Trajectory mapping of middle atmospheric water vapor by a mini network of NDACC instruments

M. Lainer, N. Kämpfer, B. Tschanz, G. E. Nedoluha, S. Ka, and J. J. Oh

---

Response to comments from Referee #2 on ACPD paper acpd-15-12777-2015:

Dear Referee #2,

Thank you for reviewing our paper "Trajectory mapping of middle atmospheric water vapor by a mini network of NDACC instruments". We highly esteem your comments and try to answer your question, concerning MLS climatologies as a priori profiles in the water vapor retrievals, and discuss about the result of your suggestion to assess errors (e.g. wind, chemistry, removal from condensed phases) of the TM approach. Your Referee comments are colored in blue and our answers remain in black font color. Since this response is submitted during phase 1 (open discussion) of the interactive discussion, the author's changes (beyond typos) to the manuscript are not included yet, but will follow in phase 2 (final response).

It appears that all these ground based microwave sensors use MLS climatologies as an apriori. What is the climatology used? Is it some kind of a seasonal average, mission average, or? There is the issue that at some level we could be comparing MLS data to itself depending on how sensitive the results are to the apriori. Also given that the vertical resolution is on the order of 10–15 km, one might want to smooth the MLS (typ < 6 km) with the GB averaging kernel.

The H_2O a priori vertical profile information x_a for the instruments MIAWARA, MIAWARA-C and SWARA is based on the same climatology. x_a is taken from a monthly mean zonal mean climatology using Aura MLS version 2.2 data from 2004 to 2008. The MLS climatology for the instruments in Hawaii (WVMS6) and Table Mountain (WVMS4) is based on version 3 data taken from August 2004 to March 2011 within ±2° latitude and ±30° longitude of each observation site. For each day-of-year the data is averaged over ±5 days.

We agree with the reviewer that if there were a large a priori dependence in a retrieval then one would to some extent "compare Aura MLS data to itself". Since our paper manuscript gives not sufficient information about the measurement response, we will improve this issue. The numbers given in the following consider the year 2012, when the 4 presented TM cases took place. For Table Mountain and the corresponding a priori contributions, or vice versa measurement responses, we refer to Nedoluha et al. (2011). At Mauna Loa the validation of the data variations down into the lower stratosphere is still missing, which is why it is grayed out in Figs. 1-2 of the paper. Data from the

Mauna Loa radiometer (WVMS6) below 5 hPa is not used in the TM case studies. The instruments providing measurements down to 10 hPa (MIAWARA and WVMS4) have commonly a priori contributions of less than 25 % (20 % for WVMS4) at this level. The only critical atmospheric layer used, in terms of a priori contributions in the retrievals, of SWARA and MIAWARA-C goes from 2–4 hPa. There is a transition from $\sim$ 50 % (at 4 hPa) to $\sim$ 20 % (at 2 hPa) of the a priori contribution. At higher altitudes the measurement response is widespread above 80 %, considering data from 2012. The SWARA H_2O retrievals sometimes show a priori contributions up to 40 % between 0.05–0.3 hPa in the summer months. As it is not clear enough in Section 2 (Data and methods) we will clarify the different behaviors of the retrievals (measurement responses) to come up with the chosen data omissions (grey bars in Figs. 1–2) for the TM. In order to illustrate the properties of the measurement response over a longer time period and altitude range, Fig. 1 is presented.

Regarding the a priori influence another parameter, the a priori covariance matrix S_a, has to be mentioned. The error of the a priori profile is defined by this matrix and the strength of the constraint of the retrieved profile to the a priori profile is controlled by it. S_a is defined as the standard deviation and the correlation length giving the distance over which the correlation (Gaussian shaped curve) between two pressure levels decreases below 30 % (Haefele et al., 2009). The values for the standard deviation and correlation length are carefully chosen to ensure a stable and sensitive water vapor retrieval.

We conclude: The fact that Aura MLS H_2O climatologies serve as a priori profiles in the 5 ground-based retrievals, which are compared to MLS after application of our TM method, is of minor relevance as we do account for bad profile sections and therefore confine the comparison of TM data where the contribution of the a priori is most of the time low. We will improve the manuscript accordingly.

Smoothing (convolving) the MLS data with the averaging kernels of the instruments is a point to be discussed. If a direct comparison between distinct profiles of two different instruments (different spatial resolutions) is done, we agree that a smoothing should be applied. But since data are averaged zonally or within a $\pm 2°$ latitude and $\pm 30°$ longitude area in the generation of the a priori profiles over several years, any fine structure would disappear and smoothing them with the GB averaging kernel would not have much of an effect. We mention also that there are no sudden changes with altitude in the MLS vertical profiles which we use for a climatology.

The authors discuss potential sources of uncertainties such as wind errors, chemistry, and removal from condensed phases (e.g. mesospheric clouds). A simple assessment of such errors could be done by taking MLS measurements near the 5 sites and advecting those profiles through the analysis performed and comparing the mapped fields to MLS. The histogram plots should provide an estimate of error and limitation of the trajectory analysis.

We gratefully acknowledge your suggestions and briefly summarize the strategy and outcome of the new investigation to estimate the error and limitation of the trajectory mapping (TM) approach. In a first step Aura MLS profiles are taken, located near the five ground-based observation sites. The chosen spatial coincident criterion was 600×300 km from the measurement locations. The 300 km go along north-south direction, while the 600 km go along east-west because zonal horizontal water vapor gradients tend to be much smaller than meridional ones. We applied a similar way of data processing to the new obtained MLS profile time series (see Sect. 2.4 in the paper). It is evident that we did not apply correction factors to account for biases, since the same instrument is used to generate the profiles. Finally we will show a similar histogram chart plot (here, Fig. 3) as for the ground-based data comparison (see paper Fig. 8, here Fig. 2). For the three pressure layers at lower altitudes (12–8, 3.5–2.5 and 1.3–0.7 hPa) it is found that deviations from the coincident domain comparison never exceed 20 %. Approximately 2/3 of all domains show less than 10 % deviation. The errors become significantly higher in the mesosphere (0.13–0.07 hPa). Estimating the position of the 2/3 value of the domains in the bar charts, it is now roughly within $\sim$ 20 % (doubled). Additionally, we now show the standard deviations $\pm\sigma$ associated to the normal distributions in Fig. 3. It is clear that the uncertainties of the TM are largest in the mesosphere (0.13–0.07 hPa) of case study A (2012-02-28). Noticeable, TM during the SSW case D (2012-01-17) reveals less uncertainties (σ is smaller).

Compared to the real TM cases, there is not much of a difference observed in Fig. 3, which is a sign that we obtained an optimal result respecting the errors of wind, chemistry or removal from condensed phases, which cannot be avoided.

Within the revised version of our manuscript we will add a paragraph in Sect. 3.5 (Validation and statistical analysis with MLS) that describes the new performed error analysis.

Minor

Page 12788 line 1 change on NetCDF to in NetCDF page 12792 line 10 change come up with came up page 12795 line 3 it appears to me that the data gap is south of the vortex.

- Page 12788, line 1: We changed “on NetCDF” to “in NetCDF”
- Page 12792, line 10: We changed “come up” to “came up”
- Page 12795, line 3: You are right and we changed “north” to “south”

Table 2 agree within

- Table 2: We applied the change in the caption; “agree to with” reads now “agree within”

References

Haefele, A., De Wachter, E., Hocke, K., Kämpfer, N., Nedoluha, G., Gomez, R., Eriksson, P., Forkman, P., Lambert, A., and Schwartz, M. (2009). Validation of ground-based microwave radiometers at 22 ghz for stratospheric and mesospheric water vapor. *Journal of Geophysical Research: Atmospheres (1984–2012)*, 114(D23).

Nedoluha, G. E., Gomez, R. M., Hicks, B. C., Helmboldt, J., Bevilacqua, R. M., and Lambert, A. (2011). Ground-based microwave measurements of water vapor from the midstratosphere to the mesosphere. *Journal of Geophysical Research: Atmospheres*, 116(D2):n/a–n/a. D02309.

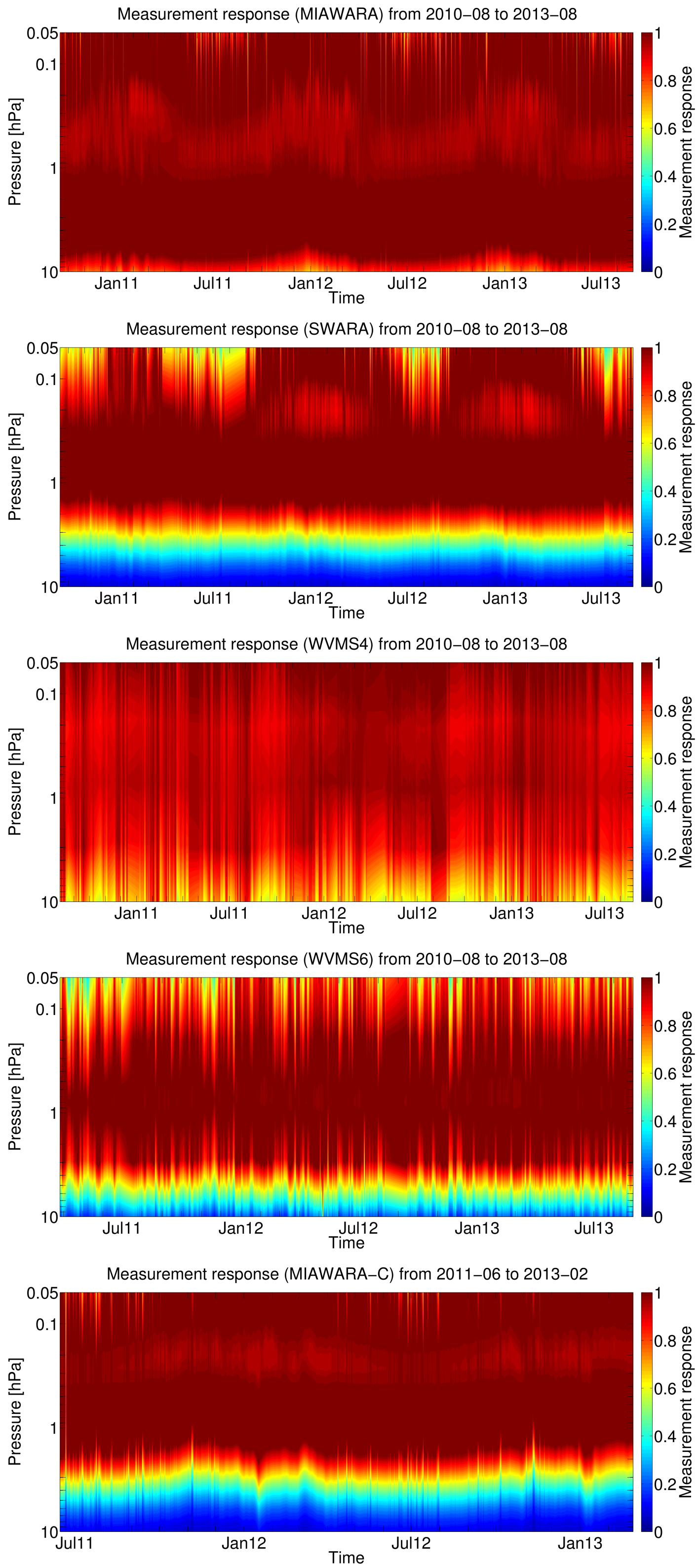

Figure 1: Measurement response of ground-based H_2O retrievals within the time periods from 2010-08 to 2013-08 (MIAWARA, SWARA, WVMS4 and WVMS6) and from 2011-06 to 2013-02 (MIAWARA-C). The contour plots show the results between 0.05–10 hPa.

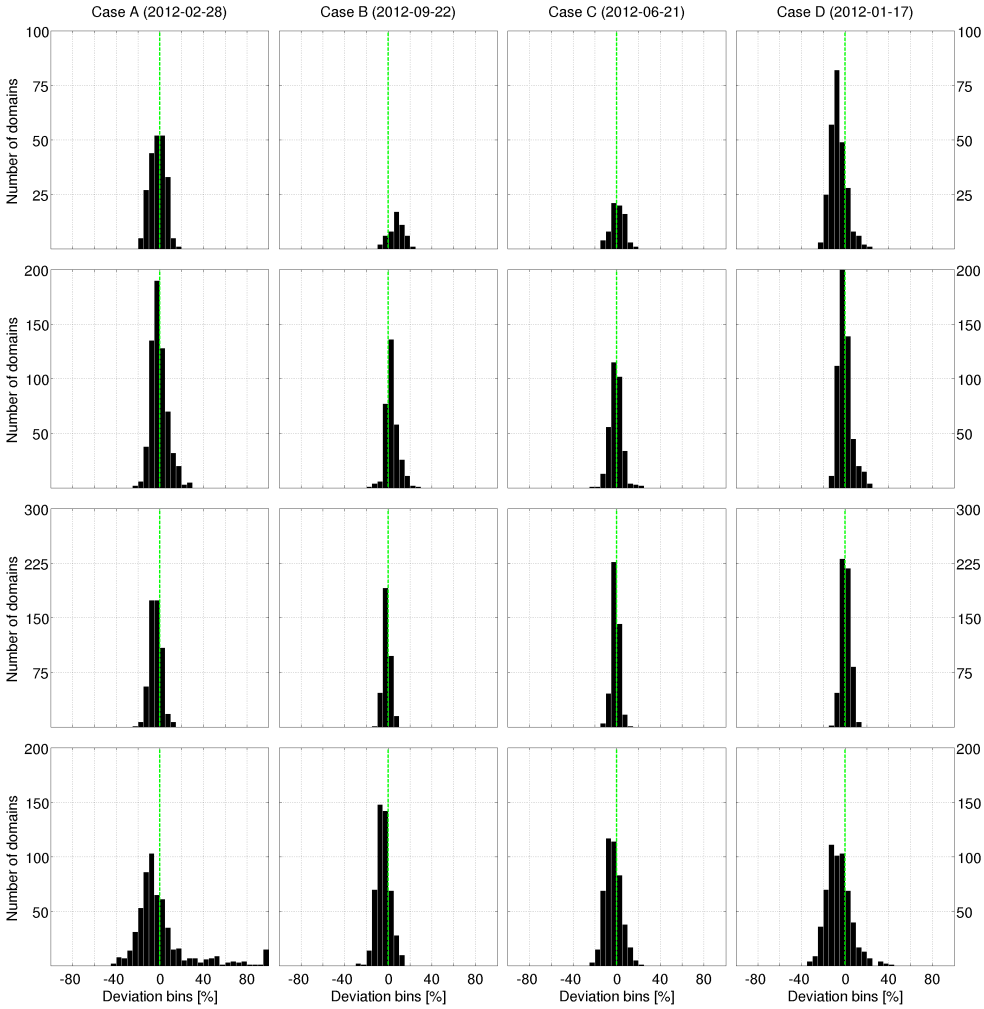

Figure 2: Pressure layer corresponding histograms of TM case study A (2012-02-28, first column), B (2012-09-22, second column), C (2012-06-21, third column) and D (2012-01-17, forth column). The number of relative difference (TM − MLS) domains in a certain deviation bin of a width of 5 % between TM and Aura MLS solution is shown. From top-down the pressure layers are 12 − 8 hPa, 3.5 − 2.5 hPa, 1.3 − 0.7 hPa and 0.13 − 0.07 hPa. Vertical green lines indicate zero deviation.

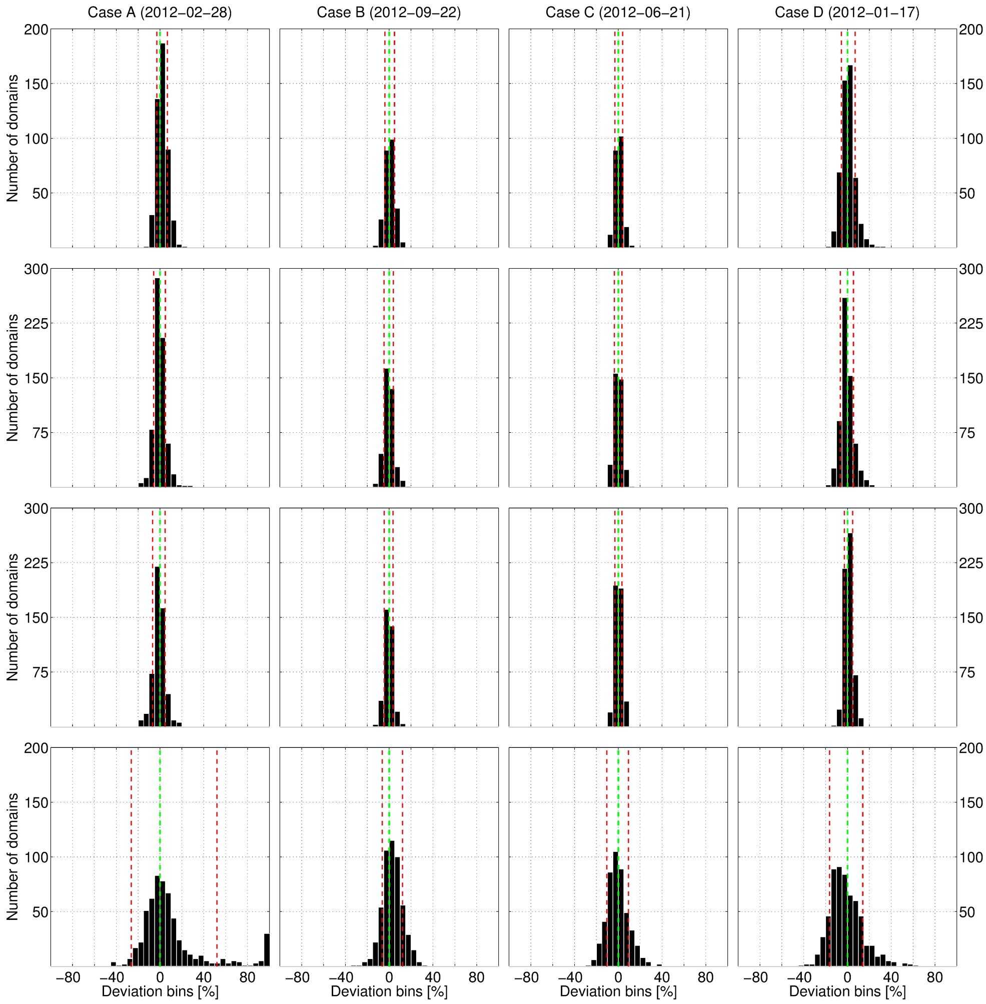

Figure 3: Histogram charts for estimating TM error. MLS water vapor profiles obtained near the five real ground-based measurement locations are advected. The 4 shown cases are temporal equivalent to the ground-based TM cases (e.g. Fig. 2). The number of relative difference ($TM_{MLS} - MLS$) domains in a certain deviation bin of a width of 5 % between $TM_{MLS} - MLS$ and Aura MLS solution is shown. From top-down the pressure layers are 12 − 8 hPa, 3.5 − 2.5 hPa, 1.3 − 0.7 hPa and 0.13 − 0.07 hPa. Vertical green lines indicate zero deviation and red dashed lines mark the standard deviations ($\pm\sigma$).