Atmos. Meas. Tech. Discuss.,
doi:10.5194/amt-2017-486-AC1, 2018

Atmospheric Measurement Techniques Discussions

AMTD

Interactive comment

Interactive comment on "Evaluating tropospheric humidity from GPS radio occultation, radiosonde, and AIRS from high-resolution time series" *by* Therese Rieckh et al.

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Received and published: 29 March 2018

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Authors' response to referee #1

We thank the anonymous referee #1 for the review and comments. We will implement the following changes according to the referee's suggestions. We have answered all comments below (for easier comparison the referee comments are included in italics). All page and line number refer to the originally submitted manuscript.

Comments:

1. The work uses ERA-Interim as reference data to quantify "biases" of other datasets. However, comparison to AMSR total column water vapor shows that ERA-Interim may have dry bias in certain atmospheric conditions. The author also states in Pg. 3 Line 13 that previous work has shown ECMWF reanalysis being drier compared to MERRA and JPL RO (although there may be differences between ECMWF reanalysis and ERA-Interim). If the authors think ERA-Interim can be guaranteed as the "truth" at least at the 4 locations discussed in the paper, they need to clarify with reasons or references to support this. Otherwise, the authors may consider to mitigate the wording such as "biases" when referring to differences between other datasets and ERA-Interim.

The reviewer brings up a good point. We have clarified in the paper that we do not consider ERA-Interim to be the "truth", but rather use it as a common reference for comparison of all the data sets. We need a baseline for our comparison, and the ERA is the most suitable data set for that purpose. ERA assimilates a high number of quality-controlled observations in a research (rather than operational) mode, which should overall minimize variability and bias around the true values. ERA also is a complete date set (unlike the observational data sets) because it has data at all comparison points and at all times. Furthermore, even though ERA is not assumed to be an absolute "truth" and without errors, ERA has the smallest error variances when compared to RO, RS, and GFS as shown in the related paper (Anthes and Rieckh, 2018).

Thus we modified the first two sentences in the section describing ERA (Sec. 2.2, P. 6, L. 13–17) to clarify: "We use the ERA as a reference (or baseline) for our comparisons. We do not consider ERA as "truth", but we do consider the ERA to be the most accurate data set (Anthes and Rieckh, 2018), because it uses quality-checked observations with a 4D-Var data assimilation scheme and an accurate forecast model

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in a research mode to produce the variables of interest here (temperature and water vapor) on a $0.7° \times 0.7°$ grid. In 2007 ERA assimilates measurements from many different observing techniques, including RS observations, AIRS radiances, and RO bending angles (Dee et al., 2011). Thus, when using the word "bias" for a data set in a comparison, we refer to the bias difference with respect to ERA."

Furthermore, we edited the following sentences: P.11 L.3, P14 L.2, P.16, L.1 (section title), P.16 L.2–3, P.17 L.1, and P.20 L.10.

2. Different datasets have different footprints as mentioned in the paper. Therefore, AIRS specific humidity represents average value within the 45 km AIRS footprint, while radiosondes are point measurement. While GPS RO is occultation, its equivalent horizontal resolution may be lower. How these differences of resolution of different datasets influence the uncertainty estimates when compared to ERA-Interim with a resolution of 0.7°?

Since RS is a point measurement, it has the potential to show variability that occurs on smaller spatial scales compared to AIRS (~45 km average), ERA ($0.7° \approx$ 78 km and less, depending on the latitude), and RO (average over ~200 km). This makes AIRS, RO, and ERA fairly comparable in terms of horizontal resolution. To account for the larger vertical variability of RS due to its ability to detect small scale features, we tested vertically averaging the RS profiles over pressure layers before interpolating to the common 25 hPa grid. Since results were very similar to the original approach (interpolation only), we used the original approach throughout the paper.

3. As mentioned on Page 8 Lines 9–13, different datasets have different quality flags that result in different sampling sizes after paired up with ERA-Interim. As quality flag of a particular dataset favors particular atmospheric conditions (e.g., AIRS quality flags

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favor conditions of less deep-thick clouds). How may these differences in sample sizes influence the general conclusions of the work? For example, if one constraints all datasets to have the same samples after paired up with ERA-Interim, will this give different patterns for plots like Figs. 3–8?

Our goal was to maximize the number of co-locations and show the results of all the data set compared to ERA. Generally, a higher number of co-locations will create a more accurate and complete picture. If we restricted all data sets to the same co-locations and sample size, we would have removed a lot of information. E.g., AIRS passes over the observed region at around 4:30–5:30 UTC and again at around 17:00–18:00 UTC, while RS are launched around noon and midnight UTC, which makes a common co-location within less than 5 hours impossible.

4. Super-refraction seems to be a big problem for GPS retrievals. The authors may consider including some discussion of how the users of GPS can know if bad quality of retrievals caused by super-refraction exists in a particular profile. Or if GPS datasets provide quality flags to inform users if such events occur?

Super-refraction (SR) can generally be detected on an individual profile basis by identifying profiles with a very sharp change in bending angle and a refractivity bias with respect to another, unbiased data set. This usually occurs in the tropics in the lower troposphere, and often at the top of the boundary layer. However, as far as we know, a robust method that can be applied operationally has not been developed so far. The authors are not aware that any RO processing center flags profiles that experience SR.

Specific Comments:

Figure 2 caption: "Scatter plots of normalized q for 7 days..." It seems that these are not "normalized q" as the units are g/kg. Normalized q should have no unit.

Thank you, the reviewer is correct. we removed the work “normalized” from that sentence.

Pg. 11 Lines 5–8: Such dubious radiosonde profiles with constant humidity profiles are easily detected and should be excluded from the matched up pairs. Otherwise, the comparison is unfair for radiosondes. If such data are excluded, will the plots of Fig. 4a, Figs 6 and 8 be drastically changed?

We do not think any portions of any of our data sets should be removed on the basis of possible or likely errors. One of the points of the comparisons is to identify such errors. Each data set may have its own set of errors or issues. To be fair, all data sets should be compared in their complete form as they passed internal (data set specific) quality control and are available for the research community. One of the purposes of our comparison study is to identify strengths and weaknesses, including errors, of all the data sets, in order that the providers of the data sets may improve their accuracy and to make users aware of the full characteristics of the data sets.

Pg. 12 Lines 2–3: For deep convective clouds (thick clouds with high cloud top), the dry bias is throughout the troposphere. For low-level, thick clouds (stratocumulus or stratus), the large dry bias is confined in the lower troposphere.

We reformulated the sentence on P.12 L.1–3 to: “They found reduced dry biases in the middle troposphere under thin clouds, but large dry biases in the lower troposphere ($>$30%) associated with low thick clouds, and dry biases throughout the troposphere in the presence of high thick clouds.”

Pg. 12 Line 12 – Pg 13 Line 2: It is good that the authors caution the problem in ERA-Interim. But in general, can ERA-Interim be regarded as a perfect “truth”? (See Main Comment #1).

Please see our response to the reviewer's main comment #1.

Pg. 18 Eqn. (4): Need a bracket for (Xk - Xkinter-center) in the equation before multiplied by 100/XERAannual.

Thank you, we added parenthesis in the equation.

Pg. 18 Line 14: Need to spend a sentence or two to explain what "inter-center mean" means. Or use an equation to tell readers how it's calculated.

We changed the sentence on P.18 L.16 after Eq. (4) to: "where k indicates the profile number, $\overline{X}_k^{\text{inter-center}}$ is the inter-center average for the k^{th} profile $(1/4 \cdot (X_k^{\text{UCAR direct}} + X_k^{\text{UCAR 1D-Var}} + X_k^{\text{JPL direct}} + X_k^{\text{WEGC 1D-Var}})$, and ΔX is the deviation (of q or N) of one particular RO retrieval from the inter-center average."

Pg. 20 and Pg. 21: The authors may consider pointing at the figure number that supports each conclusive bullet.

Thank you. Figure numbers in the conclusions are now added.

Pg. 21 Lines 10–11: "...RO should have a large positive impact on improving the water vapor analysis in data assimilation in the lower and mid troposphere." Is this statement contradicting the claim on Pg. 4 Lines 10–14 that "RO makes a relatively small contribution in the ERA reanalysis."?

In our view, the problem is that with current models, RO makes a relatively small contribution to the moisture analysis in the lower and mid troposphere because the assigned errors in the data assimilation process are too large, and so RO observations are not weighted heavily enough. To make a clearer statement, we rephrased

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this sentence to: “If assigned smaller errors (and therefore greater weights) in the assimilation process, RO could have a positive impact on improving the water vapor analysis in data assimilation in the lower and mid troposphere.”

References

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