Empirical estimation of uncertainty in radiosondes, radio occultations and model forecast with the Three Cornered Hat method

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ROM SAF

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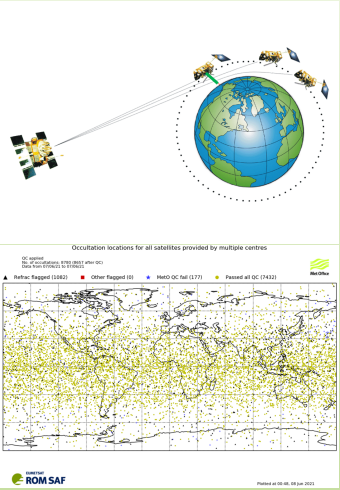
Outline

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

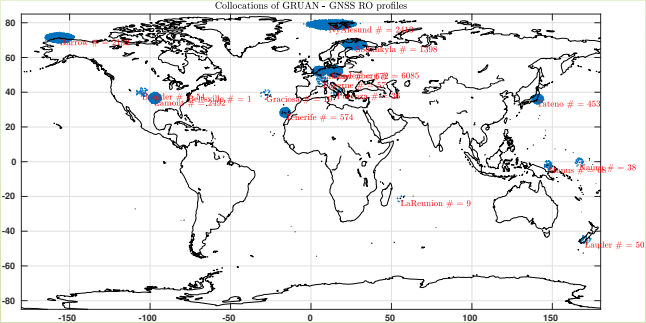
Planning ROM SAF CDR v2 (2023)

- Missions: COSMIC 1, Metop A-B-C, CHAMP, GRACE, (Sentinel 6A,... Spire)
- 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).
- Improved Level 1A, ionosphere, troposphere, boundary layer parameters, uncertainty and error covariance from 3CH analysis

Empirical determination of observation error covariance matrices

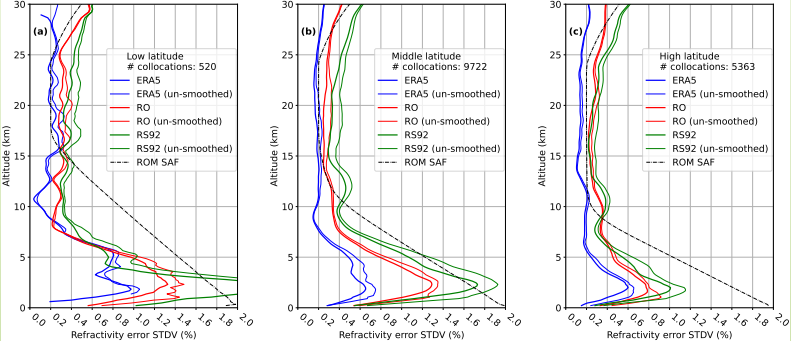
- Collocated ERA5 forecast, GRUAN radiosondes and RO profiles are used to estimate random uncertainty (error covariance matrices) for refractivity and temperature.
- Three independent data sets meaning: Zero error cross correlation. $\langle \varepsilon_{\mathrm{ERA5}} \varepsilon_{\mathrm{RO}} \rangle = 0$, $\langle \varepsilon_{\mathrm{RO}} \varepsilon_{\mathrm{GRUAN}} \rangle = 0$, $\langle \varepsilon_{\mathrm{ERA5}} \varepsilon_{\mathrm{GRUAN}} \rangle = 0$
- 17552 collocations 2006-2016. dist < 300km, t < 3 h
- G3CH; algebraic estimation of vertical uncertainty covariance matrices: $\mathrm{Cov}(g) = \frac{1}{2} \langle (g-b)(g-b)^T + (g-r)(g-r)^T - (r-b)(r-b)^T \rangle$
- Can in principle handle large bias and random noise of GNSS RO dry temperature

GRUAN-RO collocations



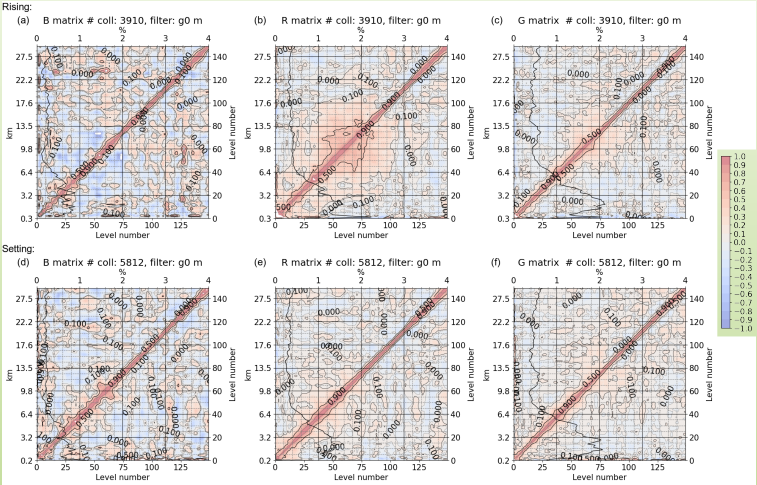
Night time only

3CH estimated random uncertainties



Refractivity uncertainties (standard deviations), for ERA5, RO and RS92, at low (a), middle (b) and high (c) latitudes. Smoothing explanation below. https://doi.org/10.5194/amt-15-6243-2022

G3CH estimate of error covariance matrices

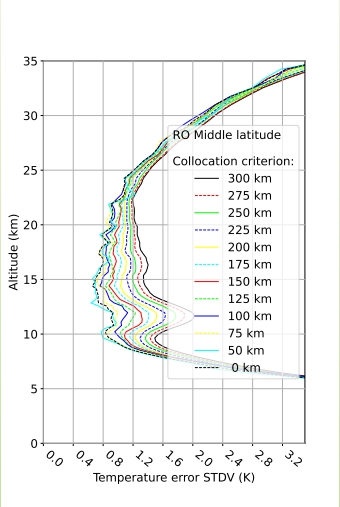


ERA5 (a,d), RO (b,e) and RS92 (c,f) refractivity vertical error covariance matrices at middle latitude, with superimposed standard deviation as function of height (black line).

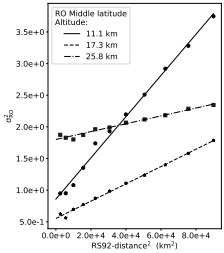
Now temperature

- Three temperature data sets: GRAUAN RS92 (GDP.2), ERA5.1 temperature forecast and RO-Dry temperature (Metop and COSMIC missions).
- For this presentation ERA5 is interpolated to GRUAN position and time (trajectory center of mass.)
- T_{dry} is calculated directly from refractivity, with the assumption that $q = 0$

Collocation error

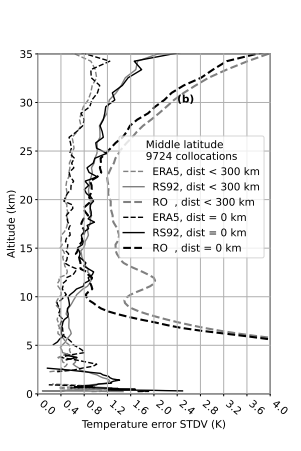


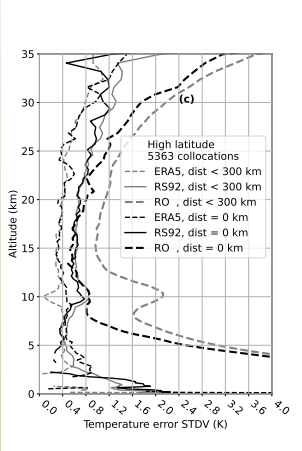
←
Temperature uncertainty of radio occultations for a series of collocation criteria. Black dashed curve shows extrapolation to zero collocation distance.



→
Extrapolation of temperature error variance of RO to zero collocation criterion at 3 different altitudes.

Collocation-corrected uncertainty estimates



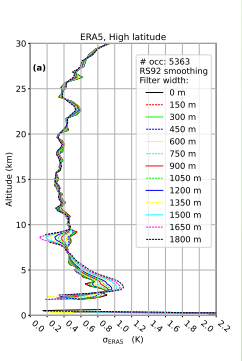


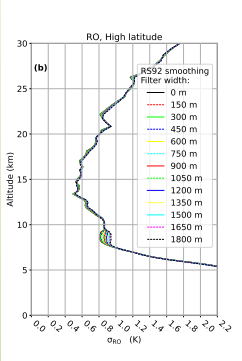
The tropospheric dry temperature uncertainty (RO) is completely overestimated because it includes specific humidity fluctuations.

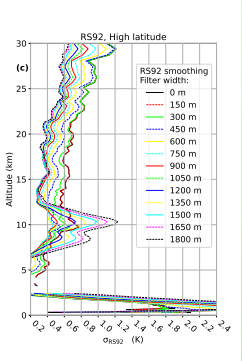
The issue with vertical correlations

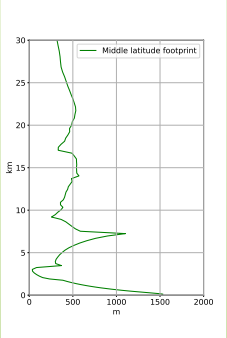
- ERA5 footprint > RO footprint > RS92 footprint
- RS92 is blamed for highly resolved features which are interpreted as noise by the G3CH
- Method: Filter to the (vertical) footprint least well resolved data set.
- Uncertainties stated with respect to vertical footprint 500 m

Effect of smoothing on error standard deviations









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

The ERA5 vertical footprint: Filter width minimizing σ_{ERA5}, when applied to RO and RS

Error components

Raw G3CH yields combination of instrument, representation, collocation and cross correlation errors:

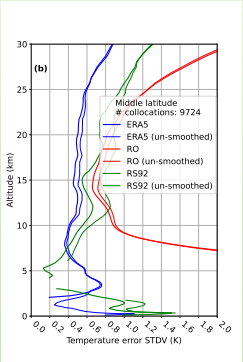
$$\varepsilon_{\mathrm{G3CH}} = \varepsilon^{I} + \varepsilon^{R} + \varepsilon^{C} + \varepsilon^{X} \tag{1}$$

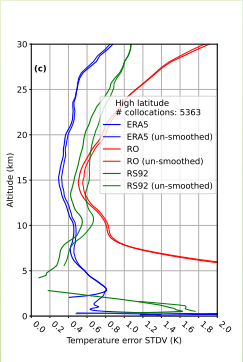
We are able to remove ε^{C} and the ε^{X} components of the three data sets. So:

$$\varepsilon = \varepsilon^{I} + \varepsilon^{R} \tag{2}$$

The final estimate of ε is stated with reference to a common vertical footprint of the three data sets, determined by the data set with the largest vertical footprint, ERA5. There is still a residual representativeness uncertainty due to different geometries of measurements.

Results: Temperature STDV and vertical correlations.





The estimated RS92 temperature random uncertainty: green thick curve.
ERA5 and RO have comparable horizontal footprints, hence 3CH attributes the residual representativeness uncertainty component to RS92.

Conclusions

- Uncertainty estimates of ERA5, RO and RS92 temperatures have been obtained.
- Collocation and vertical footprint issues have been handled
- Residual representativity RS92 uncertainty is due to sub-grid horizontal inhomogeneity
- Uncertainty must always be related to footprint in time and space.