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Replies to Interactive Comments on "Evaluation of two Vaisala RS92 radiosonde solar radiative dry bias correction algorithms"

March 10, 2016

Prelude

The authors would like to thank the reviewers and Dr. Isaac Moradi for their feedback on this study. The following document contains replies to each comment posted on the discussion board at http://www.atmos-meas-tech-discuss.net/amt-2015-258/.

This document is organized such that the name (if given) of each referee/commenter is given, and their original comment will be bolded. Replies from the author will be in *blue italics*.

In addition to addressing each individual comment provided, we have updated every figure in the paper to be neater and more professional looking – all plots are now in EPS (PDF) format, and are scalable such that image "graininess" is no longer an issue. Any comments or modifications made to the original text have been marked using Microsoft Word's "Track Changes" tool. Specific comments and modifications are reproduced, where appropriate, to the reviewer's comment(s).

Thank you again for taking the time to review our manuscript – we already notice an immediate difference in the quality of the paper. We look forward to hearing back from you.

Sincerely,
Andrew, Dave and Eli

1. Comments from *L. Miloshevich (Referee)*

I found this to be an interesting and useful study. As author of the MILO correction I'd like to offer the following feedback for your consideration:

We appreciate this comment. Thank you!

1. p 10759, especially footnote 1 where it states that RS92 does not require a time-lag correction. This is not correct. While the RS92 RH sensor does respond much faster than RS80, time-lag error can still be substantial when T < -45C. The sensor time-constant at - 45C is about 15 s, and at -70C it is 105 s. At a 5 m/s ascent rate this corresponds to a 63% sensor response on vertical scales of 75 m and 525 m respectively, which is the scale over which humidity features are "smoothed" by slow sensor response.

*Thank you for pointing out this error. The footnote has been updated to read the following (changes are **bolded**):*

*"**Although the** time lag correction was developed for RS80 radiosondes, **RS92 radiosondes also require a time lag correction**. See Miloshevich et al. (**2009**) **and Dirksen et al. (2014)** for more information."*

It's also relevant that Vaisala themselves implemented a RS92 RH time-lag correction in their Digicora v3.64 software (along with a solar radiation correction), so clearly Vaisala thinks that a TL correction is needed. Also, note that a more appropriate reference on this is my 2009 paper, not 2004 (which preceded widespread adoption of RS92).

*Thank you for pointing this out. As already given above, the footnote has been updated to reference your 2009 paper instead of your 2004 paper. As for Vaisala themselves implementing a time-lag correction in their Digicora v3.64 software, we were unaware of this and have updated the following text, starting on p. 10759, L06, to the following (changes are **bolded**):*

*"In 2011, Vaisala upgraded its DigiCORA® software to version 3.64, which included their own **time lag and** SRDB correction algorithm. **Although** the details of this algorithm are not freely available to the public**, it is possible to deactivate the time lag and SRDB during configuration of the sonde**."*

The character of time-lag error is complicated in that it affects the shape of the RH profile in the UT/LS, leading mostly to increased variability in statistical comparisons to other measurements but also to a small bias component in certain circumstances. The nature of time-lag error is illustrated in M09 Figs. 1a (red vs black) and 15a (red vs yellow). The RH generally decreases above the tropopause, so TL error in this 1- 2 km region is a moist bias, and a correction decreases the WV in this region. It is also common to see a high-RH layer that is capped at the tropopause, where TL error causes a dry bias below the base of the layer where the RH is increasing.

This is a very interesting note. We have implemented the time-lag correction according to your comments for the FLEDT data files, and use the information on your website to help facilitate the implementation. We did not, however, change our results to reflect the implementation of the time-lag correction – our reasoning is given in our reply to your next comment.

Time-lag error in the UT has little relevance for the MWR and GVRP comparisons, but may be notable and may explain some results for the AIRS comparisons. I wonder whether uncorrected TL error might explain some of the behavior you observed in individual altitude bins? The bias component is not a function of altitude and varies between profiles, so it might come across in altitude-based comparisons mostly as enhanced variability.

For the paper I recommend removing or changing footnote 1 and either: 1) implement a time-lag correction and repeat the analysis; or 2) give a better explanation of why the MILO time-lag correction was not applied and what its impact on the comparisons might be.

Please see the two figures below. We investigated the change in RH between our original results for the MILO correction (i.e. with no time-lag correction) from the time lag implemented MILO correction. The first plot shows 1 month of SGP (FLEDT) radiosondes, while the second plot shows all radiosondes launched during RHUBC-II (i.e. ~150 sondes). The blue line with squares represents the average RH in their respective 25 hPa bins (100-125, 125-150, … 475-500 hPa, etc.). In most cases, the time-lag correction makes a difference of around less than 10% below approximately 400 hPa and as high as 25% above 400 hPa. Given that our analyses mostly involve averaging data over various altitude bins, we averaged the change in RH between the two MILO corrections (time lag corrected and non-time lag corrected) and found that the ***average*** *difference is in many cases less than 1%, with a highest difference of around 2% (in the Cerro Toco data). The results for the SGP data (top figure) have an average very near 0%. The Cerro Toco data, on the other hand, shows some of the variability you suspected would occur – the time lag corrected data adds noticeably more RH at around 150 hPa, and noticeably less RH in the region immediately above it. Despite this feature, we will point out again that this average change is less than 2%.*

For the AIRS radiance closure experiment, the implementation of the time-lag correction would definitely manifest itself as enhanced variability, although our averaging resolution of 1 km (corresponding to ~50 hPa above 400 hPa) in figures 8 and 9 would likely "wash out" any of the noted differences caused by the time-lag correction. To reflect our reasoning, we have modified the text, starting on p. 10759, L06, to include:

"We note that for results shown later in this study, the RS92 RH data is not corrected for time lag error because the average change in RH between time lag and non-time lag corrected data is almost always around 0% and at most around 2% for 25 hPa bins (results not shown)."

The footnote has already been updated and stated in a reply to a previous comment.

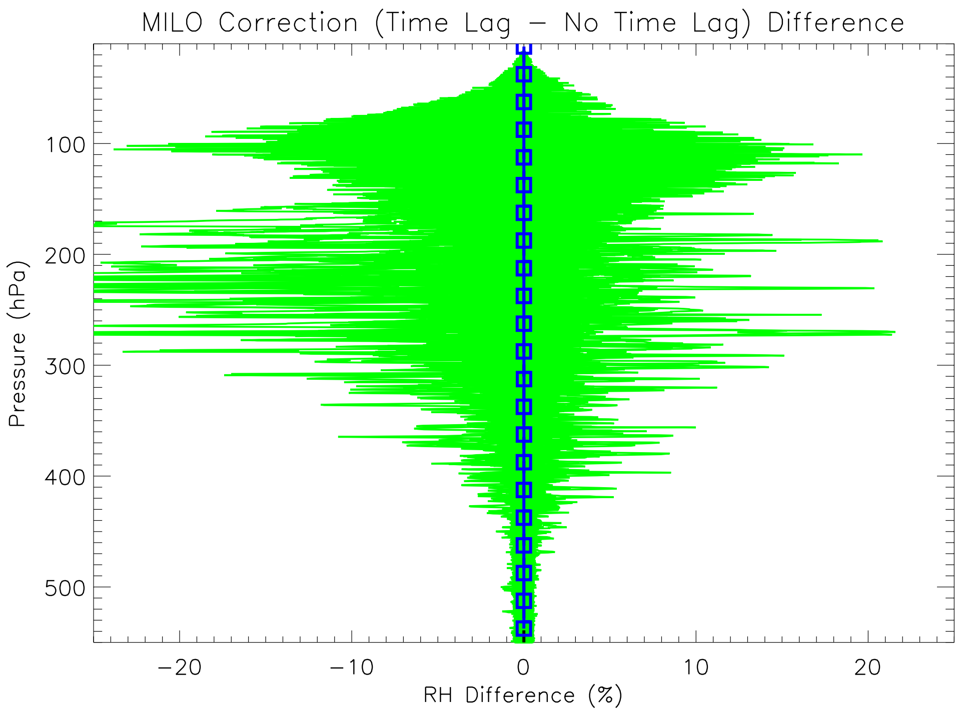

Figure: *MILO(time_lag_corr) – MILO(no_time_lag_corr) RH, averaged every 25 hPa, for the SGP site for 1 month of FLEDT data.*

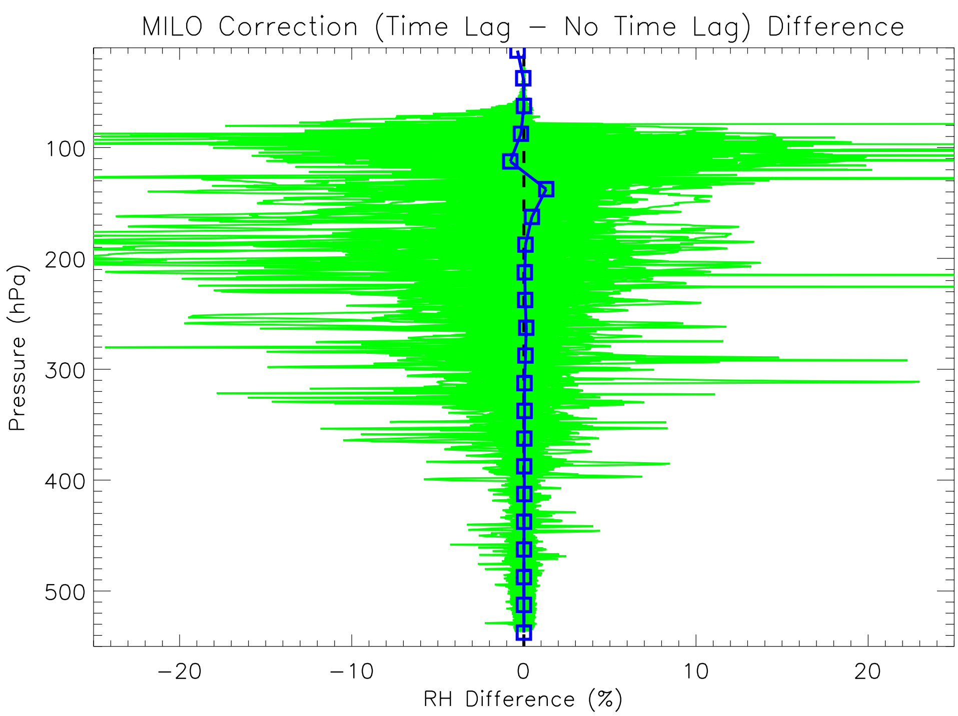

Figure: *Same as above, but for all radiosonde data from the RHUBC-II campaign in Cerro Toco, Chile.*

I suspect that you had both EDT and FLEDT RS92 data files, the former having integer RH values and a stairstep appearance in plots, and the latter having higher-resolution RH data. While it is very complicated to construct a TL correction for EDT data following the recipe in M04, it's fairly straightforward to implement a TL correction for FLEDT data because the profile is physically realistic. The data must be smoothed so that the TL correction doesn't amplify noise, but my fancy IDL smoothing algorithm is available on my radiosonde webpage at milo-scientific.com/radiosonde.php (click "RS92 Correction Method" and see especially the Overview, Notes on TL Correction, and IDL Code sections). Note also that there is a one-line time-constant expression in the Overview section (Fig. 1), which is an improvement over what's in the M04 paper (this fig is also published in Dirksen et al., 2014, AMTD).

Thank you for this information. Your code – both the time lag correction code as well as the empirical correction code - is very clean and was quite easy to implement. As researchers, we appreciate this a lot!

As already mentioned, we have implemented the time-lag correction to the FLEDT data files. Since the mean impact on the RH profile was zero, we have not applied the time-lag correction to the EDT data. All of our results in the paper do not use the time-lag correction.

2. Very dry conditions (Chile, lower stratosphere, occasionally in SGP or NSA tropospheric profiles)

It is correctly mentioned in the paper that the coarse 1% RH resolution of EDT data may be a big factor in the accuracy of the GVRP comparisons for very dry conditions (p 10764, top half). It may also be a factor for some of the AIRS comparisons. The ±0.5% RH uncertainty in the rounded EDT data corresponds to ±10% uncertainty at 5% RH, and ±25% uncertainty at 2% RH.

A suggestion for the paper is to explore the sensitivity of the comparisons to data precision/filetype by applying the solar radiation corrections to the original profiles after first reducing them by 0.5% RH or increasing them by 0.5% RH, to illustrate the impact of precision-related uncertainty on the comparisons.

We performed the sensitivity test you suggested by using (ORIG_RH – 0.5%) and (ORIG_RH + 0.5%) and then applied the respective WANG and MILO corrections. The result – for the SGP FLEDT data (top) and the entire CJC radiosonde dataset (bottom) – shows that a 0.5% systematic error causes almost no additional error up to about 500 hPa. At around 100 hPa, WANG propagates an additional 0.2% error, while MILO propagates an additional~0.3-0.4% error in RH for the SGP site. The CJC data shows heightened sensitivity to the lower RH values, with an additional 0.25% and 0.5% error for WANG/MILO respectively at 100 hPa.

*We have updated the text, starting with the sentence on p. 10764 L12 to reflect the results of this sensitivity study (changes are **bolded**):*

*"**Given** the extremely low RH values of ~10% characteristic of the CJC site (Fig. 6), the precision of the RH measurement itself **(0.5%) propagates an additional***

error as high as 0.5% in the resultant WANG/MILO corrections at the CJC site (result not shown). This adds an *additional residual error to the otherwise bias-corrected MonoRTM-computed* T_B *values."*

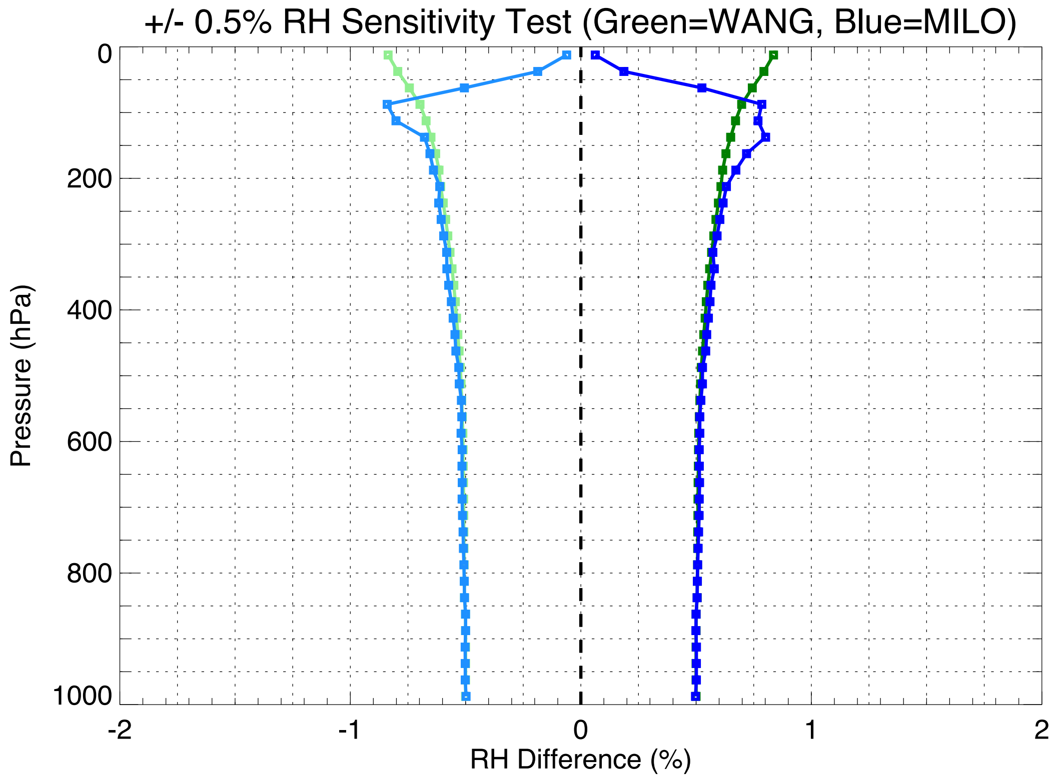

Figure: *WANG/MILO sensitivity to the precision of the RH measurement (-0.5% RH, left lines; +0.5% RH, right lines) at the SGP site.*

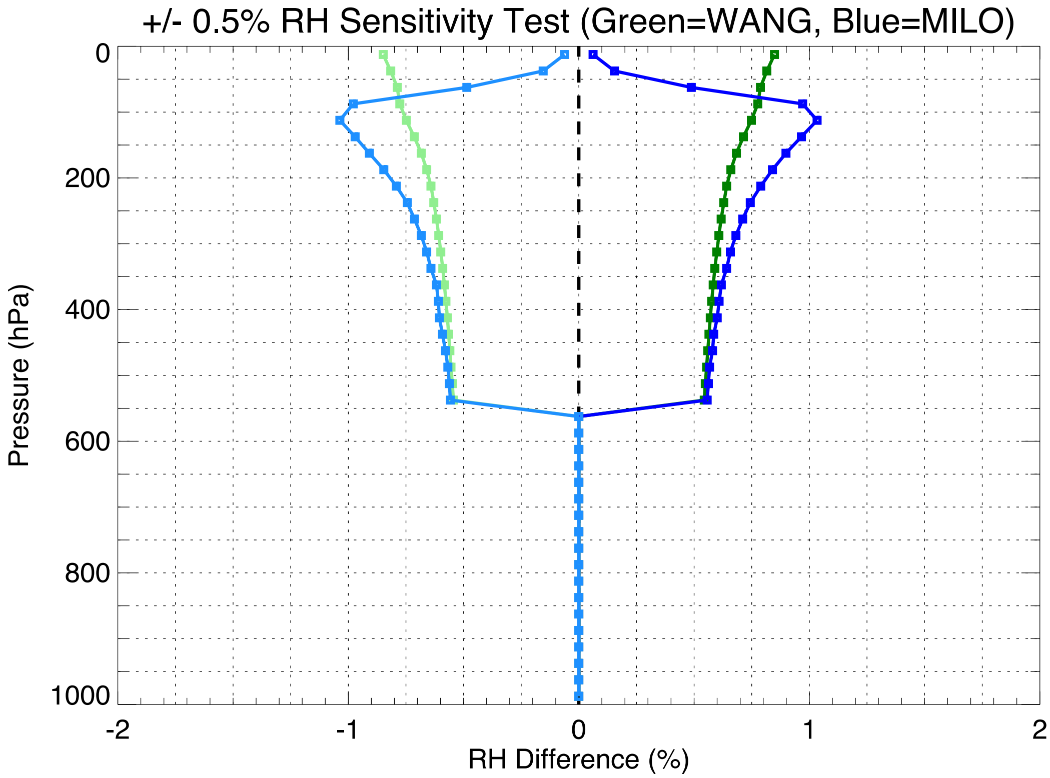

Figure: *Same as above, but for the CJC radiosonde dataset. Recall that the ground level at this site was 530 mb.*

It would be a service to the community to mention somewhere that users of Digicora III hardware should output the high RH precision FLEDT files rather than the standard/default 1% RH precision EDT files (see first bullet of "Best Practices" link on my radiosonde webpage, or refer to Appendix A of M09; also note the bullet that the 1% RH values in Vaisala data are not real).

We have added a footnote that states: ***We note that the time-lag correction is easier to apply if the RS92 data are stored with 0.1% precision (the so-called FLEDT file); Miloshevich et al. (2009) has recommended that this be done as "best practices."***

3. Some other misc comments

- In Conclusions, it might be important enough to repeat that standard Vaisala data beginning with Digicora v3.64 software include by default both time-lag and solar radiation corrections. It's important to raise awareness about this because, unfortunately, it's not apparent in data files whether or not Vaisala corrections have been applied, which is somewhat of a "nightmare situation" for Data Continuity (see final bullet under Best Practices on my radiosonde webpage).

We definitely agree with you on this, though we will point out another reviewer did mention that the time lag and solar radiation corrections can actually be turned on or off at the time of the radiosonde configuration (recall the change we made to p. 10759, L06). We feel this change is sufficient, considering we are not investigating RS92 data with DigiCORA v3.64 data.

FYI regarding data continuity, you may be interested in the following paper that compares Vaisala's empirical RS92 solar radiation correction with their new sensor that properly eliminates solar radiation error and the need for a correction altogether by measuring the RH sensor temperature: "Comparison of Vaisala radiosondes RS41 and RS92 at the ARM Southern Great Plains Site" http://www.atmos-meas-tech-discuss.net/8/11323/2015/amtd-8-11323-2015.html

This was a very interesting read, and we will be looking forward to the final version of this manuscript in AMT. Thank you for sharing this with us!

- Regarding the suggestion of adjusting WANG "cf" for cloudiness, this is an interesting idea. Conceivably, assumptions could be made allowing clouds to be inferred relative to the ice-saturation curve (see the experimental cloud adjustment approach on my Correction Method webpage (section "Algorithm changes since the published version of the bias corrections in 2009", final bullet and Fig. 4). However, this approach is really quite complicated and subject to error because there's a huge difference in cloud extinction per km for cirrus vs lower-altitude clouds, ice vs liquid, and in general just the huge variability that arises from cloud microphysical properties. Any "cf" cloudiness adjustment will at a minimum need to vary with altitude (or temperature) and water phase.

*You hit the nail on the head here. The "cf" factor in the WANG correction definitely offers an avenue for improvement of the algorithm without completely overhauling it, though the complexities you mention will likely require significant development. In the spirit of maintaining our suggestion about modifying the "cf", while integrating the complexity of such a task, we have updated the conclusions – specifically at p. 10774, L07 – to state the following (changes are **bolded**):*

*"**This change, however, may be complicated by the fact that cloud extinction varies significantly between high ice clouds and low-altitude liquid clouds, and considering the large variability in the microphysical properties between these two types of clouds, adjusting the "cf" would at minimum need to be a function of altitude and water phase. If this adjustment could be made, the WANG correction would become more robust and** would be applicable to an increased number of applications.*