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Atmospheric Measurement Techniques Discussions
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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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We thank Reviewer 1 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 1 raises some useful points that have helped us to revise and improve the manuscript. We address each point in turn. Reviewer comments are shown in italics with our response in normal font immediately below each comment.

Major points

1/ »"Important details on in-situ instrumentation used for the validation are missing, most relevant those about systematic uncertainties and sampling density. Are the systematic errors of the in-situ measurements taken into account in the analyses of the ARIES biases?"

A full description of the aircraft instruments used for validation and their respective sampling rates and uncertainties was given in Section 2.2 of the original manuscript. We believe this is clear and exhaustive for the parameters under investigation. The instrumental uncertainties were indeed taken into account when comparing within the uncertainty of the ARIES retrievals in the discussion sections; in those sections we compare the ARIES retrieval uncertainty and bias with the instrumental counterparts in order to properly understand the performance and accuracy of the MARS retrieval within the context of overall measurement uncertainty envelope (instrumental versus retrieval). We believe this comparison and discussion is clear and appropriate as it is currently presented.

2/ »"How was the in-situ data mapped in time and space to the vertical profiles or partial columns retrieved from ARIES data? What was the mismatch in time and space between the in-situ and the remote sensing data?"

This is an important question. There will always be a spatio-temporal mismatch be-

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tween in situ measurements and remote sensing from aircraft (as with any static or moving platform). Moreover, there is no singular spatial or temporal mismatch that can be calculated as the aircraft is always moving and the in situ measurements all map to the retrieved profile differently at any single point in time through the profile/column. This limitation was discussed in Section 3 for each of the validation campaigns/flights together with details on the retrieval comparison manoeuvres (e.g. vertical spiral profiles). We have also briefly discussed this source of bias when comparing the in situ and remote sensing profiles in the discussion (e.g. P3409). The important point here is that it is necessary to be able to assume that the spatial scales of transport and reactive chemistry (relative to the tracers in question here) are sufficiently small (or slow) such that the atmospheric composition does not change significantly in the time between in situ sampling and nadir retrieval from the top of the aircraft flight profile. We believe this assumption can be considered to be a reasonable one in our validation study as the maximum time and space between in situ sampling and retrieval is 35 minutes and 60 km; and airmass composition was not observed to change significantly over these scales in the in situ data obtained in each flight. As with any remote sensing validation, it is never possible to co-locate in situ measurement and retrieval exactly by the nature of the sampling/sensing and this introduces an unquantifiable uncertainty that must be minimised and rationalised (as has just been described). We have now included a new paragraph in the introduction to Section 3 (see below) describing this, as well as our rationale for safe assumption of airmass homogeneity. The new paragraph is:

“Sections 3.1 to 3.3 below describe the flights and campaigns in further detail with a focus on the validation manoeuvres and sampling principles as relevant to comparison to ARIES-retrieved data. More generally here it is important to note that there will always be a spatio-temporal mismatch between in situ measurements and remote sensing from aircraft (as with any static or moving platform). As with any remote sensing validation, it is never possible to co-locate in situ measurement and retrieval exactly by the nature of the sampling and this introduces a potentially unquantifiable uncertainty that must be minimised and rationalised. Moreover, there is no singular spatial or temporal mismatch that can be calculated as the aircraft is always moving and the in situ measurements (at various heights) all map to the retrieved profile differently at any single point in time through the column. The important point here is that it is necessary to be able to assume that the spatial scales of transport and reactive chemistry (relative to the tracers in question here) are sufficiently small (or slow) such that the atmospheric composition does not change significantly in the time between in situ sampling and nadir retrieval. This assumption is reasonable here as the maximum time and horizontal space between in situ sampling and nearest retrieval was 35 minutes and 60 km, respectively; and airmass composition was not observed to change significantly (less than the a priori variance) over these scales in the in situ data examined for each flight."

3/ »"The authors compare the quality and capabilities of retrievals from ARIES measurements at many places with those delivered by IASI, arguing that aircraft remote sensing can help to bridge spatial sampling scales between ground-based and satellite platforms. It would be a valuable complement to the paper if this was demonstrated by comparing collocated IASI results to ARIES and in-situ observations."

We agree that this comparison would be a useful study. However, we do not believe it is necessary or appropriate to include a tailored (co-located) IASI validation study in this work as it would add an alternative distracting focus, which would not stand coherently with the intended self-contained analysis of this paper, i.e. validation of the ARIES retrievals. Furthermore, we do not have co-located data with IASI beyond those collected during Jaivex and we can't therefore explore satellite validation across the range of environments that we consider here (i.e. from MAMM and ClearfLo). We will certainly consider this for future work however, where we can properly and appropriately present it in its own standalone study. However, we do already present brief comparisons to published IASI retrieval work and IASI retrieval statistics for the same parameters considered here is to add some wider context for the reader in this regard generally.

Minor points:

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»Please explain how observations from different observer altitudes have been combined to the mean profiles.

This was described on P3410 (paragraph starting on line 4). Flight-mean in situ profiles were calculated as averages of in situ data binned into 10 equidistant altitude layers. Mean retrieved profiles represent weighted mean profile and a description of this calculation is already explained in the text for retrieved profiles. Clearly, some layers have denser sampling than others (reflected in the one-sigma measurement variability shown as bars in the profiles). We have added the following sentence describing the in situ sampling density variation within section 4.1 where mean profiles are first discussed:

"In the case of the in situ mean profile, it should be noted that sampling density in each of the 10 layers may not be equal – this is captured in the one-standard-deviation red bars at each level in Figure 5b (and all similar figures for other retrieved parameters in the following sections)."

»p3408, l12: 'Sect. 2.3' should read 'Sect. 2.2 and 2.3' (?) Thank you – corrected.

»At several places you state the the residuals were 'featureless', which is in contradiction to some of the Figures, such as Figs. 4b, 8b, 10b. Furthermore, where do the 'spikes' in the NESR of Fig. 4b come from? How is the NESR from real atmospheric spectra calculated?

With the exception of Fig 10b (which we have not called featureless and discuss at length in Section 4.5), all other spectral residuals are within the NESR + radiometric uncertainty envelope. By "featureless", we mean that there is no structure in the spectral residual within this envelope. Any "apparent" residual structure within that envelope cannot be diagnosed and should be considered to be random with respect to the information content that the retrieval can provide, i.e. it should not be interpreted. However, the spikes in the NESR envelope in Fig 4b represent real uncertainties as they are part of the radiometric uncertainty that was found in the calibration of the ARIES instrument.

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This was due to small amounts of water vapour in the otherwise evacuated calibration cell used for this flight. In summary – these spikes are actually due to spectral effects of residual water vapour contamination in the calibration spectra. We have now included a sentence in Section 4. We have added a new sentence in Section 4.1 to state this as follows: "Note that the spikes in the black (noise plus radiometric uncertainty) spectrum in Figure 4b between 1360 cm-1 and 1400 cm-1 represent a real radiometric uncertainty due to spectral artefacts of residual water vapour in the calibration cell used for this flight."

»Panels cd of Figs. 4,8,8,10,13: Legends are hard to read, fonts too small. Agreed. We have overhauled all of these figures to make the font size larger, improve the plotting colour scheme, and also made the log scale on the error plots (panel d) linear for more clarity in response to other comments by reviewer 2. »A brief explanation of the various error components would be useful for people that have not read Part 1 of the paper and, in general those, who are not that used to retrieval error budgets.

We agree. We have now included a summary of this from Part 1 and included it where retrieval errors are first discussed in Section 4.1. This additional text is as follows: "Retrieval uncertainty components are shown in Figure 4d. Here (and in all analogous figures for other parameters in the remainder of this Section), the forward model parameter error is calculated along with a smoothing, measurement and systematic error, following the methodology outlined for a linear approach by Rodgers (2000) and described further in Part 1. The smoothing error represents the loss of fine structure in the retrieved state, the measurement error is derived from the total radiometric error of the ARIES instrument, and the parameter error is associated with the non-retrieval of parameters other than the target parameter. The systematic error is derived from the Level-1b processing of uncalibrated ARIES spectra."

We have also added the following reference: "Rodgers, C. D.: Inverse Methods for Atmospheric Sounding: Theory and Practice, World Scientific, 2000."

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»In the conclusions it is stated that the results compare well to ground-based CH4 measurements from the TCCON network, but neither a reference is given nor a comparison is shown in the manuscript.

This refers to the comparison with the nominal 0.2“Bias and flight-averaged repeatability compare favourably with previously reported remote sensing statistical accuracy of CH4 from the TCCON. . .”

»References: Part 1 paper: cite correctly (now published in AMT)

Corrected

»Table 2: Spectral ranges for H2O and CH4 retrievals are overlapping partly, I guess therefore, that CH4 is co-retrieved with H2O.

This is correct. H2O is always co-retrieved with any of the other parameters as discussed in Section 2 and in Part 1 of the study.

»Table 3: Check Figure caption.

Thank you. Typo spotted. Corrected to “. . .3) number of ARIES retrievals, 4) mean degrees of freedom for signal. . .”

Interactive comment on Atmos. Meas. Tech. Discuss., 7, 3397, 2014.

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Interactive Comment