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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Improved agreement of AIRS tropospheric carbon monoxide products with other EOS sensors using optimal estimation retrievals" *by* J. X. Warner et al.

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Answers to reviewer #1:

We deeply appreciate this reviewer for the valuable contributions and comments that will make this paper better. We are especially impressed with the detailed suggestions this reviewer provided that requires additional efforts on his or her part. Please see below for our answers to all the comments.

General comments:

1) There needs to be more description of the measured radiances. Are they from the

AIRS cloud-cleared radiance product, or individual spectra. How is the measurement error covariance constructed?

Answer: This is a very good point. We added the following sentences in Sec. 4 1st paragraph: "Therefore, the same cloud cleared radiances and noise are used in the AIRS OE retrievals as in the AIRS V5 operational algorithm. The measurement error covariance matrix was constructed to include the instrument Noise Equivalent Differential Temperatures (NEDT), and the computed noise resulting from errors in estimated cloud-cleared radiance, surface skin temperature and emissivity, temperature and moisture profiles, etc. (see Susskind et al., 2003)."

2) The apriori constraint matrix used in the retrievals can have a large effect on both CO profiles and DOFS, as shown in Ho et al., 2009 and Deeter et al., 2010. This needs further discussion here since you are comparing results with different constraint matrices as well as different apriori profiles. (See specific comments as well).

Answer: We agree. We have referenced above studies to stress the fact that the constraint matrix affects our retrieved CO profiles. Quantitative assessment of how the constraint matrix affects the AIRS OE CO retrievals requires large amount of sensitivity studies, which will be dedicated for a future study. See answer in Specific comments 9) for the revised statements.

3) Since you are using the global/static apriori covariance and profile from MOPITT V3 for the AIRS OE retrievals why do you compare to MOPITT V4? Maybe you could also show comparisons to MOPITT V3.

Answer: We have added AIRS OE and MOPITT V3 total column CO comparisons onto Fig. 8 and added text accordingly. See details in Specific comments 15).

4) The abstract should include a quantitative measure of improvement for AIRS OE vs. AIRS V5.

Answer: Correct. We added the following at the end of the abstract: "We conclude that

the tropospheric CO retrievals from AIRS OE and TES V3 agree to within 5–10 ppbv or 5% on average globally and throughout the free troposphere. The agreements in total column CO amounts between AIRS OE and MOPITT V4 have improved significantly with a global relative RMS differences at 12.7%."

Specific comments:

1) Intro 3rd para, give frequency range for TES CO retrievals: 2080-2180 cm-1. (Worden et al, 2004)

Answer: As suggested we added the frequency range for TES CO retrievals and a reference "2080-2180 cm-1. (Worden et al, 2004)."

2) Intro 4th para – 'similarly to TES' here sounds like TES is closer to MOPITT V3, when it is actually closer to MOPITT V4, i.e., also uses log VMR parameters. I would remove 'similarly to TES' and add later, 'MOPITT V4, like TES, also uses a log-normal VMR. . ..'

Answer: The reviewer is correct and we have modified the manuscript as suggested.

3) Intro 5th para –Add a reference for how the AIRS operational algorithm formulates AK & DOFS - Maddy et al.?

Answer: We have added the reference (Maddy et al., 2008).

4) Sec. 2 4th para – Description of Fig. 2 states SDVs are smaller for 800 hPa than 500 hPa – I don't see this in Fig 2. Vs Fig 1. – please clarify.

Answer: It was a misstatement when we meant to say that the SDVs are lower in the SH than in the NH. We've removed the part ", and meanwhile, the SDVs are smaller at 800hPa than at 500hPa" and added as a separate sentence "In both cases of 500 and 800hPa, the SDVs are lower in the SH than in the NH."

5) Sec. 2 4th para – Fig. 2 also demonstrates the monthly varying apriori used by TES since 800 hPa is more influenced by the prior for TES than 500 hPa– the description of

Fig. 2 should mention this.

Answer: We have added the following sentence at the end of Sec. 2 4th para "Fig. 2b also demonstrates that the monthly varying a priori used by TES may have contributed to the increased variability in time series at 800hPa since at 800 hPa the CO VMRs are influenced more by the prior for TES than at 500 hPa."

6) Sec. 3.2 Eq. 5 – capital X not defined – do you mean x = true state?

Answer: Yes, and corrected. 7) Sec. 4 2nd para. Last sentence should include that MOPITT V4 products are on 10 pressure levels.

Answer: We have added in the end of the last sentence in this paragraph ", while the MOPITT V4 products are on 10 pressure levels."

8) Sec. 4 4th para. If the first guess for AIRS V5 and the apriori for AIRS OE are the same, (as they are in Fig. 4 & 5) then both results should go the apriori value if there is no sensitivity. Maybe the different behavior is due to the apriori correlation in the OE retrieval. The MOPITT V3 constraint matrix has a longer correlation distance than MOPITT V4 and if the V3 constraint is used by the AIRS OE retrieval, it could influence the values near the surface more, as discussed in Deeter et al 2010. The effects of apriori correlation need to be included here.

Answer: We added the following statement at the end of Sec. 4 4th paragraph: "This constraint to the CO a priori profile in the OE retrievals is largely determined by the a priori correlation distance, which contributes to the CO retrieval differences in the lower troposphere by the two methods. See Deeter et al. (2010) for a discussion of correlation distance in the differences between MOPITT V3 and V4 CO products."

9) Sec. 5 3rd para – The discussion of algorithm differences should include the differences due to constraint matrices with a reference to Ho et al, 2009 (see below) which shows the effects of using different/same constraint matrices in TES and MOPITT retrievals, as well as the same apriori vectors.

Answer: This is a good point. We have added the following sentences: “Another source of algorithm differences is the constraint matrix as AIRS OE uses a background covariance similar to MOPITT V3 developed using statistics of the in situ measurements (Deeter et al., 2003) and TES uses a constructed covariance matrix [Kulawik et al., 2006]. Ho et al. (2009) discussed the effects of constraint matrices to the CO retrievals, as well as the effect of using the same a priori vectors, in TES and MOPITT retrievals in details. Deeter et al. (2010) discusses the difference of the constraint matrix between MOPITT V3 and V4 and the impact of the interlevel correlation to the retrieved profiles.”

10) Sec 5. 3rd para. – The latitudinal dependence of the TES DOFS is also due to a change in the Tikhonov constraint at $\pm$18 deg. latitude, [Kulawik et al, 2006], which should be mentioned in the description for the DOFS fig. 9.

Answer: We have replaced “a variable set of a priori” with: “a latitudinal dependent Tikhonov constraint in five zones (90°N – 54°N, 54°N – 18°N, 18°N – 18°S, 18°S – 54°S, and 54°S – 90°S) as described by Kulawik et al [2006],” in Sec. 5 3rd paragraph.

11) Table 1. Should also include the terms “static” for AIRS OE and MOPITT V3 and “monthly mean” for both TES and MOPITT V4.

Answer: Changed as suggested. 12) Fig. 1a and 1b captions should state differences are between AIRS V5 operational and TES V3 products.

Answer: Added as suggested.

13) Figs 4 and 5 should also show TES apriori profiles.

Answer: Our discussion in this section was mainly focused on the comparison between AIRS OE and AIRS V5 and how the retrievals behalf when the CO vertical sensitivities are low. We use AIRS 1st guess or averaged a priori profile to show how the two methods differ in the lower troposphere in reference to the prior information. We use TES CO results only as a reference to demonstrate the improvement in the agreement

between AIRS and TES CO. We don’t intend to analyze TES retrieval performance and therefore do not believe adding TES a priori profile will provide additional information to this discussion.

14) Fig. 7 – This shows the global PDFs for AIRS OE – TES differences. If possible, show the same N/S Hemis, ocean/land cases that are shown in Fig. 1a and 2a so that these can be compared more directly.

Answer: The differences of AIRS OE and TES V3 are very uniform between Northern and Southern hemisphere and between land and ocean, so a summary of global statistics is a good representation of all cases as presented in Fig. 1 and 2. We are adding the following statement in the discussion of Fig. 7: “The differences between the NH and SH and between the Land and Ocean for AIRS OE - TES V3 CO are significantly smaller than for the cases of AIRS V5- TES V3 CO shown in Fig. 1 and 2, and therefore, we only use a global summary in Fig. 7.”

15) Fig. 8 – per 3rd general comment above – consider adding MOPITT V3 comparison.

Answer: This reviewer is correct in that we used a priori similar to MOPITT V3 and we should compare our results with MOPITT V3 CO to demonstrate the improved agreement between the two sensors. We have added MOPITT V3 total column CO to fig. 8 (left bottom panel), however, we also kept MOPITT V4 since it is more current representation of the MOPITT products (Deeter et al., 2010). The new Fig. 8 is attached below, and the discussion on this figure has been changed accordingly in Sec. 5 paragraph 2. “, and the left bottom panel shows the relative difference between the two: (OE-V5)/OEÂů100%” is removed. We added: “The AIRS OE CO total column amounts are compared with MOPITT V3 (left bottom panel) and V4 (right bottom panel), and although AIRS OE used similar a priori information as in MOPITT V3, the results actually agree better with MOPITT V4. We discuss in more details of the comparisons with MOPITT V4 also because that V4 is a more current representation of MOPITT mea-

surements (Deeter et al., 2010)."

Technical corrections:

1) Abstract – add 'the' when before 'AIRS operational algorithm' and 'OE technique' and add change 'selected levels' to 'selected pressure levels'

Answer: Corrected.

2) Introduction line 2nd para, last sentence 'bursts' – maybe 'enhancements' is better?

Answer: Corrected.

3) Intro 3rd para, change 'NCAR/Atmospheric Chemsitry Division' to MOZART reference Brasseur et al., 1998 (or a website link)

Answer: Corrected.

4) Intro 4th para – take out 'the' before 'tropospheric carbon monoxide and methane' 5) Intro 5th para – change 'the sensitivities' to 'the vertical sensitivities' 6) Intro 6th para – change 'as similarly as possible' to 'as closely as possible'

Answer: Corrected.

5) Intro 5th para – change 'the sensitivities' to 'the vertical sensitivities'

Answer: Corrected.

6) Intro 6th para – change 'as similarly as possible' to 'as closely as possible'

Answer: Corrected.

7) Sec 3.1 1st para. 'physical retrieval algorithm' is not really defined here – maybe change 'The current AIRS physical retrieval algorithm' to 'The AIRS V5 operational algorithm'

Answer: Corrected.

8) Sec. 4 2nd para. Change 'dynamic' to 'monthly mean' to be more specific for a priori.

Answer: Corrected.

9) Sec. 4 2nd para. Deeter et al, 2010 has 2.8x2.8 deg for the MOZART climatology used in MOPITT V4 (interpolated to measurement locations) – not 1âŮęx1âŮę.

Answer: Corrected.

10) Sec. 4 6th para What is meant by 'selected from 34th in layers'?

Answer: We sampled 9 out of the 34 thinner layers we used for the OE retrievals to match AIRS V5 9 thicker layers only to show the AKs centered at the similar pressure levels to demonstrate where the sensitivities are. We have changed the sentences "The OE AKs are selected from 34th in layers and therefore have smaller values than the V5 AKs, which represent thicker layers (Deeter et al., 2007). The correct quantitative comparison is to use the AKs normalized by a layer thickness, . . ." to "The OE AKs are shown at selected layers from the 34 retrieval layers to match the pressure levels of the V5 AKs that uses total of 9 retrieval layers, and therefore, the OE AKs represent thinner layers than the V5 AKs. The correct quantitative comparison is to use the AKs normalized by a layer thickness (Deeter et al., 2007), . . ."

11) Sec. 4 7th para – change 'The V5 CO' to 'The AIRS V5 CO'

Answer: Corrected.

12) Fig. 7 caption – change 'convoluted' to convolved.

Answer: Changed.

References to add:

Answer: All added. Thank you!

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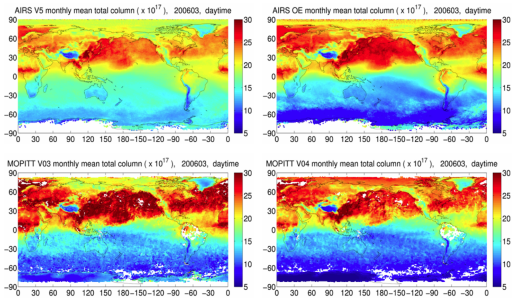

Fig. 8. The comparison of the monthly mean CO total columns (x 10^{17} molecules/cm2) between AIRS OE (top right) and MOPITT V4 (bottom right) for March 2006. The top left panel shows AIRS V5 CO total columns and the left bottom panel shows the CO total columns for MOPITT V3.

Fig. 1.