Evaluating Random Errors of Atmospheric Observations, Model Forecasts, and Reanalyses Using the Three-Cornered Hat Method

Therese Rieckh, Jeremiah Sjoberg, Richard A. Anthes
COSMIC Program Office, UCAR
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Three-cornered hat method key points

- Requires three data sets and provides error variance estimates of random errors

- Removes the impact of biases, but includes all other sources of errors: instrument, processing, co-location, representativeness,..

- Exact…unless the errors of the data sets are correlated due to:
  1) actual error correlations
  2) representativeness differences (can be large)
  3) errors introduced by the co-location process
  4) correlations arising by chance in small sample sizes (negligible in results shown here)
Three-cornered hat method key points (2)

- Note: representativeness differences impact all metrics comparing two or more data sets
- Advantage of 3CH: we derive error variances estimates for many data sets at once, and different data set combinations allow conclusions on data set relationships
- $N$ data sets give $(N-1)(N-2)/2$ estimates per data set

Data set overview

Oct–Nov 2006:
- COSMIC (C1)
- ERA5
- ERA-Interim
- MERRA
- MERRA-2
- JRA-55
- JRA-55C
- ERA-20C
- 20CR

Oct–Nov 2019:
- COSMIC-2 (C2)
- Radiosonde (RS)
- ERA5
- GFS
- CFSRv2
- MERRA-2
- JRA-55

Observations

Reanalyses with conventional obs./surface obs. assimilated

Normalization: mean ERA5
Variable: refractivity error standard deviations (%)

Results: refractivity 2006

C1

\((N-1)(N-2)/2\) estimates

ERA5 and C1 combinations:
- Actual error correlations
- Representativeness

Note: latitudinal sampling adjustment

Note that the 28 estimates would be identical if the footprints of the 9 data sets were the same and there were no error correlations among any of the 9 data sets
Results: refractivity 2006 vs 2019
C1 and C2
\((N-1)(N-2)/2\) estimates

ERA5 and C1 combinations:
- Actual error correlations
- Representativeness

ERA5 and C2 combinations:
- Representativeness

Note: latitudinal sampling adjustment
Results: refractivity 2006 vs 2019

Mean of estimates

- C2 slightly larger in lower and mid troposphere
- C2 slightly larger above 15km

→ Smaller error correlation of C2 with other data sets
→ Increased moisture in 2019

Note: latitudinal sampling adjustment
Results: refractivity, radiosonde

Mean and Stddev of estimates

- At RS locations only
- RS estimates much larger than those of other data sets
- RS estimates larger than RS intrinsic error
- Due to very different horizontal and vertical footprints (representativeness) compared to all other data sets
Results:
land vs. sea

C2-global
COSMIC-2
ERA5
GFS
MERRA-2
JRA-55
Results: rising vs. setting occultations

C2-global
COSMIC-2
ERA5
MERRA-2
Results:

rising vs. setting occultations

C2-global
COSMIC-2
ERA5
MERRA-2

rising – solid
setting – dashed
Summary

- Using many data sets in the 3CH method helps to identify error correlations from various sources.
- Representativeness differences, caused by differences in vertical and horizontal footprints of data sets, must be taken into account when interpreting the 3CH estimates.
- Error estimates of radiosondes are very large due to representativeness differences.
- Error estimates vary strongly with latitude and atmospheric conditions.
- COSMIC and COSMIC-2 error estimates are comparable to those of state-of-the-art reanalyses.