

# GNSS-RO Residual Ionospheric Error (RIE): A New Method and Assessment

Dong L. Wu et al., amt-2024-51, AMT-Review

## General comment:

In general, I think the authors addressed a quite interesting and easy to implement approach for the correction of ionospheric residual errors in GNSS-RO data. They also provided a good literature overview, discussing the ongoing work and problems on this topic over the past years. Their style of writing was also good to follow, however, there are some technical errors/typos in this paper, which leave a bit of a sloppy impression. Furthermore, the paper is quite long and hence hard to read and concentrate on. I would prefer a clearer presentation of the main results, maybe providing some of the figures only as supplementary material. Personally, I appreciate the extensive analysis the authors conducted, however some of the information might get lost due to the length of the paper. They also add as an additional study the impact of these RIEs on data assimilation. By itself, this is of course interesting and important to discuss, however, I also feel they could have split the study maybe in two papers. To first introduce the method and precisely discuss the correction of RIEs on phase delays, and a second follow-up study with the data assimilation experiments. It reads more like a scientific report than a scientific publication, which should aim to concisely summarize and present the main/key findings. In that respect, I recommend the authors to improve the general style, structure, readability, and quality of the manuscript.

Furthermore, I wanted to address, that to my knowledge a correction on phase delays was already discussed in previous literature years ago, leading to the conclusion that a correction on bending angle is to be preferred. The problem here is that the dispersion residual (different ray paths, L1 and L2) is the most dominant residual, compared to higher-order ionospheric effects. Thereby, a correction on bending angles provides better results, since profiles are studied already on a common impact parameter, instead of on excess phase (see also Syndergaard 2000). Please provide a good and high-quality discussion on this issue. Readers should be aware of that, and understand why you don't see this as an issue and recommend this correction approach based on phase delays.

Summarized, I recommend a major revision in order to improve readability and a concise presentation of key results, and to get rid of most of the technical errors (I pointed out just a few, please re-check the complete paper carefully).

## Specific comments:

L 61: ROPP is a processing package. So it is not "RO processing package **or** ROPP", better "a RO processing package **such as** ROPP"

L 71: "However, the GNSS-RO data infusion requires a key assumption about the  $\alpha$  measurements in which ionospheric contributions can be fully removed by using the sounding from two L-band frequencies"; What is meant with "Infusion", what "key assumption". Please rephrase.

L 76: Please specify your statement "unrealistic". Why? I suggest dismissing this specific word.

L 102: I think there is a “minus-sign and absolute value” missing,  $\alpha\_RIE = - |\kappa|(\alpha_1 - \alpha_2)^2$ ... please check for the correct interpretation of this method.

L 106 to 109, 121-122: please provide a bracket around  $(\alpha_1 - \alpha_2)$  in the text.

L 112: Danzer et al. (2020) validated the kappa-corrected RO data against ERAint, ERA5, and MIPAS data. Please correct that statement. Furthermore, the warming was calculated solely based on RO, as a bias between RO-data with and without kappa-correction. The sentence reads wrong.

L 240: The RIE varies, as you state, with local time, season, solar cycle, solar activity, and RO receiver type. Maybe mention also geomagnetic term here. However, what I wanted to state, the bi-local correction is able to compute these variations. Please see, (i) Syndergaard and Kirchengast (2022) introducing the theory, and as application studies (ii) Liu et al. (2020): comparing kappa and bi-local as an initial study on bending angle, (iii) Liu et al. (2024): comparing kappa and bi-local on a larger scale also on temperature.

L 282: Related to that above statement, in Section 3.2, where a discussion is done based on a comparison with the kappa-correction, I suggest adding a discussion based on a comparison with the bi-local correction too. The bi-local correction can account for negative and positive biases resulting from including the geomagnetic term (see especially the analysis of Liu et al., 2024).

L 294 onwards: is this  $(\Delta\alpha_1 - \Delta\alpha_2)^2$  a typo? I was confused. Shouldn't it be:  $(\alpha_1 - \alpha_2)^2$ ? Please correct. If I am wrong, please make this clearer in the paper, and introduce the meaning properly. Thanks for this.

L326: You introduce  $\sigma$  here for the first time, please make sure to introduce it already together with  $\mu$  in line 320.

L 508: As you already address here, the second-order error can have positive and negative contributions. Please discuss it compared to the bi-local correction.

L545: This is an important conclusion: What about missions with a lower RO top height than 120km? Is this approach as a conclusion not recommended? Which missions does this concern? Please discuss. Further, what is the consequence for a complete re-processed multi-satellite data set (climatology), if this correction cannot be applied to all missions. Does this introduce a problem?

In general, in figures.

- Please provide units in a square bracket, e.g., [ $\mu\text{rad}$ ], also for Latitude [ $^\circ$ ], solar local time [h], and so on...
- Also, the colorbars with 0.05x, or 0.07x are very confusing. Please provide a clearer solution here. Usually, one indicates the unit above or below the colorbar, and the range, which I guess means in your case 0.05 times the range from 0 to 5, might be adjusted, or the pre-factor added to the unit.
- What were the exact definitions for a “day” time and a “night” time window?
- Fig. 12: there is a strange offset in the colorbars.
- Fig. 20: increase x,y-labels.
- Please make sure that figure captions are located below the figure, and not land on the next page (see Fig. 1, Fig. 12, Fig. 20). At the beginning I thought they are completely missing. This helps the readability.

## Technical corrections:

p. 2: Please remove the table of contents.

L 13: formulation is off, “therefore residual ionospheric error (RIE) is critical to accurately retrieve atmospheric temperature and refractivity”; reformulate

L 21: formulation “and in small-scale temperature variance of the RO retrieval”. That is not a clear sentence.

L 27: Typo: “RIF”

L 101: introduced “the” so-called kappa-method

L110: delete the word “had”, use instead “Liu et al. estimated”

L 141: “wehre”

L 142: “an RIE”

L 162: In the case „of“ Fig. 1

L 209: Eq. 7: Bracket after the equation “..., with ...”

L327: Please insert “commas” between a list of symbols such as  $\Delta\alpha$ ,  $\sigma$ ,  $\mu$  and in general at several text places....

L 587: ... range, like Es, as well as an extended...

L603: ... greater **than** ...

## References, p. 36 onwards:

Please make sure that the references are given in a uniform way. For example, please compare the style in Angling et al. and Bai et al.

- Years are given after the list of names of the authors. Sometimes you put it at the end of the citation.
- Doi sometimes missing.
- Make sure that all links of the papers are imported as a link.