Atmos. Meas. Tech. Discuss.,
doi:10.5194/amt-2018-75-AC1, 2018

Atmospheric Measurement Techniques Discussions
Open Access

Interactive comment on "Evaluating two methods of estimating error variances from multiple data sets using an error model" *by* Therese Rieckh and Richard Anthes

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Received and published: 8 May 2018

We thank the two referees for their comments and constructive feedback, which we have considered in the revised paper. Their comments and our responses are addressed below. All page and line numbers in the referee's comments refer to the originally submitted version of the paper. All page and line numbers in our response refer to the revised paper.

Anonymous Referee #1 Interactive comment on Atmos. Meas. Tech. Discuss., doi:10.5194/amt-2018-75, 2018. Received and published: 26 March 2018

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Discussion paper

The paper compares two simple methods for estimating error variances from double or triple collocated data using simulated and real data. The error estimation methods are the two and three cornered hat methods (2CH and 3CH). The paper is interesting, but should be considerably improved. The present version is not suitable for publication.

We have revised the paper according to the referee's suggestions.

1. The presentation is rather sloppy, and it looks more like a report than a scientific paper. For instance, equations (18b-c-d) are essentially the same equation, and indicating cancelling terms by crossing them out (pages 11 and 12) is not the style of a scientific paper. Variance is defined, but MS (equation (2) and further) not.

We have fundamentally revised the structure of the paper, eliminated some of the equations and intermediate steps of the derivations, moved the 2CH derivation into an appendix, addressed the style issue, and made sure all the terms are defined. We have also eliminated the need for both lower case and upper case X, Y and Z.

2. More seriously, the authors seem to assume that their data are well calibrated and do not contain any representativeness errors - at least these problems are nowhere mentioned. Therefore they are surprised when pairwise 2CH error estimates are different from each other and from 3CH error estimates, attribute this to biases, and work this idea out in section 7. But the differences may very well be a matter of representativeness. Both in 2CH and 3CH the "true" signal is the common signal shared by the two or three observation systems under consideration, and the "true" signal is determined by the system with the lowest resolution, see Stoffelen (1998). The authors should consider this.

The reviewer raises issues related to calibration and representativeness errors in this comment.

Calibration: The calibration issue is closely related to the bias issue that we discuss. In the TC method, two of the data sets are calibrated against a third so that the three data sets are not biased with respect to each other. In the simplest form of the 3CH method, the data sets are not calibrated against each other, and thus some biases can exist. We investigate the effect of a 10% bias in one of the data sets and show even this fairly large bias does not greatly affect the 3CH results. However, even a much smaller bias affects the 2CH in a significant way. In addition, we also investigated the effect of biases in the related paper Anthes and Rieckh, 2018 by comparing the 3CH method to the triple co-location (TC) method (Stoffelen, 1998; Vogelzang et al., 2011). The results using the TC, in which the data sets were calibrated with respect to each other, were very similar to those using the 3CH method, confirming our results with the error model that biases do not cause large errors in the 3CH method.

To address this comment, we have added the following discussion to the beginning of Section 5:

"All four data sets have some degree of unknown bias for certain locations, altitudes, or atmospheric conditions; none of them represent the ultimate "truth" and there is no standard atmospheric data set for calibration. However, they have all been compared to other models or observations to one degree or another. We investigated the effect of biases in the related paper Anthes and Rieckh (2018) by comparing the 3CH method to the triple co-location (TC) method (Stoffelen, 1998; Vogelzang et al., 2011). The results using the TC method, in which the data sets were calibrated using the ERA-Interim data set as the calibration reference, were very similar to those using the 3CH method."

2) Representativeness errors: We mention representativeness errors in the Introduction and discuss them in Section 5. The idealized model data sets with prescribed errors we developed are free of representativeness errors; they contain only known (specified) random and bias errors. However, a portion of the specified errors in the error model may be thought of as representativeness errors. Also, the 3CH method includes representativeness errors as part of the error estimates.

The two model (ERA-Interim and GFS) and two observational (RS and RO) data sets include random and bias errors. Representativeness errors, which are included in the error estimates from both the 2CH and 3CH method, may contribute to these random or bias errors. As our results show, random errors do not cause large differences between the 2CH and 3CH methods if the sample size is large enough; only bias errors do.

We showed that biases in one of the two data sets with respect to the other will cause large errors in the 2CH method. We believe this is the issue that Dr. Vogelzang discussed in his supplement discussion. We agree with his conclusion, that the 2CH method is very sensitive to calibration (bias) issues.

We added the following paragraph on page 16 to address the comment on representativeness errors:

"The two model and the RO data sets are representative of similar horizontal scales (∼100 km), while the radiosonde data are in-situ point measurements and therefore represent a much smaller horizontal scale. However, many studies (e.g. Ho et al., 2010a,b; Kuo et al. 2004, Chen et al. 2011) have used radiosonde data as correlative data for verifying models, RO, and other data sets without applying corrections for representativeness errors. These results indicate that the different representative scales are not a significant source of error in the comparisons (unlike spatial and temporal sampling errors resulting from the time and spatial differences between the data sets, which we correct for). However, any representativeness errors are included in the error estimates using either the 2CH or 3CH method."

3. Another serious point is that the authors assume their error model to be valid without any further justification. A scatter plot of the data - the starting point of all analysis of data from multiple sources - would be helpful here. It will show if any calibration issues play a role and if errors indeed can be assumed to be independent of the observed value. The current presentation is more of a "trial and error" type. This should be considerably improved.

The error model is based on previous studies that have estimated the error profile of specific humidity. In order to justify the error model, we have added the following paragraph to the end of Section 3, page 5 line 19:

"The error model is created based on error estimates of specific humidity from several studies (e.g. Kursinski, 1997; Collard and Healy, 2003; von Engeln and Nedoluha, 2005; Wang et al., 2013). For example, Collard and Healy (2003) found that, for tropical conditions, the percentage errors for RO specific humidity varied from approximately 10% near the surface to about 70% near 300 hPa. Other studies show the errors varying from about 10% near the surface to 100% in the upper troposphere (about 200 hPa). In our error model, we specified the STD to roughly approximate the STD of RO or RS data at Minamidaitojima, Japan (Anthes and Rieckh, 2018; Rieckh et al., 2018). The assumed STD of normalized q (percent error) given by Eq. (9) is consistent with the above empirical error estimates. Thus the error model is a reasonable one in terms of its magnitude and increase with height. Since it is intended to show the sensitivity of the 3CH and 2CH methods to varying degrees of correlation between two of the data sets used in the comparison, it is not necessary that the error model be a close replication of any particular observing system, just that the magnitude of the assumed errors and their vertical distribution be reasonable.

4. A minor point: the link to Wriley (2003) gives no information on the history of the 3CH method.

Thank you; we have revised this sentence to: "W.J. Riley (2003), and references therein, provide a summary of the 3CH method."

Anonymous Referee #2 Interactive comment on Atmos. Meas. Tech. Discuss., doi:10.5194/amt-2018-75, 2018. Received and published: 27 March 2018

General comments

The authors compare error variances as generated from the three-cornered hat (3CH)

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and two-cornered hat (2CH) methods from simulated and real data sets. As expected, the 3CH results were less noisy and less sensitive to biases. The authors do a good job of presenting their widespread findings (from simulated and correlated data, as well as collocated real observations); however, I have some comments and suggestions that I would like to see addressed in their revision.

The 3CH assumes independent, uncorrelated observations, and its usefulness can be limited by the sample size, as well as the variability the source data itself. The authors do mention several times that finite sample sizes will cause the cross-correlation terms to be non-zero. However, they do not seem to address the point that the error variances produced by the 3CH method (and likely 2CH as well) can be dominated by a data source that is largely different than the other two in the trio being analyzed. Thus, the size of the relative errors from the RO, GFS, ERA, and RS observations comes into play in the accuracy of the 3CH results in Section 6.

Page 2 line 23 says that widely different errors associated with the three systems can reduce the accuracy of the estimates. We have inserted references to this in the revised paper. In our error model, the magnitudes of the errors in all three simulated data sets are similar. Previous studies of the errors of the systems tested in our paper (two model sets, ERA-Interim and GFS, and two observational data sets, RO and RS), indicate that the errors of all these systems are also of similar orders of magnitude (please see references in the paper and below). In addition, we recently used the 3CH to estimate the errors associated with these data sets and found that they were similar in magnitude (Anthes and Rieckh, 2018).

Some of the equation development is either incomplete or hard to follow. For example, on Pages 11-12, the authors derive equations for the estimated error variance of X,Y,Z. They start with the traditional equation for the variance (equations 2,3, and 4), but cross out some terms, then neglect the covariance term in the next step (because it's the 3CH estimate), then plug it back in. It took me a while to put it all together, so maybe the authors can add some additional text or format differently to help the reader

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along.

We agree and have revised the presentation of the equations by reducing the number of similar equations and clarifying the presentation. Please see also the response to Comment 1 of Reviewer 1.

The authors also seem to already possess knowledge regarding climatological processes and models to set up and normalize their model profile (section 3.1). Perhaps these numbers are taken from some of their previous work, but some additional text or references pertaining to the source or reasoning behind these numbers would be helpful.

We have provided considerably more discussion in the first part of Section 3 on the error model and its properties, including comparison with other studies of the estimated errors of specific humidity observations in the atmosphere. Please see our response to point 3 of Reviewer #1 (above) and the added paragraph discussing the error model.

Line edits The grammar and sentence structure is quite good and easy to read, I only have a few line edits to offer.

Thank you for the careful reading. We have corrected all these typos.

Page 2 Line 11: Should be W.J. Riley, not W.J. Wriley Corrected.

Line 13: 3CH, not 3HC Corrected.

Page 8 Line 17: Should x,z be capitalized?

Section 3 had confusing notation with the upper and lower case variables. We have revised the text and equations to use only upper case X, Y and Z.

Page 9 Line 3: Should be There, not These Corrected.

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Interactive comment on Atmos. Meas. Tech. Discuss., doi:10.5194/amt-2018-75, 2018.