Paper title

Response to Anonymous Referee #2

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We thank the reviewer for their time in evaluating our manuscript, especially given its length, and are excited by the positive responses that the paper received. Below we respond to the individual comments. The reviewer's comments will be shown in red, our response in blue, and changes made to the paper are shown in black block quotes. Unless otherwise indicated, page and line numbers correspond to the original paper. Figures, tables, or equations referenced as "R*n*" are numbered within this response; if these are used in the changes to the paper, they will be replaced with the proper number in the final paper. Figures, tables, and equations numbered normally refer to the numbers in the original discussion paper.

The paper is well written. It will become more comprehensive if authors add a brief description of "how much does the new algorithm improve the TCCON retrieval quantitatively" in the abstract and/or conclusion even though required accuracy is described in the introduction and the supplement.

We have added a new figure (Fig. 17 in the revised paper) that shows histograms of how the bias in the TCCON retrieved quantities versus AirCore profiles changes with the new priors. The implications of this figure are discussed in a new subsection (§5.3). We have also added some text to the conclusion that refers back to this subsection:

> "The column-average mole fractions retrieved by TCCON shift relative to in situ column averages by up to 0.2 ppm for CO_2, 13 ppb for CH_4, and 1 ppb for CO. For the standard TCCON CO_2, CH_4, and experimental lCO_2 (CO_2 with stronger sensitivity to the surface) products the new priors produce an overall improvement relative to in situ column averages. The CO and experimental wCO_2 (stronger sensitivity to the upper atmosphere) products compare slightly worse overall to in situ data using the new priors. For CO, this is likely due to overestimated anthropogenic CO emissions in the source model. Finding a way to correct this, either by using a different model run or applying a geographically-varying correction, will be a high priority for the next version of the TCCON priors. The reason for the slight worsening of the wCO_2 retrievals is not yet clear."

Line 83, "Negatively impact", Definition of "negative" or more detailed explanation will improve reader's understanding.

We have expanded this paragraph into two to better separate the (enlarged) explanation of when extrapolation errors impact the retrieval from our decisions whether to accept or address said error:

> "Errors in extrapolating the MLO & SMO DMFs will negatively impact the TCCON retrievals if the error in extrapolation introduces an error in the profile shape, due to an El Niño year, for example. **In a scaling retrieval, such as the GGG algorithm used by TCCON, the posterior optimal profile is the prior profile multiplied by a scale factor, with the same scale factor applied to all levels. At its core, the algorithm we are describing here builds the priors by calculating what date to pull the MLO & SMO DMFs from for each level in the prior. If the extrapolation error caused all the MLO & SMO DMFs to be incorrect by the same percentage, this would manifest as the prior profile being incorrect by that percentage, for which a scaling retrieval can theoretically perfectly account. However, if the error in MLO & SMO DMFs is not the same for each level in the prior, that means the error in the prior cannot be represented by the same scalar multiplier for every level, and so a scaling retrieval could never completely eliminate the error in the posterior profile.**"
>
> "Currently, we estimate the error in the MLO & SMO DMFs due to extrapolation to be about 0.25% for CO_2, 0.15% for N_2O, and 0.6% for CH_4 over a five-year extrapolation (see S2 in the supplement for details). We deem this level of uncertainty acceptable for TCCON priors. **How errors in the priors alias into the posterior state in a profile retrieval, such as that used by OCO-2 and -3, is more complex. However, the OCO-2/3 retrieval uses a relatively tight covariance matrix for levels in the stratosphere (see Fig 3-15 of Crisp et al., 2021), making it important that the priors not exhibit any long-term drift in these levels.** Therefore, when these priors are used for the version 11 OCO-2/3 retrievals, more recent NOAA data is ingested (see Sect. 4)."

Section3, ACE-FTS data. Even though number of data is limited and measurement of the lower troposphere is difficult, vertical profile from solar occultation data are accurate. What is the lower -altitude limit for the application of the paper?

We use ACE-FTS data where the potential temperature is $\geq$ 380 K (as calculated from the ACE-FTS pressure and temperature profiles). This is not due to concerns over the ACE data, but rather because our algorithm only uses ACE-derived quantities for levels in the stratospheric overworld, defined by $\theta \geq 380$ K, thus we elect to be consistent. This has been added to the bullet point list of reasons why ACE data is filtered out in Sect. 3.3.

Section 5.1 Validation with Air CORE. Description of ideal numbers of AirCore measurement at each site and discussion on ideal global distributions of AirCore sites will be helpful for readers.

While I see how this could certainly help inform future plans to expand the AirCore program, it's not clear to me how this would add to the readers' understanding of the validation methodology or results. Further, to answer this rigorously would probably need some sort of OSSE-like study, with a given truth and uncertainty. Given that, I would prefer to keep this section focused on validating the new priors with what data is available, especially given the already substantial length of the manuscript.

Lines 53 and 202 "Potential Vorticity". Potential Vorticity (PV) appears twice.
Second instance changed to just "PV".

Line 524 the Armstrong Air Force Base TCCON site, Lines 531, 535 Armstrong, Figure 15 Armstrong AFB, Line 524 "the Armstrong Air Force Base (AFB) TCCON site"? Lines 531, 534 Armstrong AFB.
Changed as suggested.

References

Crisp, D., O'Dell, C., Eldering, A., Fisher, B., Oyafuso, F., Payne, V., Drouin, B., Toon, G., Laughner, J., Somkuti, P., McGarragh, G., Merrelli, A., Nelson, R., Gunson, M., Frankenberg, C., Osterman, G., Boesch, H., Brown, L., Castano, R., Christi, M., Connor, B., McDuffie, J., Miller, C., Natraj, V., O'Brien, D., Polonski, I., Smyth, M., Thompson, D., and Granat, R.: Orbiting Carbon Observatory (OCO-2) Level 2 Full Physics Algorithm Theoretical Basis Document, Version 3.0 - Rev 1, `https://docserver.gesdisc.eosdis.nasa.gov/public/project/OCO/OCO_L2_ATBD.pdf`, 2021.