Manuscript Title: “GNSS Radio Occultation Soundings from Commercial Off-the-Shelf Receivers Onboard Balloon Platforms”

Manuscript Number: amt-2022-198

Date Reviewed: 10 OCTOBER 2022

Manuscript Summary: This manuscript introduces a novel technique to augment and increase spatial-temporal sampling of existing RO soundings using campaign balloons and commercial off-the-shelf equipment. The balloon ROs are validated against collocated ERA5 reanalysis solutions, and the results show excellent agreement above 7 km with increased biases in the low troposphere.

Manuscript Evaluation: The manuscript is well-written, following a logical, and self-explanatory structure presenting clear results and conclusions. Balloon-borne ROs have been assessed, in the past, through NOAA’s SBIR program as a possible augmentation to other satellite-borne measurements for increased sampling of the lower atmosphere. **I recommend publication of this manuscript after major revisions, which address all the comments described below.**

Major Comments – Introduction:

1. **The introduction lacks science motivation.** Describe the diverse scientific use of the RO data and include statements from e.g., Decadal Survey, NSF, or NOAA documents to demonstrate the need for balloon-ROs.
2. **Schematic of BRO.** Include a simple schematic that shows the location of the tangent point and its drift, as this is not a traditional RO geometry.
3. **Large horizontal drifts.** Mention that ARO/BRO suffer from large horizontal tangent point drifts, resulting in ROs sampling different volumes of air with altitude.
4. **Higher spatial and temporal soundings with ARO and BRO.** Explain how ARO and BRO offer higher sampling than traditional space-borne ROs, if its takes >20 minutes for an ARO/BRO. Do the authors mean higher “*vertical*” sampling?

Minor Comments – Introduction:

1. **Line 18: Replace** CO_2 with H_2SO_4, as S/X-bands are insensitive to CO_2.
2. **Line 19: State** the Japanese mission – Akatsuki.
3. **Line 23: Replace** “GRAS” (an instrument) with “MetOp” (a satellite).
4. **Line 25: Remove** “...such as both COSMIC missions.”
5. **Line 26: Replace** (Gelaro, 2011) with (Cardinali and Healy, 2014).

Editorial Comments – Introduction:

1. **Line 14:** Should read: “Due to vertical atmospheric density gradients, radio....”
2. **Line 16:** Should read: “... before arriving at a receiving antenna on Earth.”
3. **Line 44:** Maybe replace “as” with “were”? This sentence does not read well.

Major Comments – Methodology:

I feel that the methodology needs to better support the stability and well-constrained errors of the BRO retrievals, in order to demonstrate comparable quality of RO soundings with respect to established missions. For example:

1. **BRIC and GROOT payload details that need clarification:**
    - What is the GROOT sampling rate and does GROOT track pseudo-range?
    - What is the operating payload power?
    - How is the balloon POD solution estimated and what is the accuracy?
    - Why a 50-meter excess phase threshold was selected, and how?
    - What is the vertical altitude range covered during a BRO?
    - Lines 92 & 95: Explain "...*high enough quality*" and "... *poor quality ROs*."
    - Line 113: Do you think you smear out vertical structures by applying GPR?
2. **Impact of Spherical Symmetry Assumption during Balloon-RO:** The spherical symmetry approximation collapses during BRO due to the large horizontal drifts of the tangent point. How do the authors account for it, and what retrieval errors does this assumption introduce to atmospheric products? Are there any other techniques the authors could use to avoid this effect? Or this effect is significantly reduced through differencing of low and high elevation angle during BROs?
3. **Estimation of the Impact Parameter. Line 122:** The impact parameter is estimated simultaneously with the bending angle in Step b). It would be nice, if the authors perform a sensitivity test to quantify bending angle and impact parameter solutions given the balloons POD uncertainty. Unless, the balloons POD solutions are estimated at the same level of accuracy as LEO missions.
4. **Are GO and FSI applied within certain altitude ranges?** E.g., is there an altitude below which the retrieval switches from GO to FSI, or the entire profile is inverted using GO and/or FSI alone?
5. **What is the upper altitude initialization** used in the BRO Abel inversion? It would be nice, if an error propagation analysis, *or relevant discussion*, is included on these topics. **OK, you mention how the refractivity is estimated at the balloon** in Lines 148–159. Maybe it would be better to merge Section 2.4 with 2.3?

Minor Comments – Methodology:

1. **Figure 3:** Put arrows at "GNSS/receiver" & "Excess Phase" boxes.
2. **Line 143:** Should read "condition**s**".
3. **Line 154:** Technically, there is no horizontal "resolution". Maybe use "footprint"?

Major Comments – Results:

I feel that the results presented in each figure require more discussion to emphasize on the main key points. It appears that BROs are more suited for ROs above 5-6 km altitude (dry regions), due to increased biases with ERA5 down below. Perhaps, the altitude range of BRO performance should also be discussed?

1. The PBL height during WVG26 is at ~0.9 km. **Considering that below 1.5 km from the BRO receiver ERA5 is used to simulate the bending angle** (see Line 138), does this imply that the BRO will never be able to sample PBL height below 1.5 km? This is something that needs to be discussed.
2. **Figure 5a:** It would be nice, if the authors showed the difference in excess phase between the calibrated observations and ROSAP, and then discuss the results with respect to the 50-meter threshold. What altitude does the 50-meter threshold correspond to in WVG26?
3. **Figure 5c:** Explain what causes the SNR jumps of > 100 V/V at different times (e.g., at 335 s, 650 s, etc.)
4. **Figure 6a:** There is ~0.1 deg disagreement between ERA5 and GO/FSI between 6.5 and 8.5 km. Where could this difference come from? Should we trust the BRO or the ERA5? Include some text to describe these differences, and revise the text in Line 185 accordingly.
5. **Figure 7b:** The direction of the refractivity difference changes signs below 4 km. Could the authors explain this?
6. **Figure 8:** The reported refractivity difference exceeds 5% below 5 km. How does this translate to temperature error retrievals with respect to ERA5 temperatures?
7. A separate sub-section discussing various limiting factors on the BRO retrievals (and how to mitigate them) would be a nice addition.

Minor Comments – Results:

1. **Line 175:** BRO SNR is 5x smaller than COSMIC and SAC-C. Consider revising.