Response to Reviewer #1

We thank the reviewer for their detailed comments on the manuscript. We have addressed these comments as described below. All reviewer comments are presented in italic font while the author responses are displayed in standard font. Specific text that was added to the updated manuscript is provided in blue text.

The study by Johnson et al., titled "TOLNet validation of satellite ozone profiles in the troposphere: impact of retrieval wavelengths" used lidar profiles of tropospheric ozone to evaluate the equivalent retrieved from TropOMI, CriS and TropOMI+CriS using the TOPAS algorithm. This represented retrieval schemes exploiting UV, IR and UV+IR wavelengths to retrieve tropospheric ozone. The long-term plan being to use TOLNet to evaluate tropospheric ozone profiles from the new TEMPO geostationary platform. Overall, this is a nice study demonstrating the suitability of this lidar network to evaluate satellite data, with the novel use of a larger network of lidars than previously used over the US. Therefore, this manuscript is suitable for publication in AMT subject to some minor comments below:

Page 3 Lines 80-88: The paragraph suggested that there are only two retrieval schemes of ozone profiles from OMI. However, the RAL Space retrieval scheme described by Miles et al., (2015) is used for GOME, GOME-2A & B, SCIAMACHY and OMI. Therefore, this should be mentioned in this paragraph and relevant references included (e.g. Keppens et al., (2018); Pope et al., (2020); Russo et al., 2023).

Thank you for identifying this oversight. We have added the following text to the introduction section of the updated manuscript to identify and explain the RAL Space OMI algorithm: "There are three O_3 profile retrieval algorithms for OMI (NASA - Royal Netherlands Meteorological Institute (KNMI), van Oss et al., 2002; Smithsonian Astrophysical Observatory (SAO), Liu et al., 2010; Rutherford Appleton Laboratory (RAL) Space, Pope et al., 2023)" and "The RAL Space algorithm uses UV wavelengths (270–350 nm) to retrieve O_3 profiles at the native spatial resolution of the sensor (13 km × 24 km at nadir) with similar vertical resolution as the other two algorithms (Miles et al., 2015; Keppens et al., 2018; Pope et al., 2023).".

Page 7 Line 196: Should the Jacobian matrix, K, be in bold?

This has been corrected.

Page 7 Line 205: Add "in" after "12 weeks" and before "total".

This has been corrected.

Equation 3: Is the more traditional method to write this equation as Xc = Xa + AK(Xt-Xa)? Also, I don't think Xc is defined.

The O_3 profile TOPAS retrieval is conducted with relative deviations from the a priori as explained in Mettig et al. (2021) which is why we wrote Eq. (3) this way initially. However, to avoid confusion for the reader we have changed Eq. (3) as suggested by the reviewer. The following text has been added to the updated manuscript: "The TOPAS retrieval is conducted with relative

deviations from the X_a, therefore the ***AK*** is converted appropriately as explained in Mettig et al. (2021).". We have also now defined *Xc* in the updated manuscript in the following sentence: "The satellite retrievals were compared to raw observations and when convolved (X_c) with the averaging kernel (***AK***) and a priori information from each retrieval using Eq. (3):".

Page 10 Figure 2: It is true that IR tends to have slightly more information on tropospheric ozone. However, I think one sentence discussing the total DOF (as you show it in your plot and provide numbers) would be useful as the UV scheme has much more sensitivity overall (though this is middle-upper atmosphere). E.g. add a sentence on Page 10 Line 279 outlining the general picture and then focus on the tropospheric component.

We thank the reviewer for bringing up this good point. At the beginning of this paragraph, we have now added the sentence: "Each of the three retrievals display different total column DOFs (0-60 km asl) with UV+IR retrievals having the highest sensitivity (5.65) followed by UV-only (5.01) and IR-only (2.28)." along with other modifications to emphasize the differences in the retrieval's DOFs.

General point, the quality of the figures needs improving as many (especially the text) are pixelated.

We appreciate this comment and will do our best to improve the quality of the figures before final publication, if approved by the reviewers and editor.

In Figures 4,5,6 and 8, can the authors add a sentence making it clear what all the statistical metrics are (e.g. RMSE) and clearly state what the reference is. E.g. what you use as the reference to get the NMB numbers (e.g. apriori or TOLNET/ozonesondes convolved with the TOPAS Aks).

This information has been added to the caption of Fig. 4, 5, 6, and 8 in the updated manuscript.

Where possible, fit all of Table 2 onto a single page.

The updated manuscript has been formatted so Table 2 and 3 are entirely on the same page.

I find figure 8 slightly confusing. I can only see one TOLNet profile convolved by the AKs. However, as there are 3 retrievals for UV, IR and UV+IR, there should be 3 sets of AKs to convolve the TOLNet profiles. However, I don't see this. Do the authors only use e.g. TOLNet + UV/IR AKs? And for the bias plots on the RHS, make it clear what the retrievals are compared to e.g. TOLNet + AKs from one retrieval or each wavelength retrieved compared with TOLNet + their corresponding AKs?

Thank you for identifying this aspect of confusion. The reviewer is correct, on the left-hand side of Fig. 8 we only plot TOLNet convolved with the UV+IR AK. This is done to reduce the number of lines in the plot to avoid too much confusion for the reader. However, the NMB values calculated in the right-hand side of the figure use the respective AKs of each of the three retrievals. Figure 8 caption now reads as: "Seasonally-averaged vertical O_3 profile comparison of TOLNet interpolated to the satellite vertical grid (TOLNet-raw), TOLNet convolved with the TOPAS AKs (TOLNet-AK), UV, IR, and UV+IR TOPAS satellite retrievals, and the a priori profile information. The TOLNet profile convolved with the UV+IR AKs are displayed and the two other

(UV- and IR-only) convolved profiles are not shown to reduce the number of profiles presented. The direct comparison of the profiles (left column) and normalized mean bias (NMB) (right column) for UV-only, IR-only, and UV+IR retrievals compared to TOLNet-AK as the reference are displayed, respectively. NMB values for each of the three retrievals are calculated using the TOLNet profiles convolved with the correct retrieval-specific AK as the reference. NMB values of 30% and 10% are displayed using grey dashed and dotted lines, respectively. The total number (N) of co-located profiles are shown in the figure inset.".

Page 24 Line 545: Why use TOLNet raw and not TOLnet+AKs?

We thank the reviewer for catching this typo. We have corrected it to say "convolved TOLNet…".

Page 24 Lines 549-550: Add some numbers for the RMSE stats discussed.

We have expanded upon this claim presented in the revised paper to present the actual RMSE values calculated for the different observation characteristics (albedo, sza, and cloud fraction).

Page 24 Lines 555-556: The statement "b) retrievals with minimal dependence on apriori information" is too strong in my opinion. If you were discussing only the tropospheric column, where Fig2 suggests the DOF is approximately 0.7-0.8, then I would be inclined to agree as you have nearly 1 piece of independent information from the troposphere. However, as you are looking at profiles, where the DOF will drop substantially, I would be inclined to replace "minimal dependence on apriori information" with "decent independence from the apriori information".

We apologize for the confusion about this statement. Here we are discussing the capabilities of the TOLNet observations which have minimal dependance on a priori information (e.g., meteorological conditions). We have altered this statement as: "TOLNet data provides: a) highly accurate, high temporal resolution, O_3 observations for multiple continuous hours and/or days, b) retrievals with minimal dependance on a priori information, and c) profiles with higher vertical resolution compared to satellite products." in order to avoid this confusion.

Page 25 Line 585: You discuss the sensitivity of the retrieved ozone to SZA, apriori and surface albedo, but would it be worth looking at cloud fraction? E.g. looking at a cloud fraction of 0.1 vs 0.2 on retrieved ozone? CF is an important factor in retrieving any quantity from space.

We agree with the reviewer and have added this analysis to this section of the updated manuscript. The following text was added: "Cloud interference can impact retrievals of most atmospheric constituents such as O_3 profiles. Here it was determined that while systematic biases for low cloud scenes (cloud fraction < 0.2) and times of high clouds (cloud fraction > 0.2) were similar (~14 ppb), RMSE values were larger for cloudy scenes (17.1 ppb) compared to clear pixels (13.5 ppb). This study further emphasizes the impact that clouds can have a detrimental impact on the accuracy and uncertainties of O_3 profile retrievals.".

Page 26 Line 609: "and lowermost tropospheric ozone." I'm not sure you can say that here as the DOF is low at 0.1. Please provide more justification for this statement.

It has been suggested by previous studies that the TEMPO UV+VIS retrievals will have much larger sensitivity to lowermost tropospheric (0-2 km agl) O_3 compared to UV-only and UV+IR

retrievals. The following text has been added to the discussion section in the updated manuscript to support this statement: "While TEMPO O_3 profile and partial column data was not available at the time of this publication, preliminary analysis suggests that the UV+VIS-derived 0-2 km partial column product from this geostationary sensor should have DOF values between 0.2 – 0.3 (Natraj et al., 2011; Zoogman et al., 2016; Johnson et al., 2018).".

References:

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