Summary

The present paper discusses the impact of different rates (1 to 30 seconds) from the GPS and GLONASS constellation clocks on radio occultation (RO) bending angle profile statistics for Sentinel-6A and COSMIC-2 RO missions. The authors conclude that higher GNSS clock rates lead to improved bending angle profile statistics with decreased standard deviation in comparison to ECMWF short-range forecast data for GLONASS, while not much is gained by using higher rates than 30 seconds for GPS (with slight differences between different GPS blocks). This is supposedly related to known lower short-term stability of GLONASS clocks.

General comments

Admittedly, the findings in this paper are not entirely new and the authors should include previous work conducted with regard to this topic in their discussion even if from preliminary studies, e.g., Yao et al. 2023 (also reference [1] therein) who investigated the effect of higher-rate GPS and GLONASS clocks with respect to COSMIC-2 in a similar study setup. However, the work presented discusses the issue in more detail than previous studies (at least to my knowledge, the authors are advised to conduct a proper literature review for other related publications) and the authors present the results in a well-structured way providing extensive illustration supporting their argumentation.

In order to strengthen and enhance the leverage of the publication the authors should therefore expand their discussion for the following points. Since the focus of the study is on the impact of GNSS clock rates on RO data processing, it would be of interest to discuss and show how the different clock rates are applied and manifest in the RO excess phase calculation, as the point where GNSS clock data enter the RO processing. Additionally, the applied interpolation method from the GNSS clocks to the high-rate RO measurement time stamps should be included in the paper and possible implications of different interpolation methods, if there are multiple to choose from, should be discussed (in dependence of the clock rate, if relevant.

Yao, Jian, Weiss, Jan-Peter, VanHove, Teresa, "Impacts of High Rate GNSS Satellite Clock Estimation on Radio Occultation Bending Angle Retrievals: Preliminary Report," Proceedings of the 2023 International Technical Meeting of The Institute of Navigation, Long Beach, California, January 2023, pp. 995-1001. https://doi.org/10.33012/2023.18621

Dear reviewer, thank you for your feedback. Both you and the other reviewer suggested to have a look at the effects of the clock rate at the single-occultation level. This analysis is now included in Section 5, where we also investigated how the clock rate affects the vertical error correlation.

For the clock we use a linear interpolation, and this information is also included in Section 5.

We added a reference to Yao's extended abstract.

Line per line and figure specific comments:

Figures (general): On my printout the graphics are slightly blurred, please provide the figures in higher resolution. Use intermediate minor tick-marks and provide major tick-marks with shorter intervals to support the reader with the identification of relevant values in figures (applies basically to all figures except Figure 2).

Figures have been updated for quality and clarity.

L2: “Space-based RO experiments …”. For my understanding this sounds a bit too “experimental”, RO is a proven and well advanced remote-sensing measurement technique, but maybe this is commonly recognized designation. This applies to other occurrences in the text as well.

We just had in mind RO experiments on other planets, where the receiver sits on ground and not on a LEO. But indeed in the context of this special issue, there’s no need to specify it.

L2: What is meant by RO experiments “currently” require tracking of signals from GNSS? I suggest to remove “currently”.
We had in mind the proposed LEO-LEO RO experiments. But given that no such experiment exists at the moment, we removed “currently”.

L5-6: Radio occultation was already introduced as acronym, use RO acronym here.

Done.

L6: Update to “…, where the orbit and clock information for the transmitter (GNSS) and receiver (LEO) satellites is required.”

Updated.

L9: “… the study focused on the effect”, instead of “…, the focus will be on the effect”. Remove coma after “data rates”.

Updated.

L10: “… range from 1 to 30 seconds”. State which exact rates were applied if this can be stated generally. This is more informative.

Reworded.

L11: State which four month served as test data period for Sentinel-6A and also which dates served as input for the COSMIC-2 analysis.

Done.

L13: Depending on the context 30 seconds can already be considered high-rate compared to e.g., 5 or 15 minutes orbit sampling. Better to use “… higher-rate clock information”. This might apply to other occurrences in the text as well.

Done here.

L17: I suggest to replace “estimation” by “calculation” and rephrase the following part “… BA profiles based on signals from …”.

Done.

L18: Remove “an” in “requires an accurate”.

Done.

L25-26: Unclear language. Rephrase to something like: “Due to the random stochastic noises that affect GNSS atomic clocks, a smaller sampling interval is required to obtain accurate interpolations, …”

Done.

L29: Aren't the CODE final GNSS orbits provided with 15 min sampling? Please check.

They moved to 5min since the transition to IGS20. We included this info in the GNSS Table.

L35-37: This sentence does not seem logical, please state clearly what you are trying to say. Are you saying these stability analyses are "used" for high-rate corrections in order to obtain high-quality BA products. If yes, in which way are they used?

Reworded.

L42: Add verb. "The discussion and conclusions are presented in Section 5". Makes sure to follow the journal guidelines for the upper/lower case notation of keywords like Section, Figure, etc. and follow them consistently throughout the manuscript.

Done.

L45: Better to use past tense: "... was equipped ... was built ...".

Changed to "is equipped" (since S/C is still flying) and "was built" as suggested.

Figure 1: Please include OPE and STC in the title of the two figure panels, respectively. This way the reader has a direct connection to the acronyms used in the text. Also add it in "Left: Operational data stream (OPE) ..."

Done.

L58: Please correct: "... bending angle profiles are extracted from ...".

Reworded.

L62: Please indicate if you are you using matching occultation events for both processors or if they differ.

Added a sentence to clarify.

L64-67: You mention JPL final clocks used for OPE for GPS. Where have the JPL final products been introduced? I can't find them in the paragraph from L23-32. Also, why are you using different inputs for OPE: GPS (JPL final 30 s) and GLONASS (JPL RT 1 s)? In my view it would be clearer and more consistent to use the same input for both, GPS and GLONASS. Please clarify.

Clarified, and a table has also been added, to identify the rates of each set of products.

L71: Did you look for more up to date references? I did not check but Jaduszliwer et al. 2021 and references therein might be a starting point.

Jaduszliwer, B., Camparo, J. Past, present and future of atomic clocks for GNSS. *GPS Solut. 25* , 27 (2021). https://doi.org/10.1007/s10291-020-01059-x

Thank you for this suggestion. We included this reference when we discuss the AD of the Galielo and BeiDou constellations in Sec. 6.

L80: Rephrase "... described in the following are based on the re-processing of RO data ...".

Done.

L81: Please provide more details which RO receiver type is flown on S6A and COSMIC-2 and provide a reference.

Done.

L84: Is there any reference for the YAROS software?

Unfortunately not.

Figure 3: Please add a grid and intermediate tick-marks on the y-axis to support the viewer. Add "Sentinel-6A" to the title.

Done.

L96-98: So BSW5.2 was used for OPE processing and BSW5.4 for STC processing? Please clarify.

Reworded for clarity.

L103: Remove punctuation: "See, e.g, …".

Done.

L104: Plural: "… the reduced-dynamic and the kinematic orbits …".

Done.

L104: What exactly do you mean by the data handling component? The same software using the same processing setup? If so, please revise to improve clarity.

We reworded and expanded this segment.

L112: What are the different characteristics of the two oscillators?

The point here is that the measurements are time-tagged differently, since the oscillators are different. So, independent of the characteristics of these oscillators, their solution cannot be directly compared.

L115: You state that typically the spread of the different orbit solutions is below 3 cm 3D-RMS. Did you check this for the investigated time periods in this paper as well? Did you find any noteworthy deviations? It would be a valuable addition for the reader and further improve the manuscript to add a time-series plot of the 3D-RMS of the different comparisons for Sentinel-6A and the same time period as in Figure 3.

We now include an additional figure with the 3D-RMS for a set of solutions (Fig. 4).

L117: Better: "… (cf. Figure 1) …".

Done.

L120: In the paragraph from L34-32 you introduce JPL RT products with 1 min orbit and 1 s clock sampling but here you are using JPL RT products with 15 min orbit and 30 s clock sampling? Also, since it is hard to keep track which GNSS product is provided with which orbit and clock sampling rates one could consider to collect this information in a concise table at the beginning of the manuscript.

Thanks for this suggestion. We now added a Table collecting the information on the various set of GNSS products used, and refer to it where necessary.

L124: This has been shown by Fernandez et al., 2024? If yes, make this more clear by saying "… it has been shown by Fernandez et al 2024 that not much is gained in this case".

The use of 10s RINEX data is standard practice in the POD community and it's the common choice among the CPOD quality working group members when obtaining solutions for altimetry

missions (which have the most stringent POD requirements). In Fernandez et al., 2024 this is not explicitly indicated, so we reworded the sentence.

L127: Provide proper figure reference: “It is clear from Figure 3 that …”

Done.

L133: Again I am confused by 15 min orbit sampling here and the 1 min orbit sampling of JPL RT data at the beginning of the paper.

We clarified and added a reference to the Table.

L135-139: You state that using a fit would be more stable against outliers and therefore the better option, still you use straightforward decimation. What is the estimated difference between the two approaches and can you confirm that your choice does not impair the results?

We added some information, indicating that outliers are not a concern for these products, and the reason for proceeding with the simple decimation.

L141: “… obtained by”

Done.

L146: Doesn’t Sentinel-6A track GPS and Galileo on the POD antenna?

Only for the GNSS receiver. The RO receiver only tracks GPS in the POD antenna. We clarified this in the text.

L149: Better: “… as discussed in Section 3.2.”

Done.

Figure 4: Please include the time period of the underlying data in the figure caption. Also in Figure 5, 7, and 8.

Done.

L160: Add the height range to the text for convenience: “… at high impact heights between 50 and 60 km”

Done.

L176: You limit the illustration of COSMIC-2 GPS occultations to 30 s clock products in Figure 8. For consistency and to underline your findings it would be interesting to include the full range from 1 s to 30 s clock rates, in the way how it was done for Sentinel-6A or at least state that the COSMIC-2 analysis shows similar characteristics if this is true.

We now explicitly mention that the results are similar.

L180: Best performance in terms of standard deviation of what? Remind the reader that your analysis is based on bending angle statistics here.

Done.

L186: What is meant by “real” RO observations, are there any other? I suggest to remove “real”.

Done.

Figure 6: Why does the standard deviation for different clock rates reach different impact heights? E.g., in the left panel (Block-IIR) the green line (5 s) reaches about 58.7 km while the blue line (10 s) ends at 58 km?

The figure (which is now Fig.7) has been updated.

L191: It would have completed the picture to include Galileo and Beidou occultations in this study. Nevertheless, do you have any expectation on the behavior of the use of higher rate clock data from those constellations and their impact on RO bending angle statistics, given their clock stability?

We added a figure for the AD of Galileo and BeiDou in Sec. 6, and included a discussion of their expected performance in RO BA statistics.

L193-195: You mention the RO sweet-spot down to 5 km, but what about the increased standard deviation shown in your figures at these altitudes?

Indeed, we reworded to point out that the standard deviation is worse below 10 km.

L202: Acknowledgements

Done.

L221: Remove repetition of “https://doi.org/” and what is “112 395”, seems odd.

Done.

L223: Remove repetition of “https://doi.org/”.

Done.

L241: Remove repetition of “https://doi.org/”.

Done.

L257: Remove repetition of “https://doi.org/”.

Done.

L259: Add DOI.

Done.

L266: Add DOI. This is still in “Atmos. Meas. Tech. Discuss.”, update to published paper if available.

Done.

L273: Is there a online resource available?

Yes, added.

L275: Remove redundant “2019” before DOI.

Done (it was the volume number, but wrong).