Reply to short comments by H. Worden

Yi Yin et al.

First of all, we thank Dr. H. Worden for her comments. And we would like to take the chance to further explain our arguments.

> ***H. Worden***
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> *The author's reply to our comment did not address the serious deficiency that their study does not provide evidence to support their conclusions about assimilating pro- file vs. column CO MOPITT retrievals, since they did not assimilate profile data, even without bias correction. It would be necessary (but still not sufficient) to show that the assimilation of profile data, without bias corrections, performs significantly worse than column assimilation as compared to independent CO observations.*

Our argument is based on existing practice (including both what we tested here and previously documented studies) and logical reasoning. We showed that (1) when updating the surface emissions, the overall shape of vertical profiles can only be marginally improved (this happens only when the profile errors stem from surface flux errors), and (2) the posterior model biases to the MOPITT profiles vary with the altitude (with opposite signs of the remaining biases between the near surface levels and the free-troposphere / stratosphere levels).

Based on these two points, one expects that when assimilating one pressure level at a time the inversion derives different estimates of surface emissions. This expectation agrees with previous experiments demonstrated by Jiang et al., (2013, 2015, 2017) assimilating the MOPITT surface level (or near surface levels), the profiles, or the total column amounts individually, and indeed, resulted in different CO emission estimates. Hence, both inverse systems show that there is some inconsistency in the vertical CO distribution between the MOPITT data and the CTM that cannot be reconciled by only updating the surface emissions.

Further extending the second point, the remaining posterior model bias to the MOPITT profile is of the opposite sign to the other independent observations we included here in this study, which is in line with a previous validation study showing that the profile retrieval has larger retrieval biases at individual retrieval level than the total column retrieval, including a more significant temporal drift (Deeter et al., 2014).

Also, when assimilating the profile, we do not have adequate information to characterize the full observation error correlations across the vertical profile, which include not only measurement errors, but also transport-model and representativeness errors, for the inversion. Taken together, it is reasonable to conclude that assimilating the total column is more robust than assimilating the profile for inverse studies.

I disagree with their assessment that MOPITT retrieval biases cannot be corrected due to their spatial and temporal variability. Although this correction could be tedious, and it will likely be less accurate where there is a lack of validation data, bias information is provided in Deeter et al., (2014) and Buchholz et al., (2017) for MOPITT V6 and Deeter et al., (2017) for MOPITT V7.

Our argument was made for the profile retrieval; the concern is about the error correlations and the spatial variations of the vertical structure. Taking the recent practice by Jiang et al., (2017) as an example, guided by HIPPO measurements, the authors introduced a 4-order polynomial curve to correct a latitude-dependent bias for the MOPITT profiles at each retrieval pressure level before the assimilation (as cited below, Fig. 1 from Jiang et al., 2017). This empirical approach may reduce the bias for a certain pressure level, but without any guaranty on the overall column consistency. In addition, as shown in the plot cited here, for the comparison to HIPPO measurements that are mostly sampled over the ocean where CO concentration has a relatively smooth spatial distribution, we see already a large spread in the relative biases at a certain latitude for a certain pressure level. It also remains to be further analysed whether the features over land are compatible. Bias-correction for the total column is more practical given available observations, e.g. Buchholz et al., (2017) focused on the column amounts.

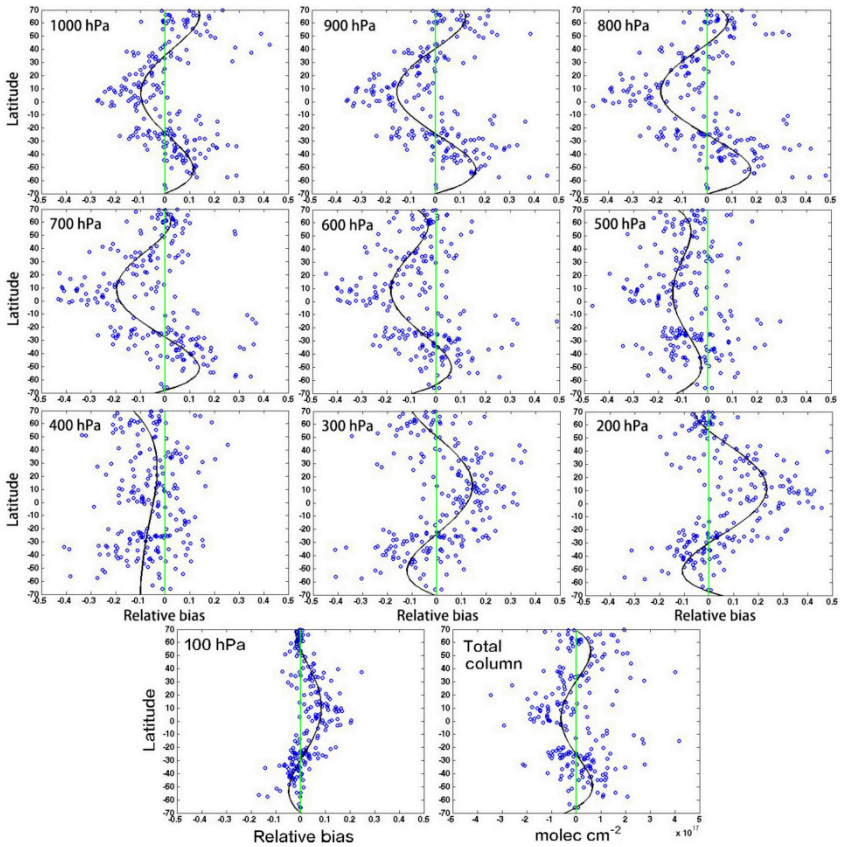

Figure 1. Difference between MOPITT CO retrievals and HIPPO aircraft measurements. The aircraft measurements are smoothed with MOPITT averaging kernels. The black solid line shows the 4-order polynomial curve fitting which is used to correct MOPITT data in this work.

After demonstrating the performance of the profile assimilation, if their conclusion about assimilating column CO vs. profiles is particular to the vertical biases in their model, they should make this more explicit in the abstract and conclusions rather than the blanket recommendation for assimilation only of column CO.

Model errors are often highlighted in CO inverse or chemical reanalysis studies as described in the introduction of the manuscript. As stated above, differences in the vertical profile between the transport model and the MOPITT data also exist in the model used by Jiang et al. (2013, 2015, 2017), so that the inversion derives different CO emission estimates when assimilating different levels of the MOPITT profile retrievals. Gaubert et al., (2016) showed, with another model, that when assimilating the MOPITT partial profile (excluding pressure level of 300, 200, and 100 hPa) for a chemical reanalysis where the control vector being the 3D-CO field, the remaining bias in the upper troposphere (defined as less than 400 hPa) changed sign from negative in the control run to positive in the assimilation, even though the reanalysis bias in the lower troposphere remains slightly negative. The authors interpreted this bias as vertical mixing of higher CO coming from the lower troposphere being too strong. Thus, differences in the vertical profile defined by the model equation and the MOPITT data is not a specific feature that only applies to our model.

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