Atmos. Meas. Tech. Discuss., 7, C5177–C5185, 2015
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Atmospheric Measurement Techniques Discussions
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AMTD
7, C5177–C5185, 2015

Interactive Comment

Interactive comment on "Climate intercomparison of GPS radio occultation, RS90/92 radiosondes and GRUAN over 2002 to 2013" *by* F. Ladstädter et al.

F. Ladstädter et al.

florian.ladstaedter@uni-graz.at

Received and published: 16 March 2015

Manuscript: doi:10.5194/amtd-7-11735-2014
Title: "Climate intercomparison of GPS radio occultation, RS90/92 radiosondes and GRUAN over 2002 to 2013"
Authors: F. Ladstädter, A.K. Steiner, M. Schwärz, and G. Kirchengast
Reviewer: Tony Reale

We thank the reviewer for the comprehensive review, the competent discussion and

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the constructive suggestions for improvements. Please find our responses below:

1. *"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. [. . .] 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."*

   We updated Fig. 3 to indicate the 200 hPa and 400 hPa levels by dashed lines, improved labeling of the pressure axis, and added a pressure altitude axis. We changed the titles of Figures 6 to 11 to clearly indicate the differences shown in the respective figure.

2. *"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. [. . .] I suggest that the increase and leveling off of this feature from 2008 to 2011 is a highpoint result of this paper."*

   Thank you for this valuable input, we added a new Figure 12 to Sect. 3.5 showing annual mean temperature differences for GRUAN and RS versus GPSRO, separated by day/night, and added the following text to Sect. 3.2: **"Another distinct feature in this layer is the perceived increase in warm bias from 2008 to 2011. A separate discussion relating the warm bias to radiation effects is given in Sect. 3.5."**

   We added the following to Sect. 3.5: **"Further investigation of the time-dependent radiation-induced bias for both GRUAN and RS is presented in Fig. 12. The increase of warm bias for the 10 to 30 hPa layer from 2008 to 2011 shown in Fig. 4 (top layer) is visible in both day- and nighttime comparisons of RS and GPSRO. The difference in warm bias between day- and**

nighttime soundings ranges from 0.2 K to 0.5 K. The GRUAN temperatures show very good agreement to GPSRO for nighttime (as described above), and a distinct warm bias during daytime. For GRUAN data, the warm bias shown in Fig. 4 (top layer) stems therefore mainly from daytime sampling."

3. *"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 50hPa. [. . .] 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?"*

   This is a result of the checks and processing of RS profiles, described in Sect. 2.2. We added the following sentence to Sect. 2.2 to make that clearer:

   "The profiles are cut outside the core region at the occurrence of the first large gap (defined as before), separately for temperature and humidity. **This causes a distinct decrease in sample size above 200 hPa, visible in all RS comparisons.**"

4. *"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?"*

   The Tropical Western Pacific (TWP) Nauru Site has much less soundings of high quality in the time range from 2011 to 2013. This results in a very low number of collocations with GPSRO (about 10 for the whole time range compared to about 120 for Tateno station or 1000 for Lindenberg station). Thanks to your comment we had another look at the Nauru results and decided to include the Nauru figure

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in addition to the other stations, since the comparison of the GTS RS data with the GRUAN processed data is valuable even with the low number of corresponding comparisons to GPSRO. This new Figure 7 is now included together with minor changes to Section 3.4 and the following sentence at the end of Section 3.4: **"A remarkable exception is the tropical station in Nauru, where there is no visible bias between RS and GRUAN below 400 hPa, and a dry bias is only emerging above. The difference between RS and GPSRO profiles for Nauru comes from a very small sample size and is only shown for completeness."**

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

   Please see answer to Item 2 above.

6. *"Figure 11 is a critical part of the paper which seems to be treated as an afterthought. [. . .] 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."*

   We added an additional panel to Fig. 11 (now Fig. 13) with the difference plot 'RO Tphys – RO Tdry' and a new paragraph: **"The difference between physical and dry GPSRO temperature (right) summarizes the results above. In the WEGC GPSRO retrieval, the retrieved physical temperature is essentially equal to the dry temperature above 100 hPa (deviating less than 0.01 K; see Sect. 2.1)."**

   The radiosonde data used in these comparison plots are in fact the RS data from the ECMWF archive, denoted RS throughout the paper. The mentioning of "GRUAN temperature" on page 11750 line 27 was erroneous and has been corrected to "RS temperature". Thank you for pointing to this.

7. *"Abstract: So perhaps at minimum remove the word 'very'."*

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We think that the agreement is generally very good, and weakened “very” by adding “overall” in the abstract, line 15: **“Overall very good agreement is found between all three datasets with temperature differences usually less than 0.2 K.”**

8. *“11738 10 to 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 . . . ”*

   We updated the number of certified and candidate stations. 30–40 ground stations is stated according to GRUAN references (e.g. Seidel et al. (2009)).

9. *“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”*

   We included several additional references to MSU/AMSU related work: **“(Wang and Zou, 2014; IPCC, 2013; Thorne et al., 2011b; Ladstädter et al., 2011; Randel et al., 2009; Zou and Wang, 2009; Mears and Wentz, 2008; Steiner et al., 2007)”**.

10. *“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”*

    We removed the phrase “for the first time” from the last paragraph in the Introduction. We could not include Bodeker et al. BAMS paper since it is not published yet.

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11. *"11740 0 to 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."*

    To clarify this point, we added the following sentence to Sect. 2.1.: **"This signifies that at 14 km and below only information from the optimal estimation retrieval enters the profiles, while at 16 km and above physical and dry parameters are identical to within 0.01 K (the physical temperature being only very slightly larger due to stratospheric water vapor)."**

12. *"11740 20 to 25: Perhaps indicate % GPSRO which fail?"*

    We added this information: **"In this intercomparison we only use GPSRO profiles which passed the OPSv5.6 quality control (these amount to approximately 70 % of all profiles), which includes plausibility checks for bending angle, refractivity, and temperature profiles."**

13. *"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?"*

    We keep the temperature profile if it is not rejected even if at the same time the humidity profile is rejected. We also tried to reject both profiles if only one fails to pass, but for the gap criteria we are using this leads to many more rejected temperature profiles. We added a sentence to Sect. 2.2 to clarify this point: **"If the humidity profile is rejected according to these criteria, but the temperature profile passes, we keep the temperature profile for further processing."**

14. *"11742 15 to 25, 11743 0 to 5: 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? What is the common log pressure grid from 1000 to 10 hpa, how many levels, average thickness, etc?"

We added the missing information to Sect. 2.3: **"All data are interpolated to a common logarithmic pressure grid before validation, ranging from 1000 to 10 hPa (near surface to about 35 km) on 351 levels. This corresponds to an equidistant grid with a level separation of approximately 100 m."**

Additionally we addressed the topic of varying resolutions by adding the following paragraph to Sect. 2.3: **"For comparison of different datasets it is important to account for diverging effective resolutions. For GPSRO the vertical resolution is dependent on altitude and the specific profile. We performed sensitivity tests smoothing the higher-resolved profiles to the lower resolution (Nalli et al., 2013). Since these tests showed only a small decrease in standard deviation we are comparing the interpolated profiles without smoothing to avoid potential biases introduced by the smoothing method."**

15. *"11745 5 to 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."*

    The high altitude initialization method depends on the retrieval method applied by RO centers. In our retrieval, the optimal estimation of the bending angle at high altitudes is performed down to 30 km, and will influence the GPSRO data as described in the manuscript.

16. *"11745 15 to 20: Typically, for global sonde, I observe that up to 75% burst above 50hPa. Your results suggest a much lower average burst height??"*

The number of available radiosonde data points not only depends on the burst height but also on our quality control, as described in Sect. 2.2. Please see answer to Item 3 above.

17. *"11746 0 to 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"*

    We added a paragraph to the Introduction about the geometry differences: **"Since measurements are performed in limb geometry, the horizontal resolution of about 60 km to 300 km along-ray and 1.5 km across-ray (Melbourne et al., 1994; Kursinski et al., 1997) is coarse in comparison to radiosonde point-like measurements. The vertical resolution varies with altitude and ranges from about 100 m in the lower troposphere (Gorbunov et al., 2004) to about 1 km in the stratosphere (Kursinski et al., 1997)."**

    In Sect. 3.2 we point to the difference in geometries: **"We consider this a gratifying and very encouraging result for both techniques, given that we must appreciate that radiosondes and GPSRO measure the temperature information by entirely independent measurement principles and very different observational geometries."**

18. *"11746 15 to 20: Sentence seems out of place, Fig 5 does not include GRUAN?"*

    Fig. 5 includes comparisons of RS and GRUAN with GPSRO.

19. *"11747 15 to 20: Similar except above 20 hPa, but I imagine this is sample size related (very small)"*

    Yes.

20. *"11748 20 to 25: had you selected TWP site I think the relative wetness of GRUAN vs GTS RAOB mite look different."*

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We included the Nauru station in Fig. 7, see Item 4 above.

21. *"11752 5 to 10: this result may not hold in Tropics, tbd"*

    We added the following sentence: **"At the tropical GRUAN station (Nauru), the Vaisala RS92 humidity data is in good agreement with GRUAN, indicating that the dry bias might be smaller in the tropical regime."**

22. *"Add references from Zou, Nalli, Bodeker . . . "*

    We added references to Zou and Nalli, see above. Bodeker et al. is yet to be published.

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