Author Response to Review of

Tropospheric water vapor: A comprehensive high resolution data collection for the transnational Upper Rhine Graben region

Benjamin Fersch et al.
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RC: ***Reviewer Comment***, AR: *Author Response*, ☐ Manuscript text

Dear Minyan Wang,

we would like to thank you very much for taking the time to review our work. Our answers to your comments are as follows:

RC: ***1. In the introduction, your response "We will scan the available literature for recently published work", why the references is not updated?***

AR: *In the revised version of the manuscript we have added 5 additional references to the introduction (L29-38) to mention studies that combine either of the methods for determining trophospheric water vapor fields. This was also stated in our authors response (revision, but not interactive discussion). In the color-marked changes PDF, the additional references were not printed in red. We have now listed them here explicitly. These were the publications we could find. If you have any further suggestions for publications to be included we kindly ask you to provide the specific references.*

> Combining high temporal GNSS measurements with satellite products with low temporal but high spatial resolutions is obvious. Furumoto, Kurimoto, and Tsuda 2003 applied GNSS water vapor measurements with radio acoustic soundings to improve water vapor profiles. Lindenbergh et al. 2008 combined Medium Resolution Imaging Spectrometer (MERIS) satellite data with GNSS data based on kriging techniques and Leontiev and Reuveni 2018 used cloud fractions derived from Meteosat-10 to improve GNSS IWV interpolation. The assimilation of GNSS measurements in atmospheric models to reduce uncertainties of water vapor simulations is another promising approach which is widely used (see Wagner et al. 2022 for compilation) and also the assimilation of InSAR derived water vapor data can improve the spatial skill of precipitation forecasts (Mateus et al. 2021). Although the combination of single observational product types with local area atmospheric modeling is common, the rigorous fusion of multiple data sources with modeling has not been documented to our knowledge so far.

References

Furumoto, J., K. Kurimoto, and T. Tsuda (2003). "Continuous Observations of Humidity Profiles with the MU Radar–RASS Combined with GPS and Radiosonde Measurements". In: *Journal of Atmospheric and*

Oceanic Technology 20.1, pp. 23–41. DOI: 10.1175/1520-0426(2003)020<0023:COOHPW>2.0.CO;2.

Lindenbergh, Roderick et al. (2008). "High resolution spatio-temporal water vapour mapping using GPS and MERIS observations". In: *International Journal of Remote Sensing* 29.8, pp. 2393–2409. DOI: 10.1080/01431160701436825.

Leontiev, Anton and Yuval Reuveni (Oct. 2018). "Augmenting GPS IWV estimations using spatio-temporal cloud distribution extracted from satellite data". In: *Scientific Reports* 8.1, p. 14785. ISSN: 2045-2322. DOI: 10.1038/s41598-018-33163-x.

Mateus, P. et al. (2021). "Continuous Multitrack Assimilation of Sentinel-1 Precipitable Water Vapor Maps for Numerical Weather Prediction: How Far Can We Go With Current InSAR Data?" In: *Journal of Geophysical Research: Atmospheres* 126.3. e2020JD034171 2020JD034171, e2020JD034171. DOI: 10.1029/2020JD034171.

Wagner, Andreas et al. (Apr. 2022). "Assimilation of GNSS and Synoptic Data in a Convection Permitting Limited Area Model: Improvement of Simulated Tropospheric Water Vapor Content". In: *Frontiers in Earth Science* 10. ISSN: 2296-6463. DOI: 10.3389/feart.2022.869504.

RC: ***2. The response on the treatment of clear/cloudy circumstances or precipitation, why it goes to the assimilation time window of 1 hour? It is not the direct response in this study.***

AR: *In our study, we use an hourly assimilation time window to correct for the fluctuating concenctrations of water vapor that remain mostly unmached in the free running models. However, it is also important to consider that by the assimilation of integrated profile observations from GNSS and InSAR, information about vertical variability is lacking (and estimated by the model). As the results indicate, the combined assimilation of GNSS, InSAR, synoptic stations, and collocation leads to the best perfomence measures (except for summer) as it maximizes the information content for time and space.*

To make this point also in the paper, we have updated subsection 3.4 as follows:

> To tie the simulations closer to measurements, all assimilation input data except InSAR data was assimilated on an hourly basis. This is particularly useful when the variations in water vapor in the lower atmosphere are more complex due to dynamic weather conditions.

and in the conclusions section we have added:

> Although WRF and tomography also provide water vapor profiles, the underlying water vapor measurements are column values only. In the case of very dynamic humidity conditions, for example, the assimilation of water vapor profiles may further improve the simulations.

RC: ***3. Figure 3, the information of latitude N and longitude E is still not in it.***

AR: *We have updated the axis annotations of Fig. 3 as suggested.*