript (section 5, page 13 lines 346-347).



[2] Regarding the errors of the standard retrieval approach, I think it is worth noting that you could certainly reduce those errors to within the mission requirements, but only by heavily post-filtering (and maybe bias correcting) the data. This new joint retrieval means you can keep significantly more data!

Indeed, this is now clarified in section 5 (page 15 lines 383-385).

[3] P2 L36: So the revisit time is daily for 40S to 40N?

The global revisit time (including 40S-40N) is 5 days. We adjusted the corresponding sentence in the manuscript to include this information (page 2 lines 38-39).

[4] P4 L111 ***"in this work we are interested primarily in XCO2 and do not discuss the retrieved aerosol properties."***

It would be interesting to at least look at how well MAP+CO2M does at retrieving the aerosol properties, compared to either MAP or CO2M alone. Does the aerosol information in the O2 and SCO2 bands add anything useful to the MAP aerosol results?

To answer this question we performed MAP-only retrievals and made comparisons of the retrieved aerosol properties in Appendix B. Please consult that section for details. In general, the results show significant improvement in the retrieved aerosol properties when MAP measurements are available. The comparison between MAP-only and joint retrieval results indicates smaller retrieval errors for the effective radius, the height and the optical depth of the coarse-mode aerosols when spectrometer measurements are included.

[5] P6 L168 "*We take the input vertical profiles of the trace gases as a given and retrieve the total columns via scaling factors.*"

Where do you get the prior profiles from?

The trace gas vertical profiles in the simulation are taken from the AFGL atmospheric profiles, with CO2 profile is scaled such that XCO2 = 400 ppm. This information is now included in the manuscript (section 4 page 11 lines 300-302).

[6] P6 L170 "*there are only 4 aerosol parameters that are not retrieved, i.e. f_{sphere}, z_{aer} of the fine-mode aerosol, and w_{aer} for both modes.*"

I understand that the radiances aren't very sensitive to w_{aer}, but why aren't f_{sphere} and z_{aer} of the fine-mode aerosol solved for? Fixing these parameters to the truth obviously becomes problematic if real measurements end up being sensitive to them.

The choice to fit f_{sphere} only for the coarse mode has been made because non-spherical particles mostly relate to mineral dust which is predominantly in the coarse mode. For z_{aer} our choice would be logical for a situation with industrial aerosol (fine mode) in the boundary layer and an elevated dust layer (coarse mode). The reviewer is correct that this choice may not be optimal. In particular, elevated layers of fine mode aerosols will be present in biomass burning plumes. It may be a better choice to fit one value for z_{aer} that corresponds to both modes, as done in Wu et al., 2016 (complete reference is given in the manuscript). This investigation is outside the scope of this paper but we mention this as an outlook in the revised manuscript (page 7 lines 185-191).

[7] P8 L212 "*the error analysis follows a two-step approach*"

Could you briefly explain the reasoning for splitting it into two steps?

In the linear error analysis, employing a one-step or a two-step approach would lead to the same results. However, with the two-step approach it is easier to understand how the aerosol errors are included in the XCO2 error computation, as explicitly expressed in equation 19.

We added a sentence in the manuscript (section 3.2 page 9 lines 230-231) to make this point clear.

[8] Figure 1 and corresponding text: make it clear when you are talking about the true scene properties vs. the retrieved properties.

Noted. The horizontal axis labels of Figures 1 and also 7 have been adjusted.

[9] P14 L357 "*With a P_{SD} above 2 ppm, XCO_2 retrievals based on only spectrometer measurements do not meet the mission requirements by a very wide margin (note that we do not apply postretrieval filtering here).*"

Can you comment on how much you might expect P_{SD} to be reduced with post-filtering in these simulations?

When we filter out the converged runs with retrieved aerosol optical depth (at 765 nm) > 0.3, the P_{SD} reduces to 1.95 ppm. Lowering the AOD threshold to 0.2 reduces P_{SD} only slightly to 1.66 ppm.

This information has been added to the manuscript (section 5 page 15 lines 376-379).

[10] P17 L415 "*Given that the improvement in ΔI=I from 3% to 2% is a major technical challenge…*"

Would reducing ΔDLP to 0.002 be easier?

We know that ΔDLP of 0.003 is feasible based on the SPEXone heritage, but reducing ΔDLP to 0.002 would be a major technical challenge as well.

[11] Figure 5: why does case 1 benefit so much from the SWIR bands?

A possible explanation could be that for case 1 the additional SWIR bands allow for better characterization of the directional and polarization surface properties, which are spectrally neutral. Given the relatively small contribution of the case-1 fine mode aerosol to the SWIR bands, the surface can be well separated from the aerosol contribution. The better surface characterization in turn leads to a more accurate aerosol and XCO2 retrieval.

[12] P21 L465 "*The details of our proposed baseline setup for the MAP-band concept is provided in Table 8.*"

Maybe put this line earlier in Section 6.3.

We have moved that line to the end of the preceding paragraph (page 21 line 485).

[13] P25 L537 "*The baseline setups of MAP-mod and MAP-band have generally similar performance.*"

But do the few scenarios where the MAP-band instrument does really poorly mean that MAP- mod is the better choice? Briefly discuss if you recommend one MAP instrument over the other, or if either would be acceptable.

We performed joint retrievals on the test ensemble with the MAP-band concept and included the analysis in section 7. Based on the results, joint retrievals with either MAP-mod or MAP-band fulfil the CO2M requirements. In this context, either concept is acceptable.

<u>Technical comments:</u>

[14] P2 L50: change to "shorten or lengthen"

Corrected (now line 52).

[15] P3 L68: change to "It clearly shows the benefit…"

We cannot identify the relevant text on the indicated page and line.

[16] P5 L135 change to "spectrometer"

Corrected (now line 145).

[17] P16 L406 looks like the highest value in Fig. 2 is actually just above 2.5, not ~2.4.

Yes, it is actually 2.52 ppm. The text now (page 17 line 432) reads: "<ΔXCO2> can be as high as 2.52 ppm for the highest ΔI/I and ΔDLP considered here."

[18] P24 L511 change to "custom"

Corrected (now page 26 line 554).

[19] P26 L549 remove "to a large extent"

Removed (now page 27 line 593).