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

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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

Sjoberg et al (2021): The three-cornered hat method for estimating error variances of three or more atmospheric data sets – Part 1: Overview and evaluation. *J. Atmos. Oceanic Technol.*, 38, 10.1175/JTECH-D-19-0217.1
Rieckh et al (2021): The three-cornered hat method for estimating error variances of three or more atmospheric data sets – Part 2: Evaluating radio occultation and radiosonde observations, global model forecasts, and reanalyses. *J. Atmos. Oceanic Technol.*, in review.

Data set overview

Oct–Nov 2006:

COSMIC (C1) } *Observations*
ERA5
ERA-Interim
MERRA
MERRA-2
JRA-55
JRA-55C } *Reanalyses with conventional obs./ surface obs. assimilated*
ERA-20C
20CR

Oct–Nov 2019:

{ COSMIC-2 (C2) *Observations*
Radiosonde (RS)
ERA5
GFS
CFSRv2
MERRA-2
JRA-55

Normalization: mean ERA5

Variable: refractivity

error standard deviations (%)

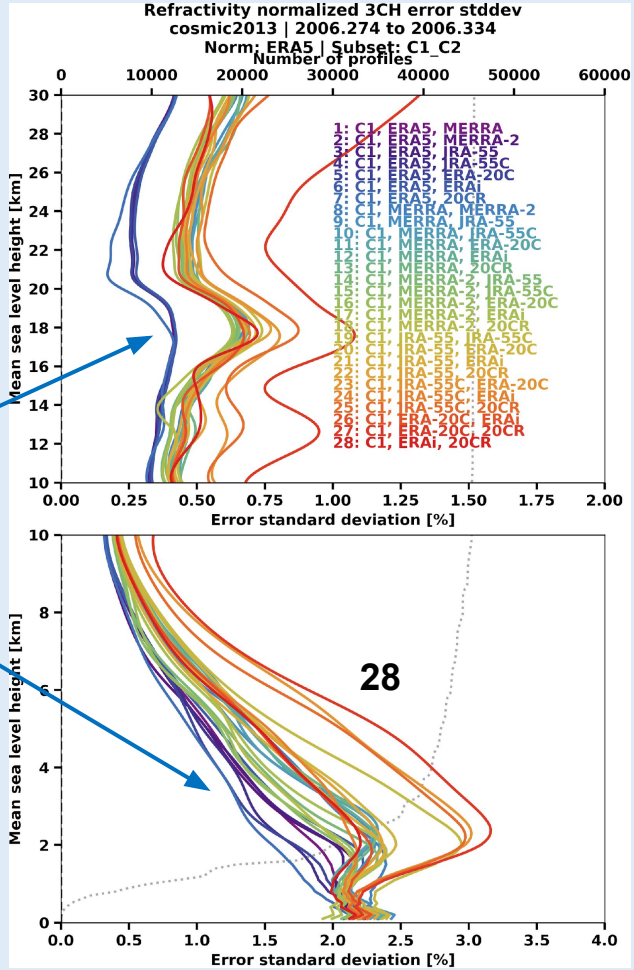
Results: refractivity 2006

C1

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

ERA5 and C1 combinations:

- Actual error correlations
- Representativeness



Note 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

Note: latitudinal sampling adjustment

Results: refractivity 2006 vs 2019

C1 and C2

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

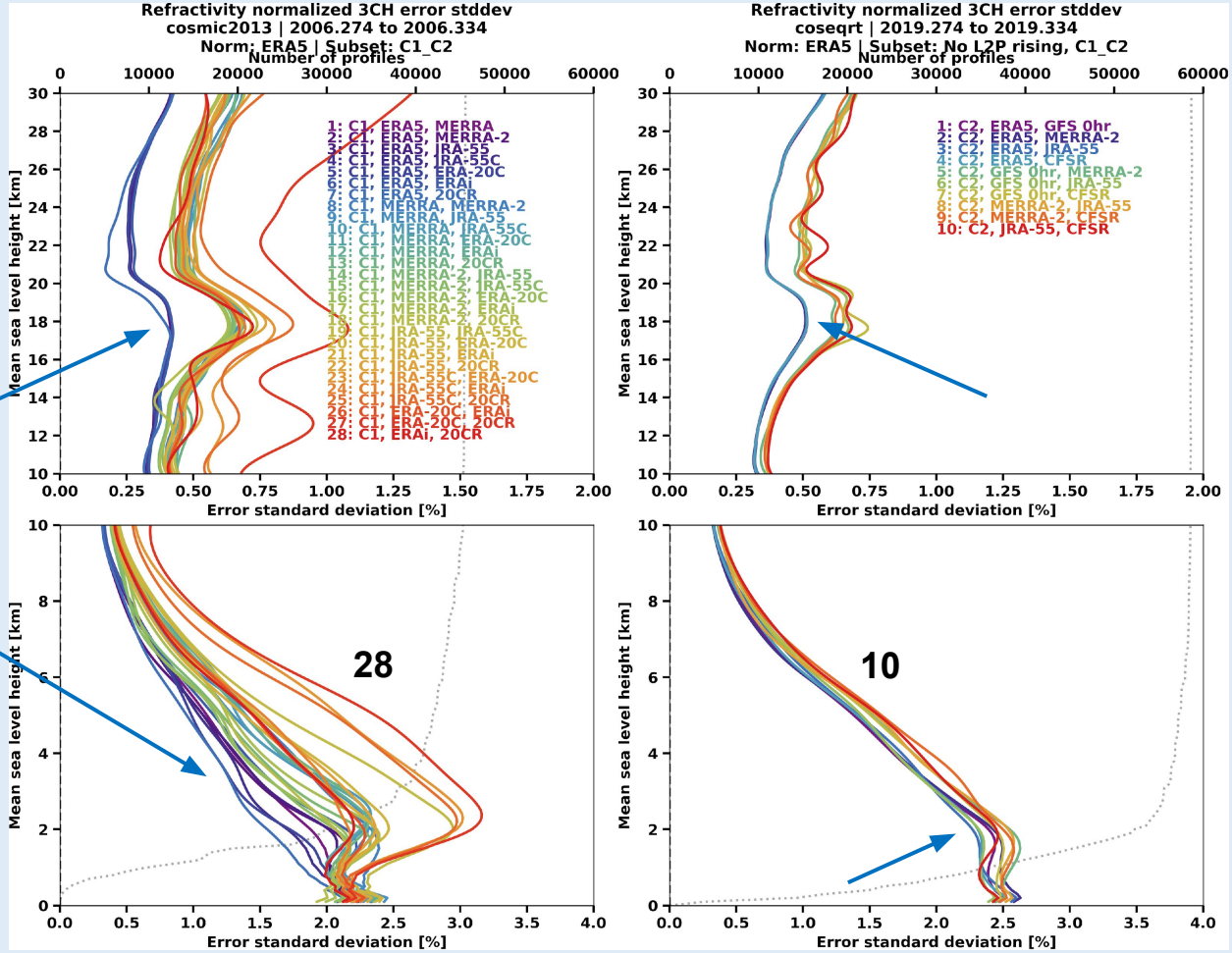
ERA5 and C1 combinations:

- Actual error correlations
- Representativeness

ERA5 and C2 combinations:

- Representativeness

Note: latitudinal sampling adjustment



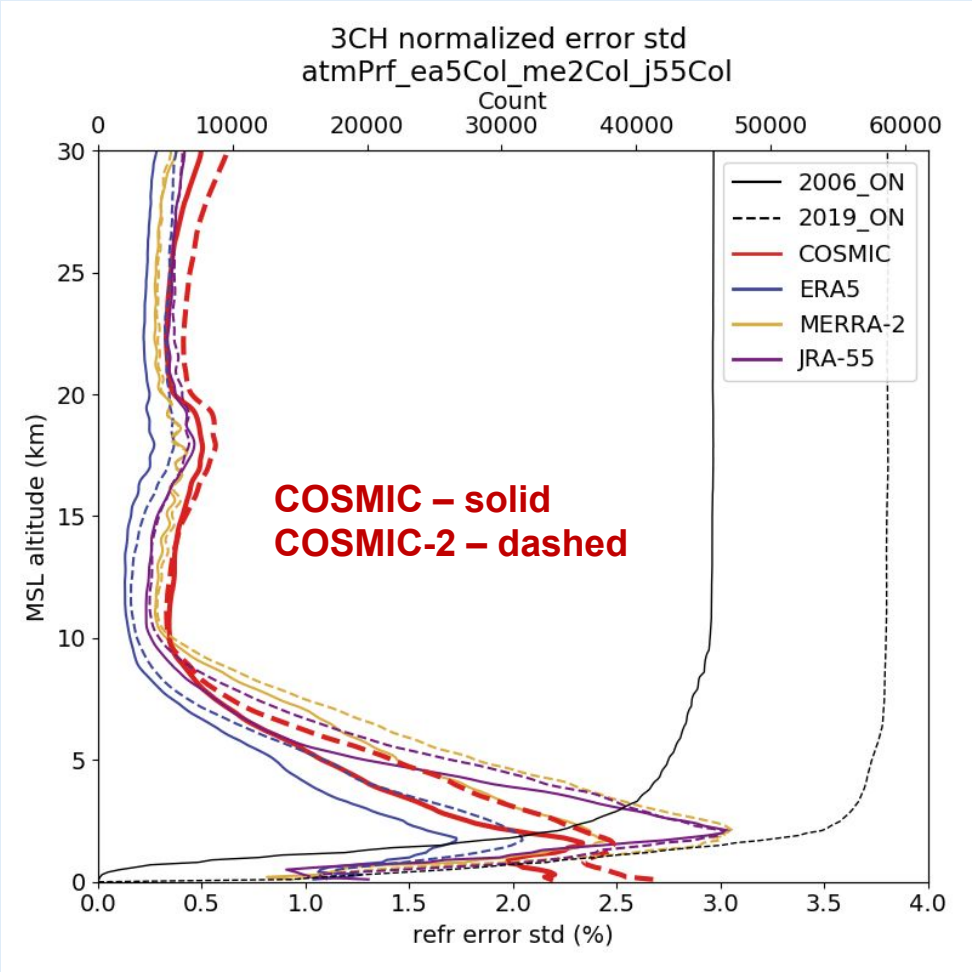
Results: refractivity 2006 vs 2019

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

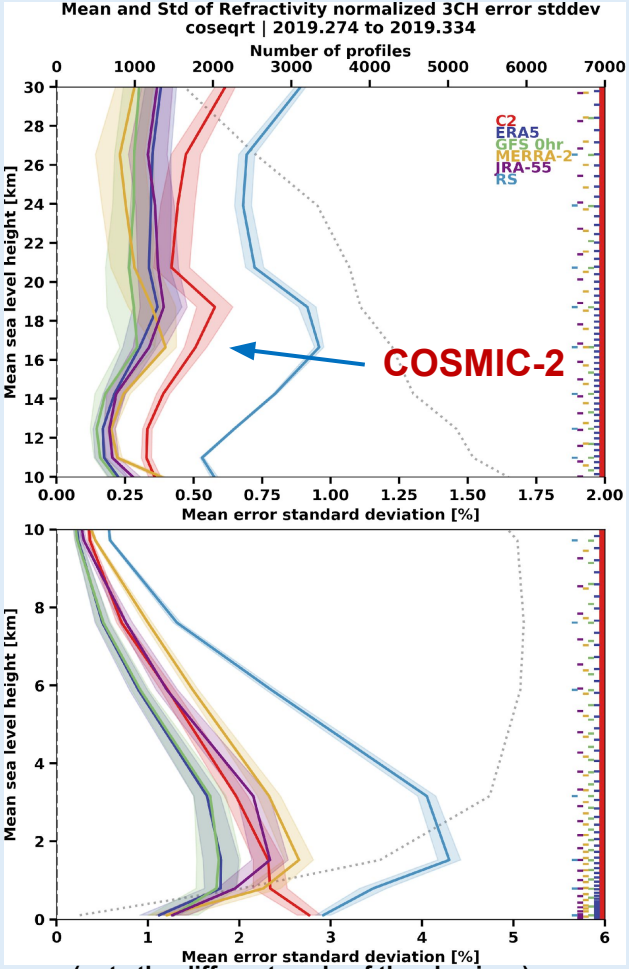
Note: latitudinal sampling adjustment



Results: refractivity, radiosonde

Mean and Stddev of estimates

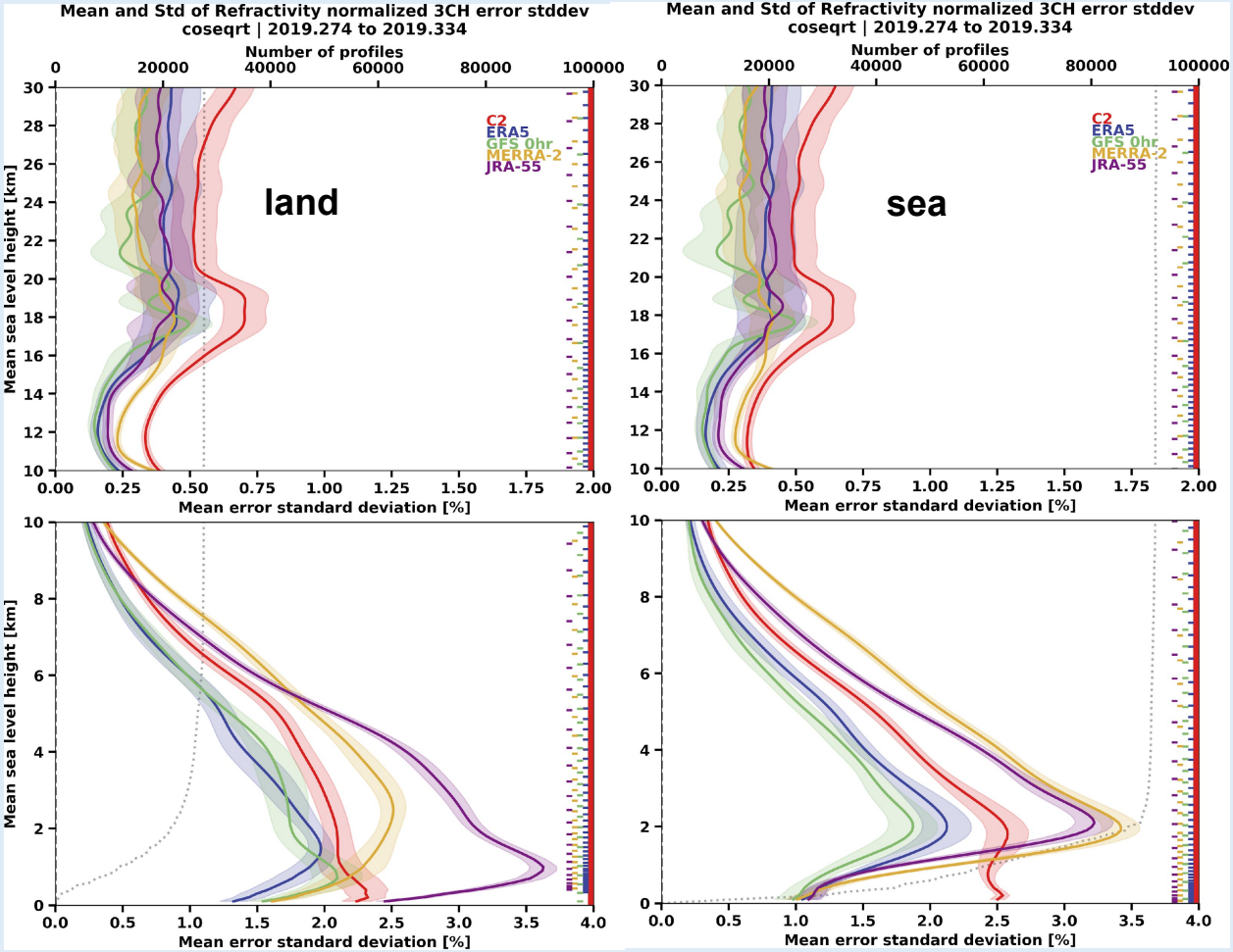
- At RS locations only
- RS estimates much larger than those of other data sets
- RS estimates larger than RS intrinsic error
- Due to very different horizontal and vertical footprints (representativeness) compared to all other data sets



(note the different scale of the abscissa)

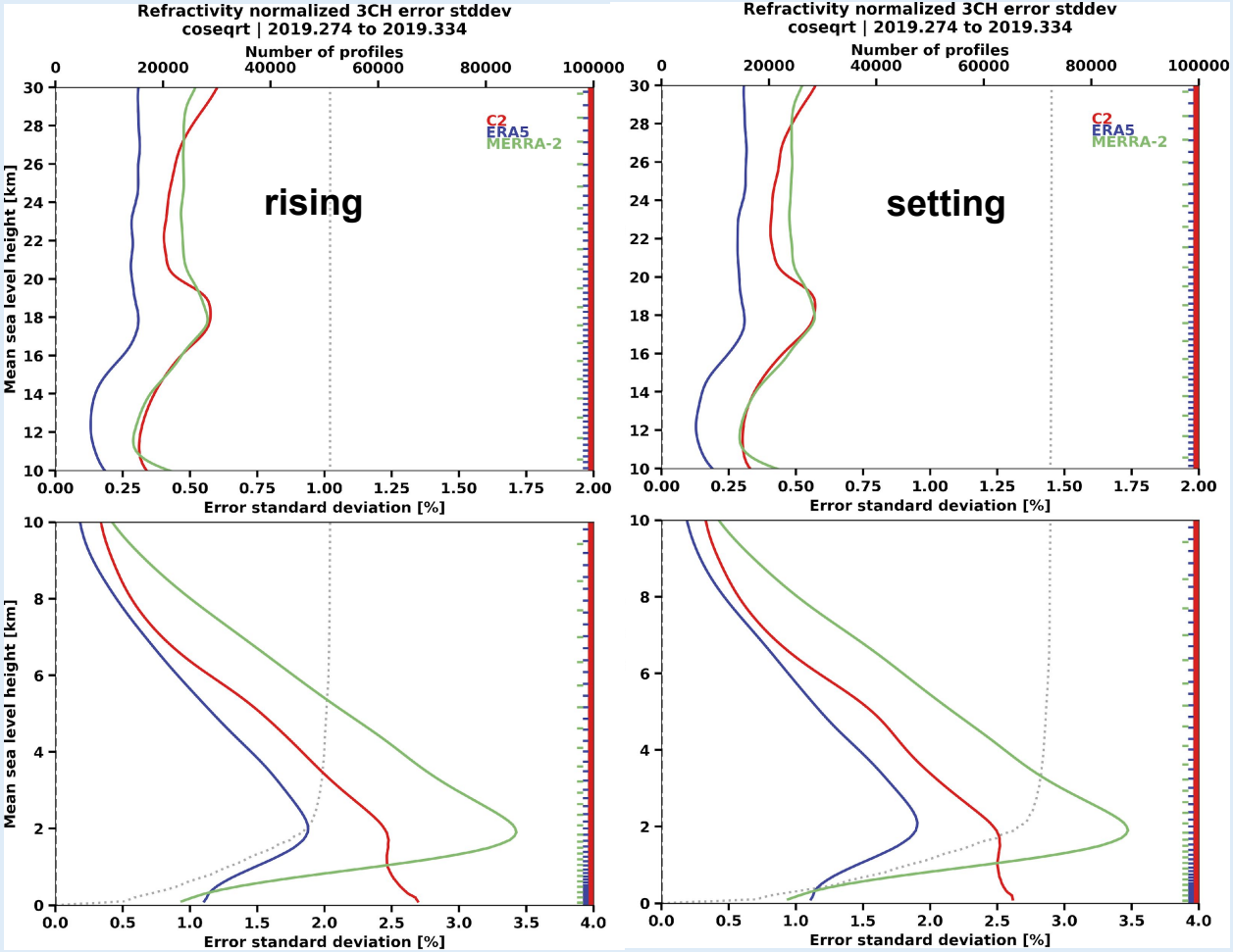
Results: land vs. sea

C2-global
COSMIC-2
ERA5
GFS
MERRA-2
JRA-55



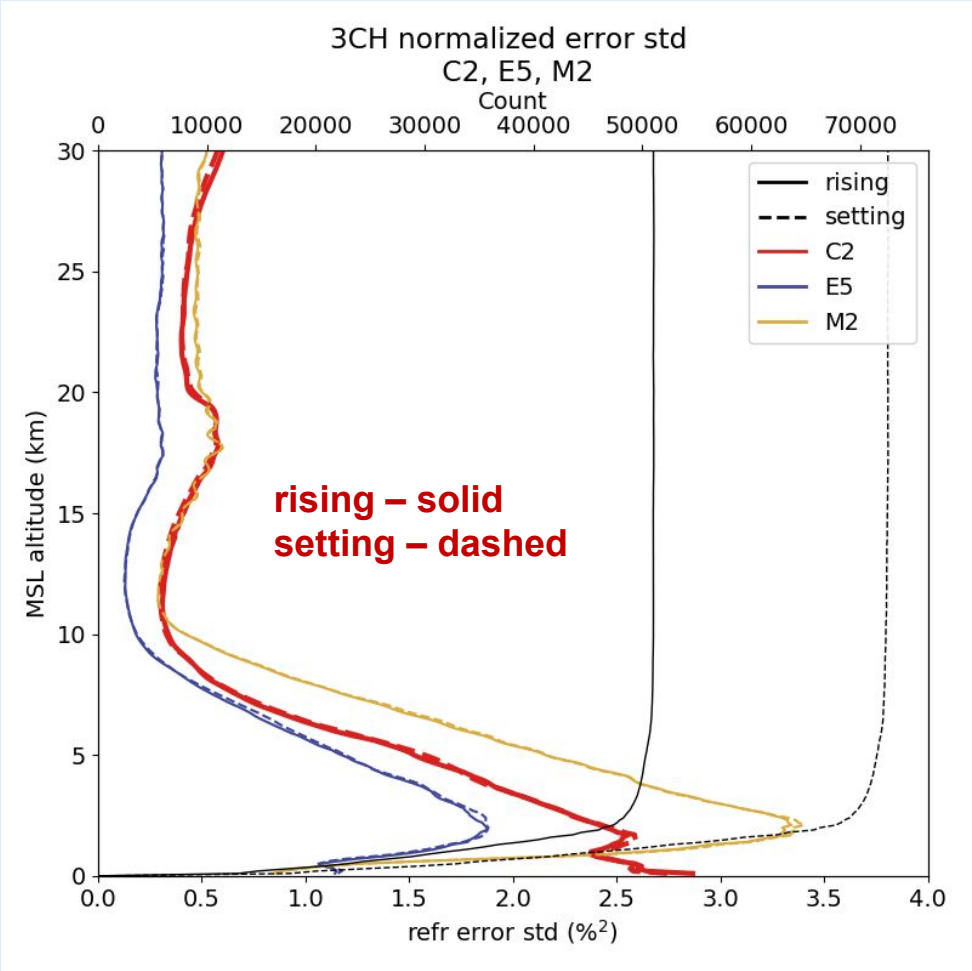
Results: rising vs. setting occultations

C2-global
COSMIC-2
ERA5
MERRA-2



Results: rising vs. setting occultations

C2-global
COSMIC-2
ERA5
MERRA-2



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