Review of: **Water vapor estimation based on one-year data of E-band millimeter-wave link in the northeast of China** by Siming Zheng et al.

Ruben Imhoff

Ruben.Imhoff@deltares.nl

November 15, 2021

Summary

The authors present a case study where they use high-frequency microwave link attenuation data for water vapor density estimations using one microwave link in Hebei, China. The study is based on one-year of 1-min E-band millimeter-wave link data and the resulting water vapor density estimations are compared to observations from a weather station placed at the transmitter of the link setup. Using the equations from the ITU-R technical note, the authors manage to produce water vapor density estimations from the link attenuation that resemble the observations well, and that on a relatively high temporal resolution. I would like to thank the authors for a clear and straightforward study and a concise manuscript, which gives scientifically relevant outcomes, in my opinion.

Despite my enthusiasm about this study, I also have quite some (sometimes substantial) points for improvement and questions. What I think is currently lacking in the manuscript, is twofold:

1) The authors use the ITU-R equations for water vapor density estimations using link attenuation as input. This is, however, an application of that method and not a new method. That is on itself not a problem, but the authors claim to have improved the model, while the improvements are not clearly stated in the manuscript. I think it would be valuable to clarify this.
2) A discussion section in which the results of this study are benchmarked, related to existing literature and where possible pitfalls and improvements can be further explained.

Below you can find an extension of my general comments, followed by specific comments (line by line) and some technical corrections.

General comments

Water vapor density estimation procedure

The water vapor density estimation procedure is based on the ITU-R technical note. The authors mention already in the abstract that they have based their estimation procedure on the equations in this technical note and that they have used an improved method of extracting the water vapor induced attenuation value. To me, it was not directly clear at which point the authors introduce their improvements on the method(s). Can I ask the authors to clarify this in the manuscript? I.e., did the authors only use an existing method and apply this for a test case or did they improve the method (both are scientifically relevant, but will lead to different statements in abstract and conclusions).

In addition, the ITU-R recommended method is used in this work and written down in equation 4 (based on eq. 1 in the reference). Only equation 4 is, however, not sufficient to solve the equation. For that, the set of equations (eq. 1 – 9 in the ITU-R technical note) are needed. As this method is so dependent on these equations, I think it would be valuable to state them in the manuscript as well, including some explanations and correct references to the ITU-R equations. Finally, the end goal is to estimate the water vapor density ρ when the attenuation is known. Although this indeed follows from the set of equations, it would be useful to add a final equation showing how ρ is computed from the other terms.

Model benchmarking

What I have missed, is a benchmark for comparison with the estimation results. The authors regularly talk about good model results, but good compared to what? I am not sure if this will be outside the scope of this paper, but a comparison with some other estimation techniques would be very relevant information and could strengthen the statements made in the paper. For instance, how do the estimation results relate to model estimates from e.g. ECWMF forecasts or local NWP forecasts, etc.?

Besides, the least the authors probably can do, is to discuss the relationship to and expected results compared to other microwave link attenuation-based water vapor estimation techniques, such as those introduced in: Alpert and Rubin (2018), David et al. (2009, 2019), Pu et al. (2021) and Fencl et al. (2021).

Discussions section

In line with my previous comment about missing some discussion about the relationship to other literature and estimation techniques, I miss a discussion section in this work. It would be very insightful to get more information on reasons for any estimation-observation discrepancies we see. As mentioned before, how do the results relate to other literature? And, what is the authors' view on possible improvements?

Specific comments

Lines 50 – 55: Here the authors introduce the millimeter wave / commercial microwave links. Can I ask the authors to briefly introduce what they are, what they are used for and how atmospheric processes can attenuate the signal? This might be relevant introductory information for a more general audience.

Line 53 – references: This may require some extra references, e.g. (but absolutely not a complete list – but that is probably also not necessary): Messer et al. (2006), Leijnse et al. (2007), Zinevich (2009), Overeem et al. (2011), Chwala et al. (2012), Doumounia et al. (2014), Uijlenhoet et al. (2018), Fencl et al. (2020).

Lines 62 – 63 "In this study, we used the method of estimating water vapor based on the ITU-R model": Could the authors briefly introduce this method here (just in words)? The authors further elaborate on the method in the methods section, but it may be helpful for readers of the paper to get a first idea of what this model is and does.

Lines 64 – 65 "Compared with the previous method, the time resolution of the retrieved water vapor density value is improved, and the estimation error is reduced.": What was the time resolution and estimation error in this ('the previous') method, and what was the length of the link path?

Lines 78 – 80: What kind of microwave link was used, i.e. commercial or for research, which brand, etc.?

Lines 85 – 90: Could the authors provide a little more information about the weather station? On what elevation was it placed, also relative to the microwave link, was the measurement setup according to WMO standards, with what frequency is data collected? How representative are the measurements for the link path? The link path crosses a river, which may result in a slightly different humidity than what is measured at the weather station at the (seemingly) more urban site (but do correct me if I am wrong - I would like to see the authors' thoughts on this).

Lines 97 – 98 "median values": A question more out of interest, would it be helpful to also use other statistics of the received signal or even the full signal to get an idea of the uncertainty in the estimation process?

Lines 107 – 108 "Since the quantization resolution of the equipment we have used is 1 dB and the quantification resolution of the water vapor density calculated by the weather station is 0.01 g/m, the resolution of the two data is inconsistent.": Could the authors elaborate a bit on this, also taking into account the length of the link path?

Lines 110 – 113: The moving average makes sense, I think. Have the authors, however, tested other moving window averages? I.e., where is the optimum and can we even go to higher temporal resolutions?

Lines 176 – 178 "We collected […] water vapor density.": This belongs in the methods section.

Lines 190 – 191 "There are many reasons for the error, and further analysis of the results is needed.": Can the authors elaborate in the discussion section on this? What errors are you thinking of and is there a threshold value for the cumulative attenuation value / water vapor density that makes it unfeasible for measurement?

Lines 197 – 205 / Eq. 15 – 17: This belongs in the methods section.

Lines 209 – 211: Can I ask the authors to quantify the results in the text a bit more? Besides, what is 'good'? This needs a benchmark, so is it better than another model or estimation method?

Lines 213 – 215 "Similarly, the evaluation result was better at 83 GHz in June, which shows that the 83 GHz millimeter-wave link has greater potential for water vapor inversion.": That makes sense, indeed, seeing Fig. 2 in the manuscript.

Lines 222 – 224 "Since the […] point measurement.": What do the authors mean with this sentence?

Lines 224 – 225 "In addition, the weather station in this paper is placed at one side of the link, so the estimated result will be different from the data of the weather station.": It may be worth mentioning this in either the methods or discussion section. Plus, what would this mean for the measurements?

Lines 234 – 235 "vapor, so more accurate measurement means better response to the dangers facing humans and their environment (Fencl et al., 2020; Harel et al., 2015).": Very true. I think the authors can even make this stronger by mentioning the potential of new, opportunistic sensors here, which potentially gives a high(er) density of water vapor density sensors.

Line 236 "1 minute": But 60-min aggregations were used and validated, right?

Lines 236 – 238 "and used the […] within this year.": State here what the method was and especially what the authors did change, so what is new.

Lines 240 – 241: Besides the best reached values, also mention the average values to give the reader an idea of the overall model quality.

Lines 241 – 242 “Compared with previous studies, our water vapor inversion results have a higher time resolution.”: How much higher?

Lines 250 – 251 “This seasonal difference is also difficult to overcome. In the future, we will consider improving water vapor monitoring in winter in our research.”: Could the authors share any thoughts on how to do this?

Table 1: Could the authors add the number of minutes on record per indicated day? In addition, can the authors say something about the variation in the measurements during the days?

Figure 3: the colors of the figure are not color-blind proof. I would recommend using different colors or to use a set of dashes in the lines. Besides, the figure is quite similar to Fig. 2 in Pu et al. (2021).

Figure 4: What I miss in the results section (or accompanying discussion section) is a little discussion about any discrepancies we see between observations and model (e.g., but note that it is not limited to this, the differences we observe on the right of Fig. 4c and the drop in the simulations, but not the observations, in Fig. 4h). Can I ask the authors to comment on this? If the comments have a more speculative nature, this would very well fit in a discussion section. In any case, it could provide valuable information, also for the future development of such estimation methods.

Table 2 & Figure 5: The monthly overview is clear and interesting. Besides this overview, I think it may also be valuable to show a figure with at least some of the metrics per time step, to visualize the hour-to-hour or day-to-day discrepancies that can take place. That is valuable information for possible operational implementations of this method.

Figure 5: What causes the high MRE peak in October, compared to the other months?

Technical corrections

Line 30 - “The evaporation […]”: The evaporation of water

Lines 44 – 45 “the radiosonde is only launched about 2–4 times a day”: Often even only once a day.

Line 100 “water vapor inversion”: From a consistency perspective, would it better to use water vapor density instead of inversion?

Line 170 / Eq. 12: Is this a conditional statement? If yes, the notation should be slightly different (to make that clear).

Line 179 “map”: I think this should be ‘graph’.

Line 205 “which shows that the use of millimeter-wave link signal attenuation can estimate the water vapor density very well.”: I think this can be removed, as the rest of the sentence already explains enough.

Line 239 “obtained”: I think this should be ‘estimated’.

Line 240 “PCC” and “MRE”: Better to write that out here, so Pearson’s correlation coefficient and mean relative error.

Figure 4: Something seems to go wrong with the figure headings, 'Spring and Summer' are on a different page than the rest of the figure. It is possible to either make the figure smaller or to make two figures out of it (e.g. spring + summer and autumn + winter). Besides, for comparison purposes, it helps when the y-axes are the same throughout the figure.

References

Alpert, P. & Rubin, Y. (2018). First Daily Mapping of Surface Moisture from Cellular Network Data and Comparison with Both Observations/ECMWF Product. Geophysical Research Letters, 45(16), 8619–8628. https://doi.org/10.1029/2018GL078661

Chwala, C., Gmeiner, A., Qiu,W., Hipp, S., Nienaber, D., Siart, U., et al. (2012). Precipitation observation using microwave backhaul links in the alpine and pre-alpine region of Southern Germany. Hydrology and Earth System Sciences, 16(8), 2647–2661. https://doi.org/10.5194/hess-16-2647-2012

David, N., Alpert, P., & Messer, H. (2009). Technical Note: Novel method for water vapour monitoring using wireless communication networks measurements. Atmospheric Chemistry and Physics, 9(7). https://doi.org/2413–2418.10.5194/acp-9-2413-2009

David, N., Sendik, O., Rubin, Y., Messer, H., Gao, H.O., Rostkier-Edelstein, D., & Alpert, P. (2019). Analyzing the ability to reconstruct the moisture field using commercial microwave network data. Atmospheric Research, 219(0169-8095), 213–222. https://doi.org/10.1016/j.atmosres.2018.12.025

Doumounia, A., Gosset, M., Cazenave, F., Kacou, M., & Zougmore, F. (2014). Rainfall monitoring based on microwave links from cellular telecommunication networks: First results from a West African test bed. Geophysical Research Letters, 41, 6016–6022. https://doi.org/10.1002/2014GL060724

Fencl, M., Dohnal, M., Valtr, P., Grabner, M., & Bares, V. (2020). Atmospheric observations with E-band microwave links—Challenges and opportunities. Atmospheric Measurement Techniques, 13, 2020, 6559–6578. https://doi.org/10.5194/amt-13-6559-2020

Fencl, M., Dohnal, M., & Bares, V. (2021). Retrieving Water Vapor From an E-Band Microwave Link With an Empirical Model Not Requiring In Situ Calibration. Earth and Space Science, 8(11), e2021EA001911, https://doi.org/10.1029/2021EA001911

Leijnse, H., Uijlenhoet, R., & Stricker, J. N. M. (2007). Rainfall measurement using radio links from cellular communication networks. Water Resources Research, 43, W03201. https://doi.org/10.1029/2006WR005631

Messer, H., Zinevich, A., & Alpert, P. (2006). Environmental monitoring by wireless communication networks. Science, 312(5774), 713–713. https://doi.org/10.1126/science.1120034

Overeem, A., Leijnse, H., & Uijlenhoet, R. (2011). Measuring urban rainfall using microwave links from commercial cellular communication networks. Water Resources Research, 47, W12505. https://doi.org/10.1029/2010WR010350

Pu, K., Liu, X., Liu L. & Gao, T. (2021). Water Vapor Retrieval Using Commercial Microwave Links Based on the LSTM Network. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 14(1939-1404), 4330-4338. https://doi.org/10.1109/JSTARS.2021.3073013

Uijlenhoet, R., Overeem, A., & Leijnse, H. (2018). Opportunistic remote sensing of rainfall using microwave links from cellular communication networks. WIREs Water, 5(4), e1289. https://doi.org/10.1002/wat2.1289

Zinevich, A., Messer, H., & Alpert, P. (2009). Frontal rainfall observation by a commercial microwave communication network. Journal of Applied Meteorology and Climatology, 48(7), 1317–1334. https://doi.org/10.1175/2008JAMC2014.1