

## ***Interactive comment on “The MOPITT Version 6 product: algorithm enhancements and validation” by M. N. Deeter et al.***

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Replies to Comments of Reviewer #1

General Comments:

1. The MOPITT team chose to use CAM-Chem simulations to derive dynamic and seasonally varying a priori information in the same period as MO- PITT mission (2000-2009). Was the CAM-Chem CO output involved data assimilation using MOPITT data, or were CAM-Chem parameters adjusted by data assimilation using MOPITT observations? If yes, how would this affect the retrieval results in MOPITT V6 products? Would this be considered using the observed information twice?

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Authors' Reply: The CAM-Chem model simulations used as the basis of the a priori were not based in any way on MOPITT products. The various emissions inventories used for the model simulations are described in the cited publication by Lamarque et al.

2. Although the validation results are compared between V5 and V6 in details, it does not provide a picture how the CO values differ between the two versions, at various altitudes, in a straightforward way. It would help the readers to know in what vertical regions V6 CO values are higher (or lower) if there is a figure, and relevant discussions, to show the scatter and correlation between V5 and V6 CO values.

Authors' Reply: Differences between V5 and V6 products will vary geographically and seasonally (because of the different a priori) and would be difficult to generalize. Beyond a priori effects, the main difference is significantly smaller retrieved VMR values in the upper troposphere (e.g., 200 hPa) due to the reduced retrieval bias. This reduced bias is apparent in both the validation scatterplots and tables.

3. It was pointed out that the drift over time happens at different directions (increasing vs. decreasing) between 200 and 800 hPa. Could you elaborate as to the reasons? Did this affect the conclusions of previous trend studies? How should the users consider this drift in their trend studies?

Authors' Reply: Currently we can quantify the opposing bias drift in the lower and upper troposphere, but we can not claim to understand the underlying source(s). The previous trend analysis by Worden et al. (2013) involved the V5 TIR-only total column product which exhibited negligible bias drift. A sentence has been added to Section 4.1 discussing bias drift and trend studies ("Since bias drift is significant ...").

Technical Comments: 4. The color of the symbols should be stated in either the figure captions or the legends for easier reading.

Authors' Reply: The plots showing the HIPPO results (Figures 5 and 9 in the original

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manuscript) both include color-coded legends for identifying which HIPPO campaign phase corresponds to each data point.

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## Replies to Comments of Reviewer #2

### General Comments

In the second paragraph, the reviewer states that '... essential information are found missing to support the conclusions on the improvements sought with v6 compared to v5. For instance the main improvement is characterized at pressure levels where the reference measurements are limited or unavailable (200 hPa). They were replaced by the v6 a priori and it is not clear how much information is really extracted from the measurements to form MOPITT CO v6 there, such that the reader is under the impression that the a priori has been actually compared to itself.'

Authors' Reply: The potential influence of the a priori on both the retrieved profile at 200 hPa (due to low sensitivity) and on the validation profile (due to the method of vertically extending the actual in-situ data) could lead to misinterpretation and is a valid concern. However, previous publications (e.g., the V4 validation paper) demonstrated that retrieval sensitivity is non-negligible even at 100 hPa. Moreover, a priori influence can not explain why the V6 validation statistics at 200 hPa are significantly better than for V5, since in both cases the same method is used to extend the in-situ data vertically. Nevertheless, we have included new material (including a new figure) to clearly demonstrate that improved retrieval performance at 200 hPa is not simply due to the new a priori. (See response below.)

Also in the second paragraph, the reviewer writes '... it is not clear why accurate CO retrievals at 200 hPa are more important than accurate retrievals closer to the surface, where presumably the bulk of the emission like with wild fires is located.'

Authors' Reply: While it is true that the V6 validation results have worsened slightly at

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the surface, there are clearly more significant improvements in the validation results at 200 hPa. For example, as shown in Table 2 for the TIR-only products, the bias at the surface increased from 1.0 to 3.5%, but the bias at 200 hPa dropped from 7.9 to 0.8%. Thus, the maximum bias over the entire profile dropped by more than a factor of two. Similarly, for the TIR/NIR products, the bias at the surface increased from 2.7 to 8.9%, but the bias at 200 hPa has been reduced from 14 to 3.4%. We do not claim in the manuscript that retrieval accuracy at 200 hPa is somehow a higher goal than retrieval accuracy at the surface; rather we attempted to minimize biases over the entire profile.

### Specific Comments

L2.6: It is not clear what "simulations" means in the context of CAM, a chemical transport model in v6, as opposed to "model-derived climatology" in v5, should be explained in 2.2.

Authors' Reply: For both V5 and V6, a CO monthly climatology was developed based on model simulations performed over a period of years. For V5, the MOZART model was used to simulate CO concentrations from 1997-2004. For V6, the CAM-Chem model was used to simulate CO concentrations from 2000-2009. The text in Section 2.2 has been revised to make this clearer.

L3.7: It is advised to give a corporate reference number or identification code to the document for later references, if the website is reorganized and the link becomes obsolete, as this frequently happens.

Authors' Reply: This is a useful suggestion, but might not be feasible in the required timeframe for publication in AMT.

L4.1-5: The description of the a priori, a key element of the last 3 releases, deserves longer explanations. CAM extends from 2000 to 2009 but is said to represent better "mean global CO" from 2000 to present. The authors should clarify in few words whether that is uniquely coming from the different period of application or (1997-2004

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as opposed to 2000-2009 for an application to 2000-present) or explain briefly otherwise what makes it potentially better. Also what prevents CAM to be run over 2009-2014 and more ? The authors should explain the practical application of CAM as a priori for MOPITT CO retrievals from 2009 to nowadays (monthly means. . . ?) They should discuss briefly too the impact on the MOPITT L2 CO products of not having directly coincident a priori CO fields, unlike what is available for the first part of the mission, in view of their accuracy/continuity of the products characteristics (for climate applications for instance).

Authors' Reply: We suggest that the new a priori will be an improvement simply because of the much closer temporal match between the period represented by the model climatology and the MOPITT mission. This is stated in Section 2.2. As far as we know, nothing prevents CAM-Chem from being run for years after 2009, however such model runs were not available to us. The reviewer's last several questions seem to suggest a misunderstanding concerning the use of a multi-year climatology as the basis of the a priori. The rationale for basing the a priori on a multi-year climatology (as opposed to CO distributions which vary from year to year) is to simplify the interpretation of observed trends. Text has been added to Section 2.2 to clarify this.

§2.3: The discussion of the differences btw v5 and v6 input fields to CO retrievals and the expected improvements is clear and well summarized. One minor question: In L4.21, how is the finer humidity profiles resolution (42 vs 26 levels) going to help the MOPITT CO products (and its underlying forward-modeling) which come anyway on a coarser pressure grid ?

Authors' Reply: Within the MOPITT retrieval algorithm, profiles of temperature and water vapor are expressed on a grid with 35 levels. Thus, the higher vertical resolution of MERRA (compared to NCEP) can be exploited and should yield a small benefit. (However, this feature itself is not a primary motivation for using MERRA instead of NCEP.)

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§2.3: More fundamental, MERRA being a re-analysis, the application period should be recalled. The authors should also clarify if these data are available for the most recent MOPITT CO production and explain the strategy for on-line (near-real time ?) generation of present MOPITT v6 productions, when MERRA may not be available. Is MERRA interpolated in space and time to MOPITT sensing ? In that perspective, I would expect satellite L2 products from companion instruments exactly collocated in space and time to be of potentially even better help. Can the authors share feeling or experience in this area?

Authors' Reply: The use of MERRA for operational MOPITT products does in fact lead to delays of 1 to 2 months between the time of observation and data delivery. This issue is now discussed in Section 2.3, along with the issue of interpolation. (We have actually adapted our processing system to exploit the GEOS-5 products instead of MERRA for near-real-time processing, however, the resulting products are not archived and are not the subject of the submitted manuscript.) While it is conceivable that Terra/MODIS products could somehow be used to improve water vapor and/or temperature profiles, this topic is outside the scope of the manuscript.

A short introduction paragraph (for instance between 2.3 and 2.4) recalling the different CO production modes (NIR, TIR and N+TIR) -as well as the rationale for this- would be useful. The validation results are namely stratified against these modes later on in the paper, which come as a surprise to the non-familiar reader. Are these 3 modes routinely generated and distributed or are they only produced/studied here for algorithm validation purposes? Same comment on NIR products available at day-time over land only. A brief sentence informing the reader in advance and explaining the reason for this would be helpful.

Authors' Reply: The rationale for producing three retrieval variants based on different observational subsets was discussed in the V5 validation paper. A new paragraph has been added to the Introduction to describe the different MOPITT products and their relative merits.

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L5.23: What is/was the cause for the latitude dependent bias? How was it fixed in v6? Was latitude itself the issue, or rather the WV content, or the mean CO load, or the temperature via the thermal contrast letting more or less of the background a priori in the retrieval retrievals at higher or lower latitude?

Authors' Reply: The underlying cause of the latitude-dependent bias has not been analyzed. However, the observation that this bias decreased noticeably in V6 products suggests that it might be somehow related to the source of meteorological data (NCEP vs. MERRA).

L5.29: The radiance correction factor for 7D is substantial. The authors should develop for what makes it so different in v6: has the RTM changed at all/so much? Is it the only effect of a different a priori or input T,WV? or is the validation dataset on which the correction is iteratively tuned significantly different?

Authors' Reply: As described in Section 2.4, the 7D radiance correction factor was revised for V6 in order to reduce the significant retrieval bias in the upper troposphere apparent in V5 products; the radiance correction factor has a much stronger effect on retrieval bias than either the a priori or meteorological data. The radiative transfer model is unchanged for V6.

L6.6: The assumption that the in-situ measurements are "exact" and "representative" is a strong assumption, yet we all make when it comes to validating satellite products. The representativeness can however be tested by comparing the satellite observation radiances to simulations using the in-situ measurements as inputs to the forward model. In case of strong discrepancies in radiance domain, the in-situ data are excluded from the validation. Is there experience of performing this verification with CO products?

Authors' Reply: Generally, we have not found it necessary to discard CO profiles because of issues with representativeness. MOPITT validation benefits statistically from the use of large sets of in-situ profiles (e.g., NOAA and HIPPO) measured at many

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locations and in highly variable atmospheric conditions.

L6.25-27: After the description of the "equivalent retrievals", Eq1, I suggest to add a sentence stating that they will be referred to as "simulated retrievals" in the validation paragraphs. This is for clarity, to help the reader in the subsequent paragraphs with this terminology (§3.1, §3.1.2...).

Authors' Reply: This is now clarified in the description of equivalent retrievals following Eq. 1. The phrase 'equivalent retrievals' has been replaced with 'simulated retrievals.'

§3: Typical or average averaging kernels of the MOPITT CO v6 corresponding to the HIPPO and NOAA correlative measurements are missing and found essential information for the understanding and interpretation of the results. It is recommended to include some representative AKs. Particularly it is not clear how much the MOPITT CO retrievals are really sensitive to CO@200hPa.

Authors' Reply: At the reviewer's request, we have added a figure (uploaded with this Comment) showing the mean V6 TIR-only averaging kernels for a selected scene. This has also resulted in the addition of several sentences in Section 3, just before Section 3.1. The new figure makes it clear that the retrieval sensitivity at 200 hPa is actually comparable to the sensitivity at lower levels.

L7.23: On the bias at 200hPa, near 0 with v6 while significant in v5. Since no in-situ measurements exist at this height, the authors are effectively comparing the a priori of v6 (presumably little sensitivity up there in MOPITT retrievals) with itself (no in-situ measurements available, replaced by v6 a priori). It is believed that the authors are essentially in fact comparing the a priori of v5 and v6 here. This a priori (v5-v6) would be a useful information in addition to the other statistics in order to understand and interpret fully the results presented in the paper.

Authors' Reply: The new figure makes it clear that MOPITT retrievals at 200 hPa exhibit useful sensitivity and are not heavily dominated by the a priori. If retrievals at 200 hPa

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simply reflected the a priori, the observed retrieval bias at 200 hPa would actually be very small for both V5 and V6 products. Many of the HIPPO profiles do in fact reach 200 hPa (as described below in the response to L9.6), and therefore provide in-situ data over a substantial range of the 200 hPa averaging kernel.

L8.11: The conclusion is surprising, namely that the biases of v6 products are larger than the biases of v5 products as one would expect v6 to be of better accuracy than v5. What is the reason for this ? Are the validation references not so accurate?

Authors' Reply: The retrieval bias for the NIR-only products has increased from roughly 3.5% to 5.5%, which is still well within the 10% accuracy goal. The change in bias could possibly result from the new meteorological data source (MERRA) or differences in the validation profile set (V6 validation results include profiles acquired after V5 validation was completed). A bias increase of about 2% is unlikely to be significant to many MOPITT users.

L8.13: add that V6 (resp. v5) TIR/NIR are referred to as V6J (resp. V5J) in the figures. Terminology other confusing to the non-familiar reader.

Authors' Reply: Figure captions have been revised to clarify the terms V6T, V6N and V6J.

L8.18: same comments as in L8.11. It seems we trade accurate retrievals at surface for accuracy at 200 hPa in V6 compared to V5. What is the scientific justification for preferring higher accuracy at 200 hPa ?

Authors' Reply: A primary objective for V6 was to bring the biases at all levels to within the 10% accuracy target, since V5 TIR-only and TIR/NIR biases in the upper trop. clearly exceeded that value. Because of the effect of the 7D radiance correction factor on biases for both the upper troposphere and lower troposphere, it is impossible to reduce the bias in the upper troposphere without increasing the bias near the surface. Nevertheless, the validation results show that the bias improvement in the upper tro-

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posphere is more substantial than any degradation in bias near the surface. This is clear in both the NOAA and HIPPO validation results. Since MOPITT data are used for a wide variety of applications for which the relative importance of the retrieval levels vary, we do not place higher importance on any particular retrieval levels over any other levels.

L8.24: "This strategy is advantageous . . ." ,suggest to give an example to support better the statement, e.g. fire emission carbon budget ? If it could be verified already that v5 or v6 give a better estimate with external references, suggest to add a reference.

Authors' Reply: Given the wide use of MOPITT Level 3 products, it seems clear that many users of MOPITT products are satisfied with one-degree resolution, and therefore benefit significantly by retrieval averaging. A sentence has been added to emphasize the use and benefit of averaging in the MOPITT Level 3 products.

§3.2: It is noted that the period of validation is outside the period of application of CAM. It would be instructive to know here how the a priori CO profiles were built.

Authors' Reply: This comment again suggests the perception that the a priori varies from year to year, which is not the case. CAM simulations were used as the basis of a multi-year climatology which should be representative of the period of the MOPITT mission. See Authors' reply to comment L4.1-5.

L9.6: "A total of 567. . ." is it a result of some data thinning, quality control ? This should be explained if any.

Authors' Reply: Only profiles reaching 400 hPa or less were used for validation. This is now stated in the text.

L9.12: the altitude range covered reaches levels up to 150-300 hPa. How many actually spans 200 hPa ? For those stopping below, how were the reference profiles completed? With CAM again, as with NOAA flasks sampling ? This is important to know as here again, the improvements in v6 profiles are characterized at 200 hPa, as

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in the validation with the NOAA dataset where actually the reference mixing ratio is the a priori.

Authors' Reply: Additional details have been added to Section 3.2 with respect to the HIPPO profiles, including the number of profiles reaching pressures < 200 hPa (141 out of 567) and the method for extending the profiles to higher altitudes.

L10.15-16: the paper is only descriptive about the long-term drift. The authors should express an opinion on the origin of this source: in the a priori ? In the instrument itself ? in the auxiliary input data?

Authors' Reply: A short paragraph has been added at the end of Section 4.1 discussing possible sources of the residual bias drift. The a priori varies monthly but does not vary from year to year, so it is not clear how the a priori could produce long-term bias drift.

L10.25: "the bias drift is improved at 200 and 400 hPa but is otherwise similar" without further information (see previous points) it is hard to see conclusive improvement/gain here as the reference data are essentially the CAM a priori at these levels.

Authors' Reply: We disagree that the validation profiles have no useful information at 200 and 400 hPa (beyond the a priori) and therefore have no value for quantifying bias drift. See responses to L7.23 and L9.12 (above) and L11.16 (below).

L10.24: there is one "bias" too many

Authors' Reply: The extra "bias" on line 31 has been removed.

L11.5-11: same comments as above wrt analyses of CO VMR@200 hPa. Not clear how much the reference is independent measurements or the a priori itself. Furthermore, the authors are invited to give some possible reasons for the strong latitudinal variations and some hints as to how they will be addressed in future, as for climate applications for instance, this might be of importance.

Authors' Reply: As discussed in the previous response to L7.23, there is no sharp de-

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cline in retrieval sensitivity at 200 hPa. The latitudinal dependence of the bias is much weaker for V6 than for V5, but has not been thoroughly investigated. (See response to comment L5.23.)

L11.13-14: I agree. It would be useful to name the types of users who would benefit from the new version and those who may want to stay with previous releases.

Authors' Reply: Any such list would presume that we understand the specific tradeoffs relevant for each application of MOPITT data. The diversity of applications of MOPITT data makes this impractical.

L11.16: With the elements presented in the paper, I feel the reduced biases are essentially an effect of the priori and not of the retrieval. The results presented should include comparisons of the MOZART-CAM priors in v5 and v6 too, as well as averaging kernels of the retrievals at 200 hPa in both versions to be more conclusive.

Authors' Reply: The reduced biases in V6 products are clearly not the result of the new a priori. In the first place, a priori itself does not directly lead to retrieval biases because retrieved profiles are always compared with in-situ profiles that have been transformed with the relation:  $x_{sim} = x_a + A(x_{true} - x_a)$ . Thus, the a priori equally influences the retrieved value and the simulated value based on the in-situ profile. Second, if the retrievals at 200 hPa were heavily dominated by the a priori, there would be near-perfect correlation between the retrieved CO and the transformed 'in-situ' CO. This is not observed either in V5 or V6. Third, the effect of the 7D radiance scaling factor (described in Section 2.4) would have no effect on the bias if the retrievals at 200 hPa were completely constrained by the a priori information. This is also clearly not true. Finally, the new figure in the paper (described in the response to comment §3) clearly shows that the retrieval sensitivity at 200 hPa is comparable to the sensitivity at lower levels.

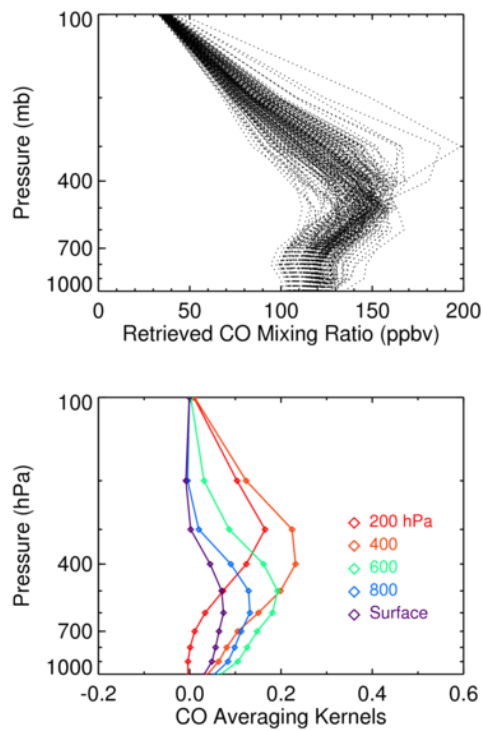
L11.21: The use of MERRA may limit the near-real time or even recent application, to be clarified.

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Authors' Reply: See previous response to comment §2.3 .

Interactive comment on Atmos. Meas. Tech. Discuss., 7, 6113, 2014.

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**Fig. 1.** V6 TIR-only retrieved CO profiles (top) and associated mean averaging kernels (bottom) for observations obtained on April 10, 2010 between 20 and 24 N, 160 and 156 W.

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