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Comment on amt-2022-198

Anonymous Referee #1

Referee comment on "GNSS radio occultation soundings from commercial off-the-shelf receivers on board balloon platforms" by Kevin J. Nelson et al., Atmos. Meas. Tech. Discuss., <https://doi.org/10.5194/amt-2022-198-RC1>, 2022

General comments:

The paper shows the retrieved bending angle and refractivity from two balloon-borne radio occultation (RO) campaigns using low-cost commercial off-the-shelf GNSS receivers. Balloon-borne RO could become an important source of information for regional weather observations and forecasts. However, it turns out that there are not many useful occultations in this study (only about 20), and the statistics shown should therefore be taken with a grain of salt (which I think the authors are aware of). It seems to me that the words describing the results make these measurements better than they actually are. This is reflected in some of the specific comments below. Since this is the first paper describing such results using low-cost receivers, and because balloon-borne RO has several benefits over other methods, I think it could be published with minor revisions.

Specific comments:

L3: Could "rates" be omitted here? Normally "sampling rate" means the receiver sampling rate during an occultation (e.g., 50 Hz in spaceborne occultations).

L7: "... show high-quality refractivity profiles in the troposphere with near-zero median difference ($\sim 2.3\%$ median-absolute-deviation) from the colocated ECMWF ERA5 reanalysis data.". I would not consider 2.3% median absolute deviation to be high-quality. Looking at the statistics later on, I would not call it high-quality. Spaceborne RO shows less than 1% median absolute deviation above 5 km. Maybe just leave out "high-quality" here (and in the conclusion).

L9: "... are worth further improvement for dense targeted atmospheric soundings to

improve regional weather forecasts." This seems a bit cryptic. Do you mean "... need further improvement ..."?

L14: "..., Radio signals" should be "..., radio signals".

L20: "late 1990s". I would say mid 1990s. GPS/MET was launched in 1995.

L23: COSMIC and GRAS needs to be spelled out.

L24: "(e.g., SPIRE, GeoOptics, Planet IQ)" I think it is "Spire" and "PlanetIQ".

L40: "... (FSI, Adhikari et al., 2016) and phase matching (PM, Wang et al., 2017)". I think it should be written "... (FSI) (Adhikari et al., 2016) and phase matching (PM) (Wang et al., 2017)". Similar comment can be made when referring to COSMIC and GRAS earlier in the same section, and to ROSAP and IAT later on.

L44: "... as part of ...". Do you mean "... was part of ..."?

L55: "onboard high-altitude balloon". Should it be plural "... balloons"?

L81: "... the NCL Zero Pressure Balloon Mission 1 (ZPM-1) was launched ...". I think a "that" is missing in front of "was".

L110: Are there any relativistic effects that need correction? I'm not sure, but would like the authors to think about it if they haven't.

L156: "The tangent point locations during the occultation event can therefore be derived from ROSAP ray-tracing". Is that how it is done in general? Are there other ways?

L157: "To better evaluate the quality of BRO refractivity profile considering the large tangent point drifting distance, the ERA5 profile at the location where tangent point at a height of 5 km above mean-sea-level (MSL) will be treated as the BRO colocated profile for comparison purposes.". Please correct the grammar and syntax in this sentence.

L150-159: This part confused me a bit. How many profiles are involved?: 1) ERA5 collocated at zero elevation angle tangent point location to compute the time series of refractivity at the receiver by interpolating the refractivity profile to the receiver height at each time stamp throughout the occultation observations. 2) ERA5 median refractivity profile of a 1x1 deg horizontal grid space surrounding the zero-elevation location. 3) ERA5 profile at the location where tangent point at a height of 5 km above mean-sea-level (MSL) will be treated as the BRO collocated profile for comparison purposes. Is that correctly understood? Why not use only one of these for all purposes? Would comparisons become worse if only one was used for all purposes? Please clarify.

Figure 4: What are the dashed lines slightly below 1 km? There are two of them. Please mention in caption. The y-label: 'Height [km]' is cut off. Is this height above surface? (not MSL that far inland, I suppose). I think it should rather be [10 N-units] (or [da N-units], da means deca) instead of [(1/10) N-units] on the lower axis.

L168: "The calibrated excess phase delay compares favorably with the collocated ERA5-derived excess phase delay". That is difficult to see. The two curves look quite different to me. Is it necessary to say this?

Figure 5: Here is shown excess phase. Is there a difference between 'excess phase' and 'excess phase delay'? I think they are the same, and I'm not sure what delay means in this context. Maybe "delay" could be omitted in the text.

L170: "... likely due to satellite-receiver geometry fluctuations.". Why would that only affect the ray tracing and not the observations? I would think that the reason is rather the steps taken to clean and smooth the excess phase data, which makes the observed excess Doppler smooth compared to the ray tracing. I suspect that the variations seen in Fig. 5b come from numerical noise in the ray tracing in combination with taking the derivative to obtain the excess Doppler (it takes only a few mm noise to create excess Doppler noise of the size seen in Figure 5, given a sampling rate of 50 Hz). How would it look if the ray tracing results were smoothed in the same way as the observations? What was the receiver sampling rate?

L174: "(141.79 V/V) is on the same order of magnitude as the mean COSMIC-1 and SAC-C GNSS RO satellite missions (700 V/V) ... this is quite impressive." I think that is a misleading statement. 141 and 700 differ by a factor of 5. That is not the same order of magnitude. Please revise.

Figure 5: Why is there a time jump in the observations in Figure 5d? Please discuss in the text.

Figure 6: How is the ROSAP bending angle calculated? From simulated excess Doppler? Or

ray traced bending angle? Please discuss in the text.

L194: "... difference between the GO/FSI retrievals and the colocated ERA5 profiles, respectively." What does "respectively" refer to in this sentence? Are there more than one ERA5 profile? Please revise.

L196: "Above 10 km, the median differences between the retrievals and the colocated 5 km tangent height ERA5 profile are both -0.27% to -0.26% with a median-absolute-deviation (MAD) of approximately 0.62%." I don't see that in Figure 7b. Looks like the median differences are about -1.5% to 4%. Are you taking a mean over some height range? Please clarify.

L197-201: I don't see the median/MAD and the numbers discussed near the end of section 3. How can you have median and MAD values for only one occultation? Please clarify.

L207: "... with the minimum bias with a median difference ..." I don't understand that part of the sentence. Can it be written differently?

Table 1: How are these values calculated? Are they average values over the respective 5 km intervals? Are the data interpolated to common equidistant levels before the averaging? Please explain a bit how they are calculated.

L214: "The ZPM-1 refractivity difference shows much more variability ...". I don't see that. In fact, the MAD is generally smaller for the ZPM-1 than for the World View flight campaign, so I don't think the statement is correct. However, since the number of occultations in the statistics is so small (also in the World View data), it is perhaps difficult to conclude if there is a true difference in the variability between the two flight campaigns. I agree that there is a bias in the ZPM-1 data relative to the ERA5 data, but could this just be a coincidence due the small number of occultations? In other words: are results statistically significant?

L221: "The limitations of closed-loop tracking receivers may also affect the BRO refractivity retrieval quality. Wang et al. (2016) found that the low SNR ...". Something very similar is mentioned two paragraphs earlier (L210-212), also with a reference to (Wang et al., 2016). Could the discussion be better coordinated to avoid this repetition? It is not clear to me if it is the same thing or two different things (just with different words and emphasis) that are discussed.

L234: Who does "their" refer to here?

L260: "Overall, we show that high-altitude balloons with RO payloads can be launched in all weather conditions ...". I don't think it was shown in this paper. Was there severe weather in the campaigns?

L284: "... leaving the final 11 cases presented in Section 4". But in Section 2.2 (L100), it say 13 cases. Please clarify.

Figure A1: Is there a difference between GPS Piksi 1 and GPS Piksi 2? I don't think there was a distinction made anywhere in the text. Is it for the two different campaigns?

L367: <https://doi.org/10.1175/2008BAMS2399.I> should be <https://doi.org/10.1175/2008BAMS2399.1> (1 instead of I at the end)