Constraining radiosonde random uncertainty with collocated radio occultations and model data

J. K. Nielsen

ROM SAF

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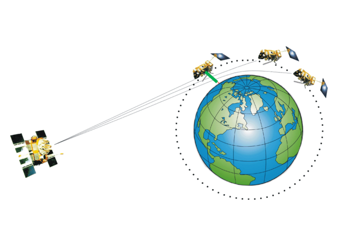
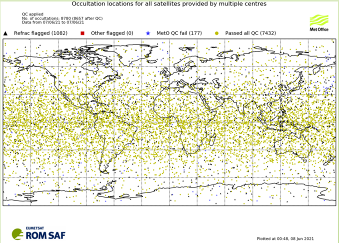
Outline

The RO technique





Bending angle $\rightarrow$ Refractivity

$$N = k_1 \frac{P_{\text{dry air}}}{T} + k_2 \frac{P_{\text{water}}}{T} + k_3 \frac{P_{\text{water}}}{T^2}$$

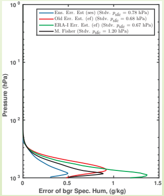
600-700 daily profiles per LEO

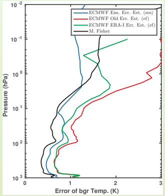
- Vertical resolution $<$ 250 m
- Horizontal resolution $<$ 300 km

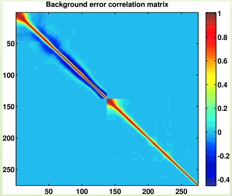
Planning ROM SAF CDR v2

- Missions: COSMIC 1, Metop A-B-C, CHAMP, GRACE
- More than 10^7 profiles
- Time span: 2001-present
- Variables: Bending angle, Refractivity, Dry temperature, Temperature, Spec. humidity, Pressure, Surface pressure
  + gridded data
- GRUAN radiosondes to be used to estimate random uncertainty (error covariance matrices) for refractivity and ERA5 background state.

Specific humidity retrieval from GNSS RO







Sensitivity to tropospheric humidity.
Method: 1D-Var (http://www.romsaf.org/product_documents/romsaf_atbd_1dvar.pdf)

$$N = \kappa_1 \frac{P_d}{T} + \kappa_2 \frac{e}{T^2} + \kappa_3 \frac{e}{T}, \ \mathbf{x} = (\mathbf{T}, \mathbf{q}, \mathbf{p_s}) \tag{1}$$

$$J(\mathbf{x}) = \frac{1}{2}(\mathbf{x} - \mathbf{x}^b)^T \mathbf{B}^{-1} (\mathbf{x} - \mathbf{x}^b) + \frac{1}{2}(\mathbf{N} - \mathbf{N}(\mathbf{x}))^T \mathbf{R}^{-1} (\mathbf{N} - \mathbf{N}(\mathbf{x})) \tag{2}$$

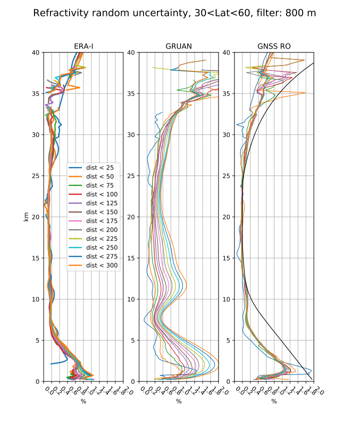
Basic problem: **R** and **B** determines result — and they are very hard to get!

Generalized Three Cornered Hat (G3CH)

- 17552 collocations 2006-2016. dist < 300km, t < 3 h
- Three truly independent data sets: ERA5 (forecast), GRUAN (RS92), GNSS RO (dry temperature)
- Interpolation to 137 levels
- Algebraic estimation of vertical uncertainty covariance matrices, e.g.: $\mathrm{Cov}(g) = \frac{1}{2}\langle (g-b)(g-b)^T + (g-r)(g-r)^T - (r-b)(r-b)^T \rangle$
- Can in principle handle large bias and random noise of GNSS RO dry temperature

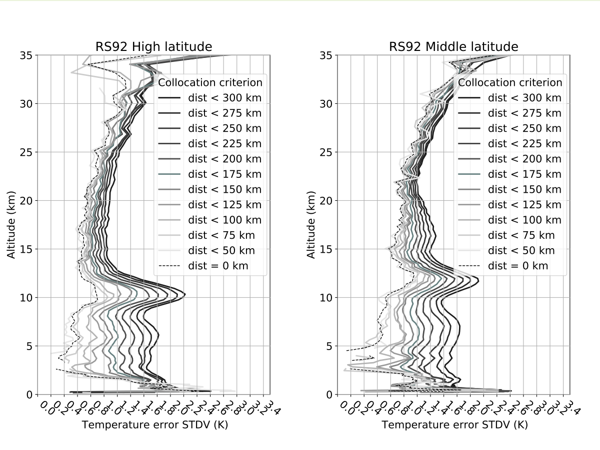
Refractivity uncertainty estimates, Mid Latitudes, filter = 800 m

Refractivity:



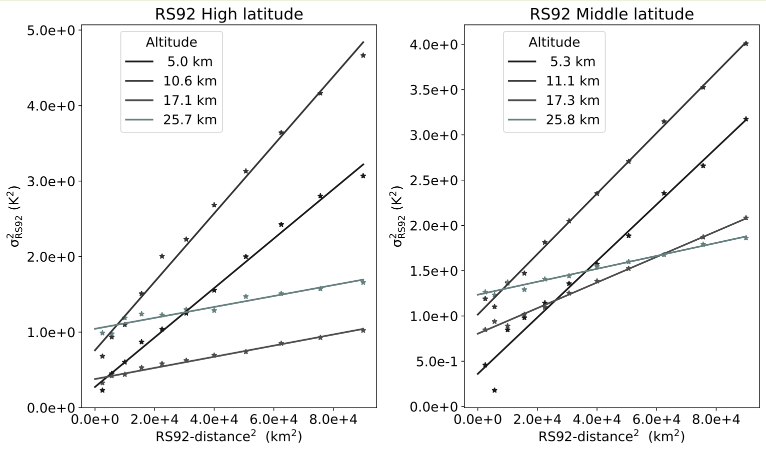
We already did this for the refractivity, which is more straight forward.
Presented at ICM12 (Nielsen et al. in preparation).

Sequence of collocation distances.



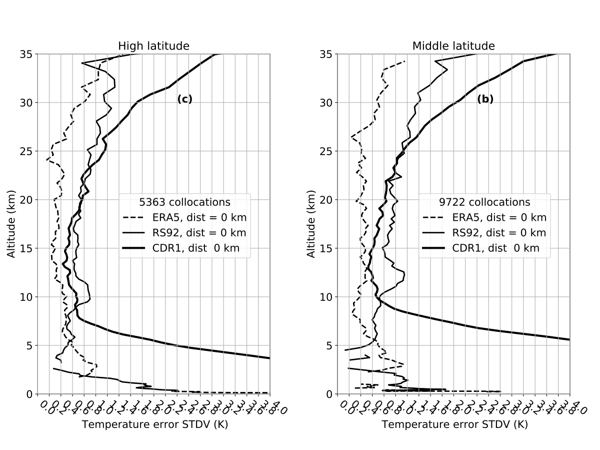
There is still a residual representativeness uncertainty due to different geometries of measurements.

Extrapolation of covariance matrices to zero distance



Just some examples of the extrapolation.
To few tropical profiles b.t.w.

Resulting uncertainty estimates

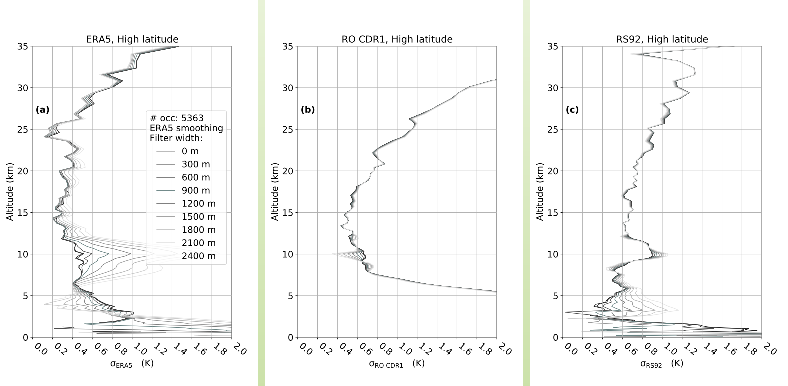


The dry temperature uncertainty (RO) is completely overestimated because it includes specific humidity fluctuations.
But we are after the ERA5 temperature uncertainty.
RS92 uncertainty is a bi-product.

The issue with vertical correlations

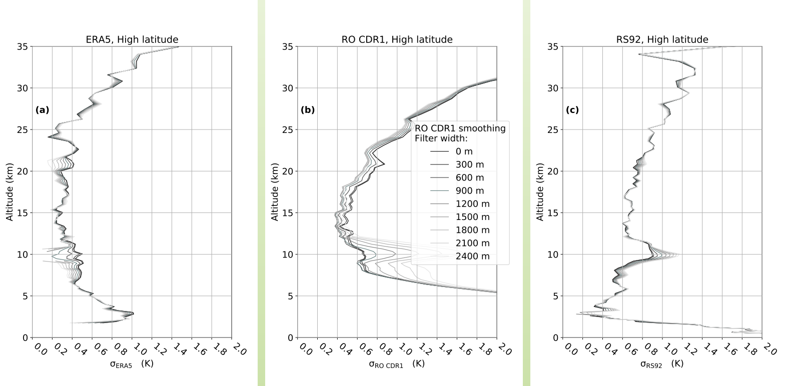
- ERA5 footprint > RO footprint > RS92 footprint
- RS92 is blamed for highly resolved features which are interpreted as noise by the G3CH
- Method: Apply sequences of vertical filters
- Filtering (smoothing) of RS92 removes this uncertainty component
- - but it also removes some of the actual measurement noise
- The unfiltered uncertainty estimate represents an upper limit for RS92 uncertainty.
- The minimized (by filtering) uncertainty represents a lower limit for RS92 uncertainty.

Filter on ERA5, high latitudes



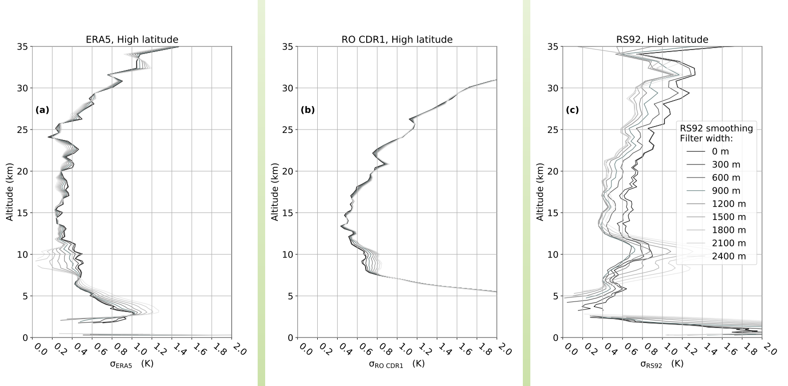
Smoothing of ERA5 pulls ERA5 even further away from RO and RS92. (Forget about the boundary layer)

Filter on RO, high latitudes



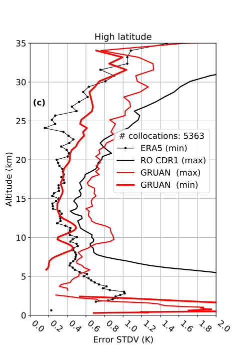
Smoothing of RO brings RO closer to ERA5 without getting in conflict with RS92. I.e. RO and RS92 have highly resolved features that they don't share. Smearing of the tropopause pulls RO away from RS92

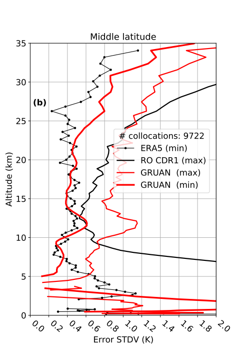
Filter on RS92, high latitudes



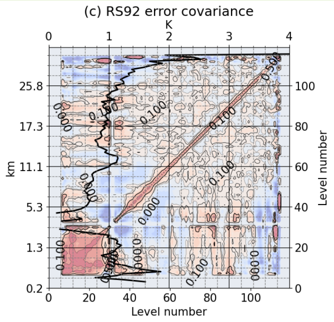
Smoothing of RS92 up to 1800 m brings it closer to ERA5, and only slightly further from RO. — Except at the tropopause.

Results: Temperature STDV and vertical correlations.





The estimated RS92 temperature random uncertainty is somewhere between the red curves. But! It contains residual representativeness uncertainty also. Off-diagonal areas in the covariance matrix e.g. due to ground check?



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Conclusions

- 3CH can be used to estimate unsystematic uncertainty and error correlations of three independent measurement techniques.
- Can possibly be applied to multiple flights.
- GRUAN radiosondes can help to constrain RO refractivity uncertainty and ERA5 temperature uncertainty in the troposphere.
- As a bi-product an upper limit for RS92 “uncorrelated” uncertainty is derived.
- RS92 vertical correlation matrix has a dominating narrow component and a component ranging over the whole stratosphere.