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Review: Climate Intercomparison of GPS Radio Occultation RS90/92 RAOB and GRUAN over 2002 to 2013 (Ladstadter et al)

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Summary:

The paper provides results comparing GPSRO retrived temperature and moisture profiles processed with WEGC (Wegener) OPSv5.6 against conventional and GRUAN processed RS90 and 92 RAOB beginning 2002 through 2013. GPSRO are form variety of satellites but results mainly focus on the larger number of CHAMP and COSMIC (after 2008) observations. Results are comprised of standard vertical profiles comparisons for global seasonal means, annual comparisons with through the period including breakdown for respective satellite (ie CHAMP, COSMIC, etc) against conventional RAOB and finally results comparing identical samples of conventional/GRUAN RAOB for selected sites. The paper is well written, providing a cohesive progression of results and relevant, efficient text discussions

Scientific Question/Issues:

In review of this paper I took the opportunity to review all the results before actually reading the author discussion of the results. I will thus provide my comments on the plots then go back and specifically comment on the text.

PLOTS

Aside from figures 1 and 2, which clearly demonstrate the increase number of observation available pre 2005 versus post 2010 and comprises one of the messages of this paper, I was seemingly on a different wavelength with the authors in identifying the key results and tendencies. I should pre-qualify my interpretations by stating that they are somewhat based on a background of comparisons of GPSRO (mainly from COSMIC UCAR processed retrieval) versus all conventional RAOB (including RS90/92) at my disposal beginning 2008 (and also routinely shared with NOAA and GRUAN colleagues but (unfortunately) not yet published). I will state at the onset the high degree of consistency between the results in this paper (vs OPSv5.6) and those I have reviewed (vs the UCAR nrt) GPSRO processing versions; consistent with author statement on overall consistency among respective agency GPSRO processing schemes (ie, Wegener, UCAR, JPl, etc) is evident. More formal comparisons among the respective agency retrieval approaches, including more focused results against Tdry in the dry atmosphere and more strict inter-comparison of such differences in respective Tdry, refractivity (and bending angle) spaces represents a nice potential collaborative inter-agency follow-up to this work. A question to address id show large are such differences in the context of climate change signal?

Another so-called pre-concept on my part upon entering this review is the relatively high value of GPSRO as a UT and strato (up to 10 hPa (maybe 5hPa)) reference Temperature. For moisture and temperature in relatively moist regions the respective GPSRO retrieval approach, for example for OPSv5.6 the use of ECMWF as a priori and the relative weighting within the 1DVAR which parses the

retrieval with respect to temperature and moisture, highly affect the outcome, reducing its value as a parameter to monitor climate, other platforms, etc.

For Figures 3 onward, please clearly state that differences are RAOB-minus-GPSRO. **Include 400 and 200 Hpa on plot, maybe as dashed line across**

In looking at figure 3, what is most striking is the red differences in the upper left panel for mean temperature (and moisture). So right away the known warm bias in daytime upper level RAOB during day is indicated. It is not clear what is going on with moisture but later in the record the documented dry bias in the UT (blue) is revealed. It is clear looking at the lower panel that the T results are likely sample related, further discussed/verified in Figs 4 and 6. It is a little confusing, for example, when comparing these results side by side it first appears that the red signatures for T and q are same level, which they are not; **perhaps some cosmetic adjustment to plots can be done.**

Figures 4 and the upper panel of Fig 5 are key results of the paper. The discussions point out the reduction in the Stratosphere perceived warm bias around 2005/06 but in my view the most interesting result is the increase in warm bias for the 30-10 hPa layer from 2009 to 2011. This suggests increased radiation induced RAOB error introduce with the advent of RS92 (and radiation correction provided by vender). **Stratifying these results by day/nite would confirm this and add a nice result to this paper, would nicely compliment Fig 10**. It is also of interest that this increase is much smaller but still evident in the 30-100 hPa layer, then disappears (although reappears below 300 hPa but in this case likely more related to the OPSv5.6). The increased perceived warm RAOB bias for 30-10hPa and 30-100 hPa agree with results seen with the STAR NPROVS+ (this appears to be a feature when comparing against other global RAOB type as well...). I suggest that the increase and leveling off of this feature from 2008 to 2011 is a highpoint result of this paper.

Figure 6 shows that the change in signature between 2005 and 2006 is sample related. I think this was evident from the previous results and that a lot of paper landscape was used to show this that perhaps was not needed. An aspect of these results I do not understand is the sharp sample size drop-off beginning at 200 hPa. In my experinec the sample size of RAOBS is pretty consistent up to about 50 hPOa, with no less than 25% sample reduction. That is, 75% of RAOB balloons make it to 5ohPa.

Figures 7, 8 and 9 show for respective GRUAN sites, key results of paper. Again, why are the sample sizes for the GTS RAOB samples sharply dropping off above 200 hPa, whereas the GRUAN do not. I am aware that for Tateno, there is no GTS RAOB q distributed above 200 hPa, but T are available. For LIN and SOD T and q are typically available up to 50 hPa over GTS; **can you check this?**

Also, I think it would have been very useful to use TWP site instead of TAT as it represents a tropical environment, this more global representation. Is there a specific reason you chose TAT over TWP? For example, published results exist which suggest that the dry bias in GTS relative to GRUAN mite not hold in tropics.

Figure 10 nicely illustrates that the warm bias shown in Figs 4 are due to daytime sample component. Tis should be stated.

Figure 11 is a critical part of the paper which seems to be treated as an afterthought. The point here is that if GPSRO are to be considered a reference temp., it is the Tdry and not the retrieved T that will be the reference measure. Thus, in any retrieval strategy I would recommends that once the moisture content gets below some threshold that the T retrieval default to the Tdry. In looking at Fig 11, this appears to be pretty much the case for OPS v5.6. Similar we have seen his in UCAR nrt but the differences in bias can approach 0.1 to 0.2 K particularly around 10hPa. The review of interagency differences in Tdry (or refractivity or Bend Angle) I think is key and again represents a nice future collaborative effort, GRUAN, etc.

I recommend you provide a difference plot of left-minus-right. Also indicate in annotation that these are GRUAN RAOBS. Are these all GRUAN RAOB or just TAT, LIN and SOD.

TEXT

The following are recommended clarifications:

Abstract good. Overall well written text. I can quibble about statement that "very" good agreement is found … and whether agreement between 0.2 and /or 0.5 qualifies as very good. Technically, this would depend on the respective uncertainty which is known only for GRUAN RAOB and what is actually required to monitor/detect climate signals. Given respective uncertainty estimates, the so-called "K" profile analysis would determine whether these data are consistent with their estimated uncertainties (available only for GRUAN). What is actually required for use in climate monitoring is another matter. So perhaps at minimum remove the word "very".

Introduction

11738 … 10-15 … GRUAN would serve as a transfer standard to help correct and utilize the full global network. GRUAN also provides anchor points for long term climate monitoring. GRUAN WG defines/ establishes best measurement principles for climate and enforces them at certified sites. There are only about 4 certified sites (LIN, Lauder, Boulder, SOD …). I know it is the plan, but 30 to 40 certified sites is quite optimistic …

11738 … 20 … substantial uncertainties due to inter-satellite differences for MSU/ AMSU/ATMS handled by SNO adjustment of calibration … see Cheng-Zhi Zou work and include as reference

11739 … 15 … " use GPSRO for first time … ", also routinely provided by NPROVS+ operated at STAR … hopefully future collaborations among national/international agencies on the horizon; can reference BAMS GRUAN publication, 2014 which mentions such activity … Bodeker et al

Data and Methodology

11740 .. 0-10 … Above 200 Hpa the Tdy and not Tretrieval is parameter of choice for GPSRO input to climate and validation of GRUAN, etc … I do not understand half sine weighted, needs better

explanation and a reference. Are you saying above 16km the retrieval is Tdry. If this is the case then Tdry and T physical are identical above 16km in Fig 11?. If so this should be stated.

20 to 25 … Perhaps indicate % GPSRO which fail?

11742 … 5 to 15 … Similar criteria for gaps, etc as applied in NOAA STAR NPROVS. If there is a gap in T do you also reject the moisture profile and vice-versus?. I would recommend both profiles be complete with minimal gap otherwise reject, there would not be many rejections added, right?

15 to 25 … Please specify the vertical density of interpolated profiles used in validation, for example a common procedure at NOAA is to interpolate all data to the so-called 101 level, etc … see Nalli et all, JGR. For example, you start with the high density GRUAN, mandatory and sig level GTS and some vertical density of GPSRO, how does each get to common vertical density for validation?

11743 … 0-5 …What is the common log pressure grid from 1000 to 10 hpa, how many levels, average thickness, etc?

Results and Discussion

11744 … 5-10 … Would help to show 200 and 400 (and 700) on plot

11745 … 5-15 … There are two things, background through the high altitude initialization and retrieval apriori. I was thinking the former not a factor till above 5hPa ?. Elaborate a bit more.

15-20 … Typically, for global sonde, I observe that up to 75% burst above 50hPa. Your results suggest a much lower average burst height??

11746 … 0-10… furthermore, they have very different geometries. I suggest at some point you discuss geometry differences between RAOB (point) and GPSRO (250 km along ray path) which further elevates the minimum expected difference

15 to 20 … Sentence seems out of place, Fig 5 does not include GRUAN?

11747 … 15 to 20 … Similar except above 20 hPa, but I imagine this is sample size related (very small)

11748 … 20-25 … had you selected TWP site I think the relative wetness of GRUAN vs GTS RAOB mite look different.

11749 … It mite be nice to illustrate a case of collocated profiles for day vs night. When determining nite, I assume this only applies to the RAB, for example, you do not require GPSRO to be between 10AM to 2PM for day)

Also of interest is result (Rudd et al, I think published) siuggesting a veryr slight systematic bias increase (but within typical GRUAN uncertainty) for GRUAN RAOB vs GTS due to induced radiation error (during day) … GRUAN are modifying their radiation correction strategy

Conclusion

11752 … 5-10 … this result may not hold in Tropics, tbd

20-30 … Is 20,000 occultations per day feasible? There is also pending programs (at NOAA) to collocate satellite anchored to each GPSRO and move into the radiance space. There is also the discussion on value to try and sample at GRUAN concurrent with GPSRO overpass … all food for thought

Summary

Good thorough well organized report indicating that differences between GPSRO, conventional RAOB and GRUAN RAOB are well within reason. After 2007 the samples are healthy. Results (Fig 4) do suggest some systematic differences among various GPSRO missions but these may be sample related. A core result of interest is perceived increase in +bias (RAOB-minus-GPSRO) between 100 and 30hPa and particularly between 30 and 10 hPa (Fig 4, 2008 to 11), invite more discussion. Clearly indicate on all results that differences are RAOB-minus-GPSRO and add 200 and 400 Hpa on Fig 3. Lacking from GPSRO providers is formal uncertainties for the profiles, etc (which could be used in comparisons vs GRUAN to determine consistency; "K" profiles). An area of interest is how uncertainty varies with height for T (and q); for satellite community (cal/val) this extends to 10hPa and above. Add references from Zou, Nalli, Bodeker …

Recommended for publication with minor revisions.