Atmos. Meas. Tech. Discuss., 7, C2404–C2412, 2014
www.atmos-meas-tech-discuss.net/7/C2404/2014/

Atmospheric Measurement Techniques
Discussions

Interactive comment on "Atmospheric composition and thermodynamic retrievals from the ARIES airborne TIR-FTS system – Part 2: Validation and results from aircraft campaigns" *by* G. Allen et al.

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Received and published: 29 August 2014

We thank both reviewers for their careful and expert consideration and review of our paper. We thank them especially for recognising the scientific merit of the work as both a technical resource on the capabilities of the ARIES instrument and the MARS algorithm; and the wider context surrounding retrieval and limitations for airborne infrared sounders.

Both reviewers have raised a number of useful specific suggestions and have offered

constructive critical comment with the purpose of improving the final manuscript. This has helped us greatly to improve the content of the revised paper here, especially in terms of clarity of text in places and figures. We will now address each of these comments in turn.

Reviewer 2 raises some very useful general and specific comments and suggestions to improve the presentation of the analysis. We have separated the general and specific comments and reply to them in turn below. Reviewer comments are shown in italics and our responses are in normal font immediately below each comment.

General comments:

1/ »In the retrieved profile figures, the comparison that is important is ARIES compared to the in situ convolved with the ARIES averaging kernel as compared to all error except smoothing error (as smoothing error is removed when the in situ data is convolved with the ARIES averaging kernel). It is hard to see this comparison on the plots because of the other quantities plotted in figures 7,9,14 and 15. The standard deviation on the a priori is particularly distracting. A comparison of a priori variability versus total error is seen in the (d) panel of the retrieval metrics figures. For temperature, errors on the order of 0.5K and above should be apparent on the plot but the scale does not allow this discrimination. The plot shown for temperature could be replaced by one where zero is the in situ convolved with the ARIES averaging kernel, or an additional plot could be added for this.

We assume that the reviewer is referring to the right hand (panel b) plots in the figures 7, 9, 14 and 15 highlighted in the comment. We agree that the a priori comparison in panel b for each parameter is not necessary as this can be seen readily in panel a, and diagnosed from panel d of the retrieval metrics figures. Therefore, we have removed the a priori profile from panel b in figures 7, 9, 11, 12, 14, and 15 for clarity as suggested. However, we have retained the in situ mean profile in panel b as we believe that being able to see the non-convolved in situ profile is still a useful illustration of the limitations of the MARS scheme as the convolved profile can be misleading when (and if) there is poor sensitivity, which could otherwise mask the inability of MARS to move away from the a priori (e.g. where averaging kernels and sensitivity are small). We also agree that the scale on the T retrieval profile comparison makes it hard to see the small error bars on this scale. We have taken the reviewer's suggestion of differencing the convolved profile with respect to the in situ profile

2/ »MACC is used for the initial guess and a priori. In the methane and ozone sections, comments are made about the MACC biases. The version of MACC used should be specified. I did not see the source of the water and temperature a priori in this paper (The Illingworth companion paper says these were from CAMELOT). A brief paragraph or table should be added to specify the prior for each species in one location. E.g. Table 2 could be augmented to include this information.

Thank you for these useful suggestions. We have now included the MACC version (version ii) used for a priori data for trace gases. Note that ECMWF reanalyses were used for T and H2O initialisation as described in Part 1. This information has also now been summarised in the revised manuscript. We have included a new Section 2.4 that describes the a priori dataset and links to Part 1 of the study as follows:

"A full description of the choice and source of a priori data used to initialise MARS can be found in Part 1. In summary here, temperature and water vapour profile priors were extracted from co-located ECMWF operational analysis fields produced by the ECMWF Integrated Forecasting System (IFS Cycle 29r2) on a 2.5deg $\times$ 2.5deg geospatial grid on 91 hybrid model levels. Trace gas profile priors were extracted from the MACC-II climatological dataset. For further details on prior surface properties (temperature and emissivity) and other auxiliary datasets, please refer to Part 1."

3/ »The "d" plots of the retrieval metrics are stated as log(error) which is confusing. This is actually regular error plotted on a log scale. The values are hard to parse. For example the text states "The total a posteriori retrieval error for individual retrievals

(orange line in Fig. 4d) in this example ranges between 1000 ppm (10%) at the surface and 120 ppm (22%) at 7 km." This would be much easier to read if it were not plotted with log scale. Also, the exact value of the small errors (e.g. less than 1 ppm) are not important and should not take up half the plot. Percent error for H2O also may be more useful.

We agree. Thank you for highlighting this. There was the potential for some confusion here. The scale was indeed absolute error plotted on a log scale. We have changed panel d in all retrieval metric plots to a linear scale as suggested to add clarity for the principal error components.

4/ »For all species with biases, the bias should be compared to the IASI bias. It is important that it is either very carefully characterized, or shown to be consistent with IASI if it will be used to augment IASI results.

We agree though the reviewer has slightly misinterpreted the purpose of our study. The ARIES dataset is not intended only to directly augment IASI results, though we do of course expect that to be a useful spin-off of this new airborne capability in the future. However, we have compared ARIES retrieval uncertainty to IASI general (statistical) uncertainty where possible from the literature, for wider context. We have added more detail on temperature and water vapour comparisons to IASI in our revised discussion. Comparisons to IASI uncertainty for temperature and water vapour are now further discussed in Section 4.2 and 4.3. We have modified and added new sentences to Paragraphs 1 and 4 of Section 4.2 discussing temperature to this end:

"...implicit to the a posteriori error calculation, which is consistently 0.6 K (Fig 6d) across the tropospheric profile and dominated by the smoothing and measurement uncertainty terms (Fig 6d). This compares favourably with typical singular retrieval uncertainty reported for IASI in the troposphere and represents a significant improvement at the surface (0.6 K between 800 mb and 300 mb, increasing to 2 K at the surface, Pougatchev et al., 2009)."

“From Table 3, we see that mean bias averaged across all flights is -0.7(±1.9 K), compared to a 2.1 K standard deviation in the in situ dataset. This bias is similar to reported temperature biases for IASI in the troposphere (±0.5 K between 900 mb and 100 mb, Pougatchev et al., 2009).”

We have also modified and added new sentences to the final paragraph of Section 4.3 discussing water vapour as follows:

“The individual profile uncertainty compares similarly with that reported for IASI (10

We have added a reference that discusses IASI validation, as follows: Pougatchev, N., August, T., Calbet, X., Hultberg, T., Oduleye, O., Schlüssel, P., Stiller, B., Germain, K. St., and Bingham, G.: IASI temperature and water vapor retrievals – error assessment and validation, Atmos. Chem. Phys., 9, 6453-6458, doi:10.5194/acp-9-6453-2009, 2009.

Specific comments:

»Abstract: specify aircraft height. Line 18: "Partial column mean biases". Partial columns between what elevations?

This refers to the weighted-mean bias over the partial column between ground and 9 km. We have amended this sentence in the abstract to more fully describe this as suggested as follows:

“Partial column mean biases (and 1σ bias) between the surface and 9 km, when averaged. . .”

»Line 20. Are the "typical a posteriori errors" the total error? For comparisons to in situ with averaging kernel applied, the error should not include smoothing error, see general comments. See also conclusions comments that more information is needed in the paper on the averaged results.

Yes, this is the total error at convergence. We have now included this term (total error)

in brackets in the text for clarity where “a posteriori” is introduced. We agree that including smoothing error is not useful when comparing the retrieved profile with the convolved profile. However, when comparing non-convolved in situ data with retrieved profiles, it is useful to include the smoothing error term when examining overlap within the errors in the profile. That comparison is a very important one (as discussed above) as it does not mask the inability of MARS to move from the a priori, which would otherwise look very good on its own (where vertical sensitivity might be poor). To make this distinction clear, we have added more detail in our discussion text to treat these 2 comparisons (and their different errors) separately (non-convolved -and -convolved in situ profile versus retrieved profile).

»Section 4.3, Temperature. line 16. "The AK peak at each altitude is only slightly dependent on information content from other levels and is typically smoothed over a 1 km length (when using 10 levels at 9 km flight altitude)." In reading this I would assume 10 distinct averaging kernel peaks. However, the full-width-half-max of the temperature averaging kernel is 2 km. Change this to +-1 km length or other such text.

We agree. We have changed this to the +/- 1 km description in this sentence by adding the tolerance symbol.

»page 3414 line 14 discusses temperature errors or biases on the order of 0.5-1K, however this is impossible to see on Fig 7.

Agreed. The scale on Fig 7 b has now been changed as described earlier and this can now be clearly observed.

»Section 4.4 line 13. Some explanation should be given as to why CH4 sensitivity peaks 2 km below the aircraft. I would assume that this is true only if the aircraft were between certain altitudes?

This is not a trivial explanation but it is given in Part 1 of the study (and now also discussed in the revised text). The reason for this peak is because of the optical depth associated with the strong versus the weaker absorbing methane lines across the wide spectral band used here for CH4 retrieval. While the strong lines (that produce the most spectral differential signal) saturate on length scales less than 1 km, the weaker lines saturate at various lengths between 1 km and the ground. The convolution of this information content from all spectral lines for CH4 creates an AK peak at 2 km below the aircraft mostly independent of aircraft height (in the troposphere). We have referred the reader to Part 1 for description of this effect in the revised text here.

We have added the following to the end of Para 1 of Section 4.4 to this end: "The reason for this is due to the optical depth associated with the strong versus the weaker absorbing methane lines across the wide spectral band used here for CH4 retrieval. While the strong lines saturate on length scales less than 1 km, the weaker lines saturate at various lengths between 1 km and the ground. The convolution of this information content from all spectral lines for CH4 results in an AK peak at 2 km below the aircraft mostly independent of aircraft height (in the troposphere)."

»Section 4.4 line 22. The in situ with the averaging kernel applied should be compared to the sum of all errors except the smoothing error as noted elsewhere.

Agreed, as discussed elsewhere. We have modified para 2 of Section 4.4 to read: "The total a posteriori uncertainty (Fig 8d) for independent retrievals is significant at 100 ppb (5%) of in situ concentration across the profile, which is again dominated by the smoothing and measurement (radiometric uncertainty) components. However, when comparing the convolved profile with the retrieved profile (where smoothing error should not be considered), we should note that the total uncertainty (dominated by the measurement term, see Figure 8d), is smaller at 20 ppb (1%) throughout the column."

»For CH4, ozone, and CO in situ, refer the reader to Table 1 for the instrument.

We are not clear on what/which part of the paper the reviewer is referring to here. The instruments used for validation are clearly described in Section 2.1 and 2.2 and linked to Table 1 there. It would be repetitive to do this each time in situ measurements are

referred to subsequently in the paper.

»Conclusions. The TCCON network is mentioned in the conclusion but nowhere in the paper. TCCON results do not seem relevant to this paper as they are total column results.

TCCON uncertainties and bias were clearly discussed in Para 3 of the Introduction. We have modified this sentence of our conclusion to read "Bias and flight-averaged repeatability compare favourably with previously reported remote sensing statistical accuracy of CH4 from the TCCON network (0.2%) and the MAMAP aircraft instrument (2%) and...", which not uses the biases from Toon et al., 2009 already discussed in the introduction.

»"Dataset-averaged a posteriori errors were 0.4%, 9.5%, 5.0%, 21.2%, and 15.0%, respectively." Which datasets are averaged? The numbers listed here do not appear in the text of the paper. A description of how these numbers is calculated should be included.

This statement refers to the overall means shown in Table 3, i.e. they are column-weighted averages for all flights from all campaigns as described in the discussion section. We have amended the following sentence in the Conclusions to make this clearer: "Dataset-averaged a posteriori uncertainties for singular retrievals were 0.4%, 9.5%, 5.0%, 21.2%, and 15.0%, respectively, representing a typical uncertainty for single ARIES FOV retrievals.".

Note also that these numbers are discussed explicitly and fully in turn for each parameter in Section 4 together with a description of how they are calculated (i.e. as sampling weighted means) but are only summarised in the conclusions.

»Figure 4 and similar. The Measurement and Parameter error colors are too similar.

We agree. Thank you for noting this. We have changed the colours to make this clearer.

»Figure 6b. The noise is obviously too large. The noise should be adjusted to a more realistic value

The noise envelope plotted in Fig 6b is confirmed as correct and it is realistic, corresponding to 0.1

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