

Response to Reviewers

We thank the reviewers for their comments and the time spent preparing them.

Reviewer 1

Major comments:

1. The title: "can GNSS-RO extend the SABER climatological record?". The main content of this work is the effects of observational filters on the parameters of derived GWs from SABER and GNSS-RO. The title does not match the main content. Please clarify the extent and/or the aspect on which the GNSS-RO can extend the SABER climatological record.

The main purpose of this paper is not to just address the observational filter differences between GNSS-RO and SABER measurements, but also to show that given the known observational filter differences between both techniques. We find that by simply smoothing GNSS-RO raw data with 2km we can largely reproduce SABER results at the tropics, which is important in the sense that SABER is in its 23rd year of an original 2-year mission and we want to make sure that the data and the results from this valuable observation can be continued. GNSS-RO on the other hand is launching new missions and will continue to provide measurements in the future. This main purpose has been highlighted in the Abstract and in the conclusions with an additional figure (Fig. 12) that is added to show the matching timeseries of both GNSS-RO and SABER over the studied period (2007 – 2022) at the tropics. Therefore, we believe that the title now better matches the body of the paper and hence is suitable for the revised manuscript.

2. Abstract: Only the purpose and method of this work are presented. It is better to present some quantitative results in the abstract.

This has added to the revised version of the paper (L16 – L19).

3. Comparing the difference of E_p and vertical wavelength: the difference between those derived from SABER and GNSS-RO are compared in the manuscript. However, the absolute of values of E_p and vertical wavelength derived SABER or GNSS-RO are not known, consequently, the statistical significance of the difference is unknow. Otherwise, one may provide the percentage contributions of E_p (and vertical wavelength) on the total E_p from both SABER and GNSS-RO. Also, the statistical significance of the differences should be provided.

2 Figures have been added to the Appendix section under supplementary figures to show the absolute values of E_p and vertical wavelength (Fig. A1 and Fig. A2, respectively) for each instrument, and the reader is referred to them in L352.

4. Please summarize the main similarities and differences of SABER and GNSS-RO in studying the GW-QBO interactions.

A summary of the main similarities and differences between GNSS-RO and SABER is added to section summary and discussion starting from L582 to L595.

Minor comments:

1. Figure 2 caption, "the thick"-->"The tick". The ticks are unreadable in panel (c) of Figure 2 and in other contour figures (Figures 3, 5, 6, 10, 11).

Done for all the mentioned figures as well as the supplementary figures.

2. L266: How to determine the upper limit of horizontal wavelength (2000 km) measured by SABER and GNSS-RO?

It is not possible to determine the upper limit of horizontal wavelength measured by GNSS-RO, it is only an estimate. The upper value is omitted to avoid confusion.

3. L269: Since the lower limits of vertical wavelengths are different (2 km for GNSS-RO, 4 km for SABER). For a fair comparison, the analysis to GWs to GWs with vertical wavelength shorter than 12 km. The lower limits of the vertical wavelengths of both measurements should also be mentioned.

We did not fully understand the first part of the comment, however the lower limits of both GNSS-RO and SABER data used in the study are already mentioned for GNSS-RO: in L265 and for SABER: in L268.

4. L278-279: "panel (a)"-->"panel (a) of Figure 3"? "panel (b)"-->"panel (b) of Figure 3"? Fixed.

5. Section 4.2: There is no description on the 2019 disruption.

A description of the 2019 disruption is added to the revised version of the paper (L371- L373).

6. L366: Where can I refer and how can I understand the statement "the shorter wavelengths detected by GNSS-RO are associated with a larger range of E_p compared to SABER"?

Omitted for brevity.

7. Conclusion: It is better to conclude the new finding(s) and/or limitations more specifically and quantitatively of this work. Other than the qualitative statements such as, "emphasizing the importance of selecting an appropriate instrument for targeted gravity wave studies", etc.

The conclusion section is rephrased in the revised version to highlight the importance and the main purpose of the study.

Reviewer 2

General Comments:

1. Section 2.2: With different instruments and centers using different processing techniques of the 13 different GNSS satellites/missions, could this have an impact on your results? For example, is there any sensitivity or different between your results if only COSMIC were used vs. only Spire? Also, what is the breakdown of profiles from each of the different missions? This would also help to demonstrate how different this study is from the COSMIC/SABER work in Wright et al. 2011 & 2016.

A new figure is added to the revised manuscript (Fig. 13) in section 6.3 which shows how E_p varies between the different instruments if they were selected individually and how the density of the data coverage increases with time to improve the accuracy of E_p estimation. Text has been added to explain the impact of the number of profiles per day on the estimation of E_p (L593-L604). More text has also been added about why this study is different from Wright et al. 2011 & 2016 in the introduction section (L66-L70)

2. This is a bit more of a technical correction but there are some issues with citations throughout, my guess is just from a mix-up of \cite, \citert, and \citep in LaTeX. I've caught a few of them and written their line numbers here, but suggest double checking this throughout the manuscript:

a. Line 181, 183, 203, 204, 382, 413, 564, 565, 566/567, 577/578, 597, 600, 601

Fixed. Thank you very much for providing the line numbers of the citations that require correction.

3. Section 4.1 and Figure 4: This section would greatly benefit with some statistical significance testing of the power spectra peaks. I especially struggle with Line 315-316 and the statement that there is a persistent peak at 1.25 years evident in all three datasets, where the zonal wind peak is very small (and smaller than other, seemingly random, peaks). Significance testing against a red noise hypothesis and a 95% significance curve would do a lot to strengthen your argument; or if the results end up being not statistically significant, could help inform your analysis and discussion.

Statistical significance is calculated for the primary peaks of all of the three time series; zonal wind, GNSS-RO Ep and SABER Ep using False Alarm Probability and added to the revised manuscript in L334-L339. Thank you for the suggestion, it added more reliability to the results.

4. In the current discussion and conclusions section, it feels that the use of GNSS-RO to extend SABER is more of an afterthought rather than the purpose of this paper based on the title. I strongly recommend adding more detail here to make the story more compelling. One potential suggestion would be to add a figure showing a comparison of the time series of Ep across the period of SABER and the smoothed GNSS-RO data at some height or for some layer. If the time series line up well, this would be a good demonstration of the ability for RO to continue the GW climatology of SABER.

Thank you very much for this suggestion. A new figure (Fig. 12) and a new subsection (section 6.3) are added to the revised manuscript in the section on adjusting the observations showing a comparison of the time series of Ep across the period of SABER and the smoothed GNSS-RO data at $Z = 30$ km. The matching between both time series confirms the main purpose of the paper to use GNSS-RO to extend SABER. The figure also shows the distribution of the Ep from both instruments at all heights and how the smoothing of GNSS-RO brought the distribution of its data closer to SABER Ep distribution.

Specific Comments:

1. Line 32: Please define SABER and GNSS-RO at first use

Fixed.

2. Lines 61-62: The results of the previous study mentioned here seem particularly relevant to this work and should be mentioned/discussed further here. Additionally, please define COSMIC at first use.

See response 1 in the general comments. The second part is fixed.

3. Line 68: I would be careful at calling GNSS-RO an “instrument”, perhaps calling it a “technique” here is more fitting?

Done.

4. Line 77-79: use the main ERA5 citation at the end of this first sentence

Done.

5. Line 85: What is the vertical resolution in the stratosphere?

This has been added to the revised text (L93).

6. Section 2.2: Mention the GNSS vertical resolution here, like how the SABER resolution is mentioned in 2.3

Done (L111-L112).

7. Section 3.1: I'm a bit confused as to why the GNSS-RO data is oversampled and interpolated to 0.1 km levels (more than 10x the original resolution) while the SABER data is interpolated to 0.5 km (4x the original resolution) to avoid oversampling. Then the RO data is down sampled to 0.5 km anyway, so what is the purpose of the intermediate step? Please explain.

This is mainly for file storage reason and does not affect the results. we store it at this resolution for other purposes.

8. Line 130/575 and throughout: Please ensure proper use of "grid spacing" rather than "grid resolution" where appropriate.

Fixed.

9. Lines 176-178: The ending of this paragraph feels a little jumbled and a bit unfinished, specifically in the last sentence. I suggest reworking to make clear that the RO dataset coverage is not sufficient for the method being described.

The paragraph is rephrased and additional information about the method is added to make it clear (L184-L188).

10. Line 180: "...significant advantages in terms of more robust derived values over a binning approach" what does this mean exactly?

This has been rewritten in a better way to clearly understand what it means. (L190)

11. Figure 2: I suggest either reorganizing this figure or adding in additional titles/labels to make the differences in the panels clearer. Specifically, since there is no x-label for panel b, it looks as if the panel has a shared x-axis range of 28 months as panel c. Additionally, add a label to the colorbar for panel c

The x-axis labelling is moved to the top to make it more clear to the reader. A label is added to the colorbar for panel c.

12. Line 217-218: This is a pretty subjective statement (though I don't disagree), maybe add a little more detail about their main differences?

Fixed and more details has been added to the revised version (L228-230)

13. Line 230-231: I had to read this a couple of times to understand, I suggest reordering the sentence for clarity so that it reads "these two metrics are chosen as they can be measured easily using both instruments, unlike more heavily-derived..."

Fixed (L243-L245).

14. Line 284: where does this “90% larger” number come from? Should this say 900%? Or 9 times larger?

Fixed (L297-L298).

15. Line 485-486/Figure 4: I think it is important to mention that the SABER distributions do have a more pronounced tail to smaller wavelengths.

Added (L511-L512).

16. Figure 10 caption: I think this caption needs to be a little more descriptive (particularly in the last line) so that it explains what the 2 km smoothing is applied to even though it is described well in the text

Done.

17. Line 571-573: Please add a citation here. Additionally, it could be helpful to provide approximate wavelengths for convection

Added (L644-645).

18. Line 579/580: “The sampled Ep revealed noteworthy results” is a bit of an abrupt transition, I suggest reworking

Rephrased (L651-L652).

Technical Corrections:

1. Line 47: “that SABER instrument” → “that the SABER instrument”

Fixed.

2. Line 182: PWs → GWs

Fixed.

3. Line 215: include → includes

Fixed.

4. Line 374: “the observational filters of these” → “the observational filters are of these” or something similar

Fixed.

5. Line 589: such → Such.

Fixed.