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Interactive comment on "Estimating observation and model error variances using multiple data sets" *by* Richard A. Anthes and Therese Rieckh

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This manuscript applies the N-cornered hat technique to estimate errors in geophysical measurements: radio occultation, radiosondes, ERA-Interim reanalysis and weather forecast outputs at four locations in the tropics and subtropics. The N-cornered hat technique is closely related to the method of triple collocation, which has been widely applied to geophysical datasets in the literature (as the authors note). However, some subtle differences between the approaches are missed in this analysis, which may impact the results.

One important difference between triple collocation (TC) and the three-cornered hat (3CH) is the treatment of the underlying truth. TC treats the underlying truth as a random variable (Stoffelen 1998), whereas 3CH does not. As a result, TC requires an additional assumption compared to 3CH: the errors must be uncorrelated with the un-

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derlying truth. Since the underlying truth is not considered to be a random variable in 3CH, the correlation between the errors and truth is always zero. So, should the underlying truth be treated as a random variable (as in TC) or as deterministic (as in 3CH)? I would argue that, for assessing the stability of clocks, the assumption of a deterministic underlying truth is quite reasonable. However, when considering atmospheric applications, as in this study, it is hard to justify. The atmosphere is a chaotic system with substantial internal variability. Differences between measurements can be due to measurement errors, but they can also be due to the internal variability of the chaotic system. In Figure 3a, for example, there are clear differences between the specific humidity profile estimated by GFS and RS on 13 January, 2007 at 00:23 UTC. Even if the measurement and modelling errors of both GFS and RS were both zero, we would expect there to be some difference between these two profiles because of the internal variability of the system, even accounting for some assimilation of observations into the GFS. Yet the 3CH implicitly attributes ALL differences between different measurement types to measurement errors in one or more measurement types. This seems misguided and is one of the reasons TC is typically applied to geophysical measurements rather than 3CH. Treating the underlying truth as deterministic rather than random leads the authors to neglect the impacts of possible covariance between the errors and the underlying truth, which is likely biasing the error estimates in this study.

A second important difference is that TC accounts for multiplicative biases in the measurements in a way that 3CH does not. 3CH implies the following measurement model:

$i = T + e\_i \ldots$ (1)

where T is the unknown true value, and e_i is the error in measurement i. In contrast, triple collocation starts with the measurement model:

$i = a\_i + b\_i{}^*T + e\_i \ldots$ (2)

where a_i and b_i are additive and multiplicative biases, respectively (see Gruber et al. (2016), equation 1). The advantage of the measurement model in TC is that it is

robust to multiplicative biases. If multiplicative biases exist but are not factored into the measurement model (as in 3CH), the multiplicative biases will lead to substantial correlations between the errors and the unknown truth. In turn, the neglect of these correlations will bias 3CH error estimates.

Given both of these problems with the analysis, it is not surprising that the estimated errors (for example, in Figure 10) are not internally consistent (as they should be, if either technique – 3CH or TC – were applied appropriately). While 3CH and TC are similar in many respects, there are good reasons to use TC rather than 3CH when characterizing errors in geophysical data. Therefore, to address these concerns, I recommend the authors reframe their analysis using TC rather than 3CH. The differences between the techniques are relatively small, but significant, and warrant a substantial rewrite of the manuscript, in my view.

Specific comments Line 7, p 16: "…indicate that our estimates are reasonable and consistent with these studies." It seems unreasonable to be making this claim given the estimates in this study vary enormously. It is easy for an imprecise estimate to be consistent with previous studies, but this is not particularly informative.

References

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