

Response to the Referee comments for manuscript Nr. amt-2023-86

Original questions/comments of the referees are marked by **RC:** and set in *italic font*.

Replies to the questions and comments by referee #1, Hugh C. Pumphrey

RC: *The measurement of water vapour in the stratosphere is an important and difficult process; the comparison of the various ways of achieving it is an important task. This paper takes on that task and does so with a great deal of care and of attention to detail. It should be published, subject to some minor corrections, mostly to do with the figures.*

Reply: We want to thank Hugh Pumphrey for his good opinion of our work and for his helpful comments on several aspects of the presentation.

RC: *Most figures: it would be an improvement if all figures with a logarithmic pressure axis had that axis labelled in the same way. As it is, some figures (e.g. B1) have many labelled ticks between 100 and 10 hPa. Some have many ticks but few labels (e.g. Fig A4, right column) while others (e.g. fig A4, left column) have no labels or ticks between 100 and 10 hPa.*

Reply: A more harmonized scheme for the logarithmic pressure axes will be applied.

Action: A more harmonized scheme has been applied to all plots with pressure axis.

RC: *Figure 1: The colour used for SGP/HUN/FTS is very similar to that used for TMF/LSA/HOU. The authors might like to consider revising their colour scale to ensure that all groups of three stations which share a colour are easily distinguished from the other groups.*

Reply: However the colours strongly depend on the medium, several changes in the color table will be implemented to attempt to render the colours more discriminable.

Action: Changes in the color table have been implemented to render the colours more discriminable.

RC: *Figure 2 (and every other figure which shows SAGE-III) data: The pure yellow colour used for SAGE-III is almost invisible against a white background. Another colour should be substituted.*

Reply: For reasons of consistency with the WAVAS II papers published already, we prefer to keep this specific colour for SAGE-III.

Action: None

RC: *Figure 4: The size of the left-hand panel, and the scales used, makes it quite hard to see both the MLS and TMF data clearly.*

Reply: We shall change the vmr-axis range and use a different method of presenting the standard deviations in the leftmost panel.

Action: Figure 4 has been changed accordingly.

RC: *Figure 5: It might be helpful to the reader to add the latitude of BLD to the caption to save the reader having to look back to Figure 1 to work out whether the station is tropical or not. Alternatively, this information could be in the running text at line 283, as has been done for HIL at line 297. The figure and the symbols in it are rather small; the authors might consider making the figure wider (there is plenty of sideways space on the page) or making it a single column figure with the two panels one above the other.*

Reply: BLD latitude will be added in caption and running text. Figures of this type will be made wider and the symbols will be enlarged.

Action: BLD latitude has been added in caption and running text. Figures of this type have been made wider and now show enlarged symbols.

RC: *Figure 7: The caption might remind the reader to look at figure 1 for the meaning of the colours and symbols.*

Reply: The caption will be changed to remind the reader to look at figure 1 for the meaning of the colours and symbols. Additionally, the symbols, together with their corresponding three letter codes, have been added to the figure.

Action: Colours/symbols and the three letter codes have been added to the figure and the caption has been changed accordingly.

RC: *Figures A1 to A3: The running text includes nearly five pages of text discussing these figures. It therefore does not seem appropriate to relegate them to an appendix.*

Reply: We think it to be simpler (for the reader) to have text and plots separated. If a hardcopy is used, the corresponding text and figures pages can be held side by side. If the digital version is used, opening a second copy of the paper and placing the windows side by side is easy. Mixing of text and figures would force the reader to many unnecessary scrolling actions, skipping interspersed text/figures in search for corresponding information. So, we'd prefer to stay with the current layout.

Action: None

RC: The referee had listed several technical corrections.

Action: All technical corrections were justified and have been addressed in the revised manuscript.

Replies to the questions and comments by referee #2, Xin Zhou

RC: *The long-term changes in the stratospheric water vapour and its climate impacts have long been one of the key science questions for the climate community. Validation of satellite data is fundamental for it. The authors provide a comprehensive and careful comparison of all available satellite data records from 2000 to 2016 to FP data. These results would be very useful for future studies on stratospheric water vapour using satellite measurements. I am in favor of publishing the paper after the following points have been considered.*

Reply: We want to thank Xin Zhou for his good opinion of our work and for his helpful comments on several aspects of the presentation.

RC: *Line 26: "Ding-Zhu et al. 2015" in text and its reference are in incorrect format, which should be changed to "Hu et al., 2015"*

Reply: Thanks for pointing this out! Citation and reference will be corrected.

Action: Citation and reference have been corrected.

RC: *Figure 1: The legend is confusing. It seems only RVM has two locations due to the ship cruise. In this case, it is better to only use one marker for each station except two for RVM in the legend.*

Reply: We shall use single symbols in the legend and add some caption text to clarify the special case of RVMirai.

Action: Legend and caption in Fig. 1 were changed accordingly.

RC: *Line 154: "Therefore we have decided to minimize the contribution of natural variability using this method..." What is the natural variability here? Is it the internal variability of water vapour itself? Why using the closest satellite profile can minimize the contribution of natural variability?*

Reply: The assumption simply is, that, on average, deviations of water vapour with respect to values at a given location and time increase with spatial and temporal distance. So, with decreased distance, again on average, we can hope to reduce this contribution to the overall deviations.

Action: None

RC: *Line 202: "Comparison of the two profiles, with the FP data simply interpolated to the coarser grid of the satellite instrument, but not smoothed (black diamonds), is misleading since the MIPAS instrument is unable to solve the sharp feature in the profile." I understand the reason, but the "truth" is compromised due to MIPAS current capability.*

Reply: We do not quite understand the comment. The referee is right in stating that

the "truth" is compromised due to MIPAS' current capability. This holds for all SATs and virtually for all remote sensing measurements. For our comparisons we assume that the "truth" is much more closely represented by the FP measurements. In essence, we consider it to BE "the truth". As we state in the manuscript (lines 204-207): "By application of the averaging kernel and a priori profile to the FP profile according to Eq. 5 (...) the FP profile is transformed into the profile the satellite instrument would measure if the hygrometer profile was the truth." So, there is no question as to whether the SATs can see the truth. However, since they can not, we do the best what can be done: apply (smoothing) kernels to the FP data to render the both types of data sets better comparable.

Action: None

RC: *Figure 4: The grey and blue lines and shadings overlapped with each other, making it not easy to distinguish between the two.*

Reply: We shall change the vmr-axis range and use a different method of presenting the standard deviations in the leftmost panel.

Action: Figure 4 has been changed accordingly.

RC: *Line 273: "Below 100 hPa, close to the tropopause it has a sharp peak of -25 %." Why MLS has a negative bias, instead of positive, relative to the FP when it cannot resolve the sharp water vapour decrease (as suggested by Figure 3)?*

Reply: There are several factors which contribute to this behaviour. The station BIK (used in Fig. 3) is a tropical site, i.e. the tropopause/hygropause is 1) quite high in the atmosphere, and 2) therefore usually shows a sharp minimum of temperature and water vapour vmr. At non-tropical sites, the tropopause/hygropause is by far not as sharp. Therefore, one would not expect a strong positive bias peak at the TMF site at altitudes above the tropopause. Moreover, the MLS data presented in Fig. 4, and discussed in Sect. 3.2, already has underwent the convolution procedure with the appropriate kernel, which, as Fig. 3 illustrates, considerably decreases the problems caused by incompatible vertical resolutions of satellite and FP profiles. The general picture can be gained from Figs. 19 of the supplement: A negative bias of MLS just above the tropopause can be seen in almost all FP sites of moderate to high latitudes, e.g., NYA, SOD, LIN, BLD, BEL, LDR (see supplement, Figs. 19). Actually, as can also be seen in Figs. 19 of the supplement, MLS shows a positive bias just above the tropopause at BIK, and at other tropical sites, e.g. TRW, KTB, RVM. All in all, we are confident that the comparisons between properly convolved FP profiles and satellite data are sound and reliable.

Action: None

RC: *Figure 7: It may be worth to put the symbols for FP stations on the plot to save*

the readers' effort to go back to Figure 1, and likewise for Figure 5 and Figure 6.

Reply: OK, will be done.

Action: Done

RC: *Line 321: Add a space between "within" and ""*.

Reply: OK, will be done.

Action: Done

RC: *Figure A1-A3: These plots in Appendix seem to be essential to the paper.*

Reply: We think it to be simpler (for the reader) to have text and plots separated. If a hardcopy is used, the corresponding text and figures pages can be held side by side. If the digital version is used, opening a second copy of the paper and placing the windows side by side is easy. Mixing of text and figures would force the reader to many unnecessary scrolling actions, skipping interspersed text/figures in search for corresponding information. So, we'd prefer to stay with the current layout.

Action: None

RC: *Figure 8: Some of the bars exceed the x-axis limit.*

Reply: Yes; the focus was to show in some detail the values for the many good performing instruments. However, all values used for Fig. 8 can be found in Tables 3 and 4.

Action: None

RC: *Figure 11 and Figure 12 are somewhat in contradiction. Figure 11 suggests that "MLS-FP time series show little or no evidence of drift until 2010" at 68 hPa, but Figure 12 is showing significant positive drifts at this level for the full records from 2004 to 2016. It would be helpful to provide the profiles of drifts for each of the two periods.*

Reply: We will add a panel (b) to Figure 12 that shows the vertical profiles of drifts for the pre-change point period of each MLS-FP record of differences. This should make it clear that most of the drifts from 2004 to 2010 were not positive and statistically significant, while most of the post-change point drifts, (then shown in panel (c)) are.

Action: Fig. 12 has been changed accordingly.

RC: *Line 899: "Four SATs had mean drifts with magnitudes $> 2\% \text{ yr}^{-1}$ in one pressure interval ..." It is more straightforward to just name them here.*

Reply: Will be changed to "GOM, HAL, MST and MOM had mean drifts with magnitudes $> 2\% \text{ yr}^{-1}$..."

Action: Text has been changed.

Further changes to the manuscript

1. Some parts of the text have been rewritten to be more precise (see, e.g., caption of Fig. 17, or the section on SG2 (SAGE II) in the drift section.
2. The manuscript section "Summary and conclusions" has been re-ordered (see difference file) and some statements therein have been rewritten to be more precise.