

General comments:

The paper describes the impact of using different clock rates in the correction/processing of GNSS observations and retrieval of bending angles (BA) from radio occultation (RO) data. It is shown that using increased clock rates for GLONASS occultations reduces the standard deviation in Sentinel-6 and COSMIC-2 BA relative to ECMWF forecasts at high altitudes. This is an important result for both NWP and climate applications. It is also shown that for GPS occultations, the residual clock noise mostly depends on the GPS transmitter type (and to a smaller extent the used clock rate), with newer GPS Blocks having less clock noise.

The paper is well organized and well written, and I recommend publication with minor revision. My comments below are mostly suggestions for text improvements. One suggestion (see below) goes to providing one example (one occultation) of the impact on the excess phase as a function of time for different clock rates. I think it would be interesting to see this and it would in my view improve the paper, but it is only a suggestion.

Dear reviewer, thank you for your feedback. We welcomed your suggestions and have looked at both the effect of the clock rate at the single-occultation level and on the vertical error correlation (see new Sec. 5). Please see below for a point-to-point response to your comments.

Below you'll find a point-by-point response to you comments.

Specific comments:

Line 40: I would add "and results are presented in section 4" after "set-up is described in section 3". I know it is implicit when you have parenthesis "(section 4.1)" and "(section 4.2)" in the next sentence, but it becomes more clear with an explicit statement. Also the parenthesis "(section 2)" in the previous sentence could be "as described in section 2" to be explicit. Normally parentheses should just contain clarifying information, not changing the meaning of the sentence if they were to be left out.

Text updated accordingly.

Line 58: "forward-modelled bending angle profiles extracted by the European Centre for Medium-Range Weather Forecasts (ECMWF) short-range forecasts" I suppose what is meant here is that the bending angles are forward-modelled based on temperature, pressure, and water vapor profiles extracted from ECMWF short-range forecasts. But that's not what the sentence says. The sentence should be revised.

Thanks, indeed that's what it's meant here, and we reworded accordingly, adding also a reference to the ROPP.

Line 78: slight -> slightly

Updated

Line 114: It is unclear to me what "processing-center-independent cross comparisons" mean. If it was the opposite, i.e., processing-center-dependent cross comparisons, I would maybe understand it as comparisons of solutions from different processing centers. However, strictly speaking you are saying that it is the comparisons that are processing-center-independent. I'm not sure if this is really what you want to say. I have the same issue regarding "SW-" and "receiver-" if the dash refers to "independent". There is also "receiver-independent way" in line 110 that I don't fully understand. Overall, could the sentences be re-formulated to become more clear?

You make a subtle point, but we think that the wording is correct: If the solutions we compared were based only on the GNSS-POD receiver, the result could be biased, if, e.g., there was any problem in the receiver itself. Once we compare the solution obtained with data from the GNSS-POD receiver with the one obtained with data from the RO-POD receiver, the comparison is then receiver-independent, in the sense that it does not rely on a single receiver. The same applies when using two independent S/W and when comparing solutions computed by different processing centres. We think that this should be clear.

Line 119: I would say "(cf. section 1)" if what you mean is that you already stated something similar. In section 1, the similar statement (line 20-22) refers to both positions and clocks, but here only to clocks. Maybe the reference to section 1 here is not needed at all.

We agree, the reference to section 1 has been removed.

Line 120: "One is obtained using JPL RT GPS products with clocks at 30 seconds and orbits at 15 minutes". I suppose you here downsample to 30 seconds and 15 minutes, respectively. I think you should include that in the sentence, since these numbers are different from those given in the introduction. E.g., ... using JPL RT GPS products, downsampling clocks to 30 seconds and orbits to 15 minutes".

Thank you for noticing this. We changed the text accordingly. We also added Table 1 to summarize all the GNSS data sets that we used.

Line 136: fit -> smooth (I suppose that is what you mean).

We'd use a fit to smooth the data. The text has been reworded accordingly.

Line 136: Not sure if this is necessary: "For example, if every 30th data point were an outlier, the 30 s downsampled product would contain little useful information. With this caveat in mind, the direct decimation represents a conservative choice since it could increase the relative percentage of outliers, thus adding to the loss of information in the downsampled products." It seems obvious that this could in principle happen, but is it a real concern? Is there any reason to believe that the fraction of outliers would increase? If there is no real concern, I think these sentences could be removed.

Thank you, indeed it was not necessary to include this sentence. We removed it and slightly reworded the text.

Line 147: a RINEX -> RINEX data

Updated.

Line 148: Also here "(cf. Section 3.1)". Should it be "Section" or "section"? I'm not sure what the AMT guideline says.

Thank you, indeed the guidelines indicate that "Sect." should be used (and also, that for figures "Fig." should be used). We updated the entire text accordingly.

Line 149: illustrated -> mentioned.

Updated with 'discussed'.

Section 4, before Section 4.1: Would it make sense to give one example of excess phase as a function of time over about half a minute at the beginning of a setting occultation where the excess phase is close to zero (with not too much ionosphere) to show how the noise in excess phase is reduced when the clock rate increases? I haven't seen that before, and I think it would

be very illustrative. It would help to understand the characteristics of clock errors (and corrections) on the phase data. Excess phase differences using two clock solutions at different rates might also be very illustrative - I have never seen it.

Thank you for this suggestion. We now have a separate "Discussion" section, where we show plots that illustrate the impact of the GNSS clock rate on both the single-occultation level and on the overall vertical error correlation.

Line 153: "following the approach of Figure 1". Do you mean "similar to Figure 1"? Maybe it is not needed in the sentence.

Reworded.

Figure 5: It is difficult to distinguish between 01s and 30s, as well as between 02s, 05s and 10s (also in the right panel). Maybe choose more distinguishable colors.

The figures have been improved in quality and the color palette has been updated for better readability.

Comment to the results in Figure 5: Although there is not much gained in terms of standard deviation using higher clock rates for GPS, there could be a difference in error correlations. This in turn could affect standard deviation in derived refractivity (or in data assimilation of bending angle). I'm not asking for refractivity statistics here, but maybe my suggestion above of giving an example in excess phase could shed some light on this.

Thank you for this suggestion. We now have a separate "Discussion" section, where we show plots that illustrate the impact of the the GNSS clock rate on both the single occultation and on the overall vertical error correlation.

Figure 6 caption: hardware -> GPS transmitter types (I suppose), not unique -> not consistent with the other GPS Blocks (or something similar).

Reworded.

Figs 4,5,6,7,8: Discussions of results in the last sentences of the figure captions should be moved to the text (or just removed if already discussed in the text).

We think that a figure caption that also delivers, concisely, the main points, is worth having to help the casual paper skimmer, even though this results in some redundancy between text and captions.

Line 177: "there is an improvement in going from Block-IIR, to Block-IIF, to Block-III". But is the picture for a given Block about the same for COSMIC-2 as for S6A?

No, for C2 the statistics are worse. The reason is a lower quality of the POD solution for the C2 spacecrafts. A sentence has been added to the main text.

Line 184: I couldn't find anything about clock noise in (Harnisch et al., 2013). Please check if it is the right citation/reference.

Thanks, it should have been indeed Hauschild et al. 2013. Fixed.

Line 190: Maybe the part on ROMEX needs update, or could a more general statement be made?

This part has been partly rewritten, and the ROMEX experiment is now referred to only as a dataset comprising all four large GNSS constellations. We don't mention it directly as a possible source of data for studies like this one, since most of the ROMEX data is at the L1A level.

Line 194: I couldn't find the word "sweet-spot" in (Kursinski et al., 1997). Maybe this citation is not needed here.

Indeed it's an informal definition, we move the reference to avoid confusion.