Actions to extract specific humidity from RO

Joe Nielsen, Kent Lauritsen, Hans Gleisner, Stig Syndergaard and Vinicius Barbosa

Danish Meteorological Institute

September 13, 2024

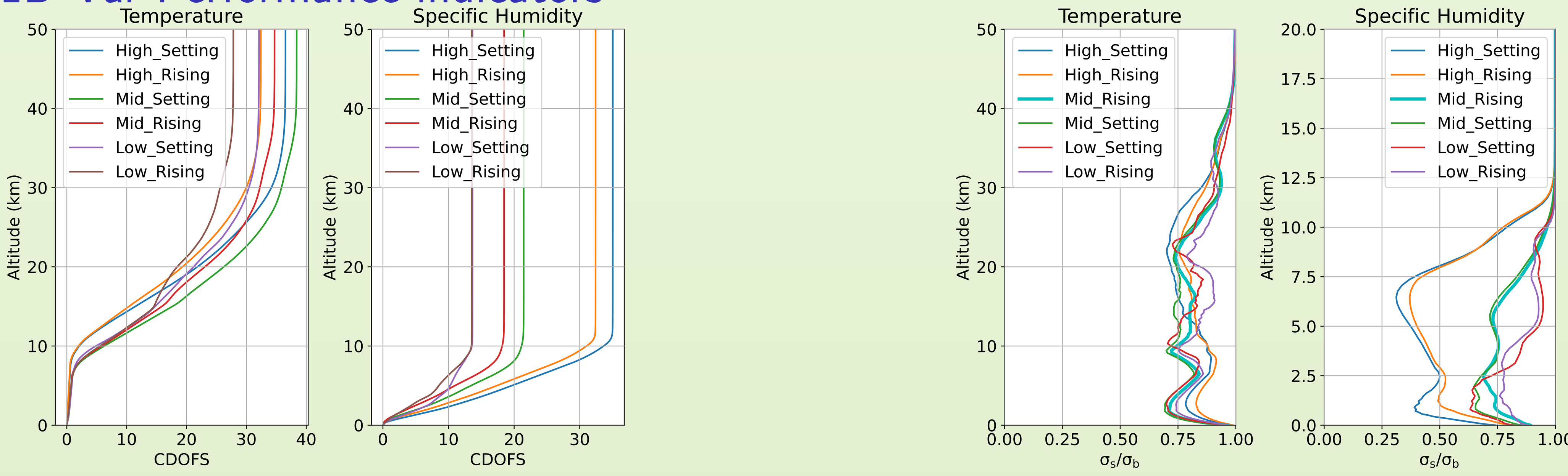
Abstract

The ROM SAF is aiming at closing the outstanding issues regarding humidity estimation from RO. The characterization of uncertainties of both RO observations and background temperature and specific humidity is determining for the 1D-Var derived specific humidity, and close attention must be given to ensure that the uncertainty estimates reflects the true uncertainties of these input data. Here we describe the procedures, based on a generalized Three Cornered Hat (G3CH) method, for empirical estimation of uncertainties and error covariance matrices for refractivity profiles and background temperature and specific humidity profiles. These methods are evaluated by comparison to GRUAN radiosonde relative humidity. It is also demonstrated how positive biases are removed by allowing negative specific humidity in the 1D-Var solution.

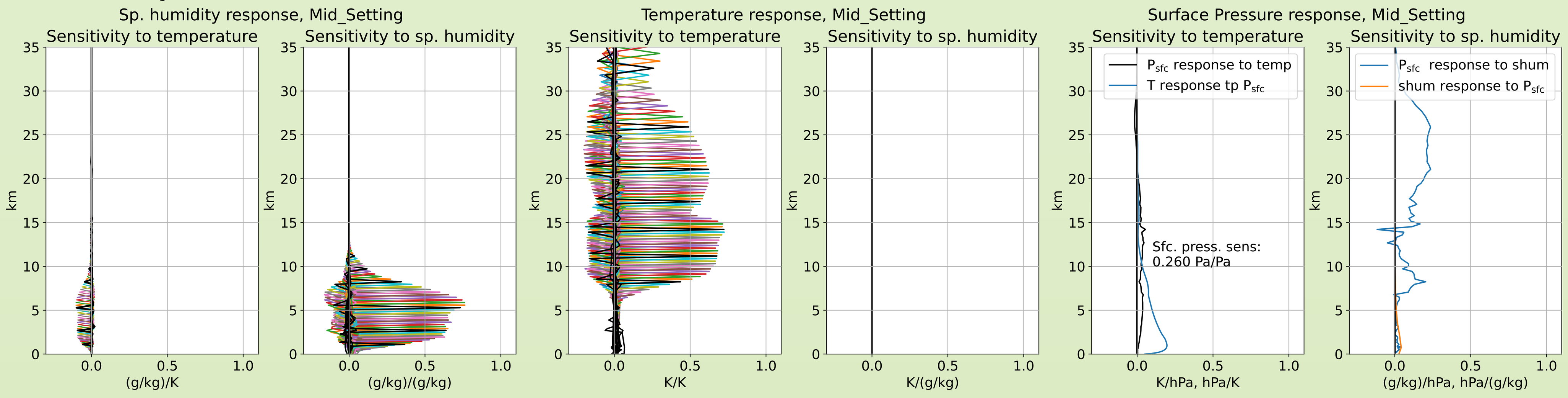
Introduction

Tropospheric Specific humidity products derived from radio occultations do not possess the same purity as stratospheric temperature products do, but they still provide some value to climate research, because no other tropospheric humidity climate data records can provide global coverage with comparable vertical resolution. The development of a RO-based specific humidity product must include an approach to optimize the information content, ensure stability and include a strategy to handle sampling uncertainties and avoid biases.

1D-Var Performance indicators



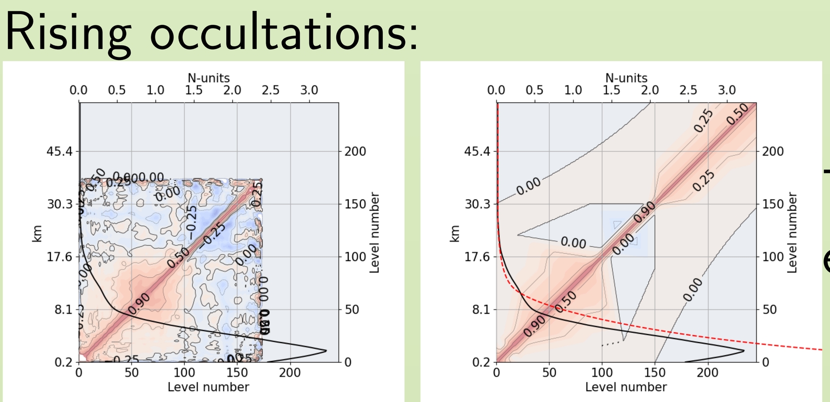
• The Cumulated degrees of freedom (CDOF, left) shows how many independent data points we can expect to retrieve in a single RO profile. For humidity CDOF reaches 12 in the tropics and more that 30 in polar regions. The prior fraction (right) shows how much the uncertainty is reduced by the 1D-Var.



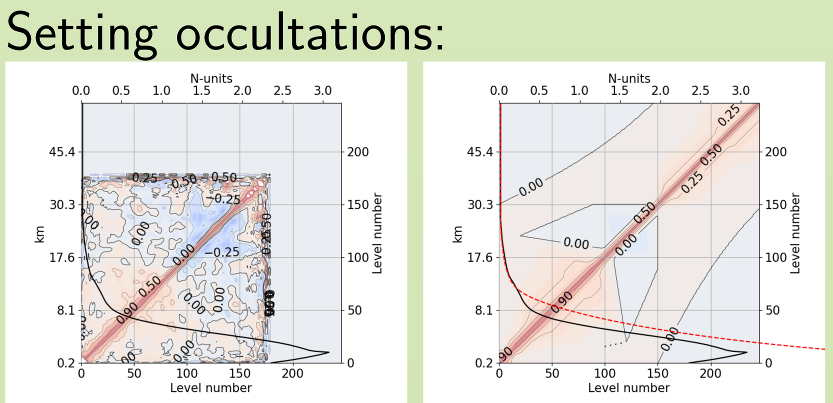
• Mean of averaging kernels, for mid latitudes.

Emperical uncertainty estimation (G3CH)

Rising occultations:



Setting occultations:

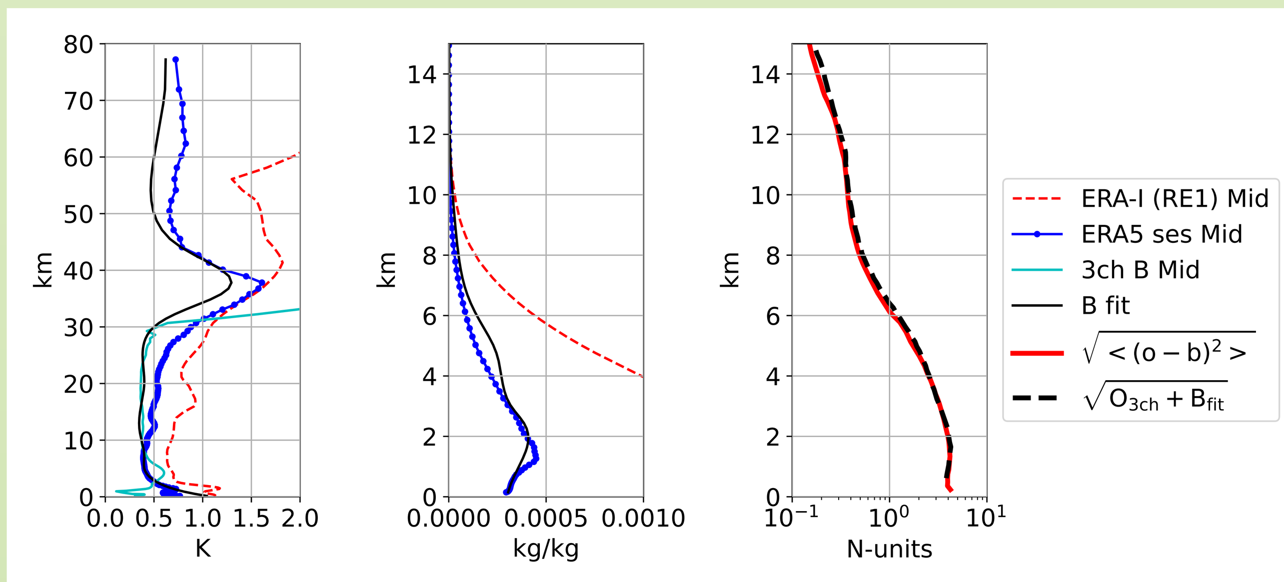


• G3CH estimates of refractivity error covariance matrices at mid latitudes (left), and corresponding parameterized matrices (right). Black curves show uncertainty (STDV), and red dashed curves show the previously assumed uncertainties used in RE1

The refractivity error covariance matrices are estimated via the generalized Three Cornered Hat method [1]

- 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.
  $\langle \varepsilon_{\mathrm{ERA5}} \varepsilon_{\mathrm{RO}} \rangle = 0$, $\langle \varepsilon_{\mathrm{RO}} \varepsilon_{\mathrm{GRUAN}} \rangle = 0$, $\langle \varepsilon_{\mathrm{ERA5}} \varepsilon_{\mathrm{GRUAN}} \rangle = 0$
- 35000 collocations, distance < 300 km, $\Delta t < 3$ h
- G3CH; algebraic estimation of vertical uncertainty covariance matrices:
  $\mathrm{Cov}(r) = \frac{1}{2}\langle (r-b)(r-b)^T + (r-g)(r-g)^T - (g-b)(g-b)^T \rangle$
- Can in principle handle large bias and random noise of GNSS RO dry temperature

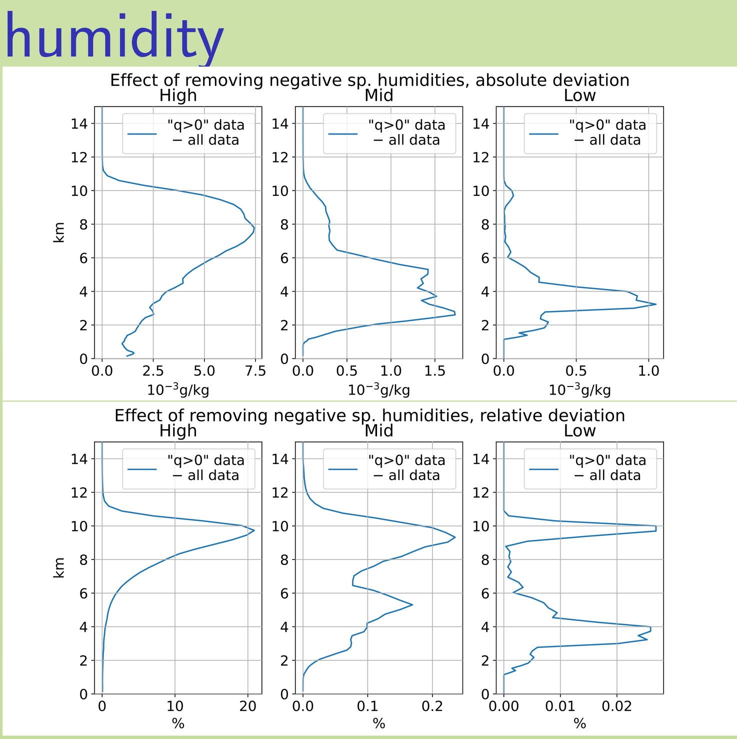
Tuning the background error covariance matrix



• Tuning the background error covariance matrix.

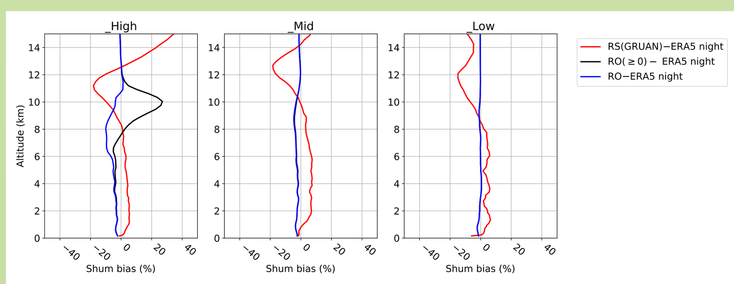
In the temperature and specific humidity plots (left and center), the dashed red curve shows the uncertainties assumed in RE1. The blue curve with dots show the diseminated ERA5 uncertainties. The cyan curve show G3CH temperature uncertainty estimate, and the black curves show the resulting fitted uncertainty estimate. The right hand plots show the combined observation and background uncertainties mapped to refractivity space (black dashed) and the root mean square observation minus background (red). The correlations in B are assumed to be identical to the GRUAN-ERA5 vertical correlations.

Why we allow negative humidity



• A bias is introduced if the specific humidity is forced to be positive, especially when the specific humidity values approach the noise level.

Gruan validation



• Specific humidity of RO and GRUAN compared to ERA5. RO specific humidity is generally negatively biased compered to both GRUAN and ERA5. The black curve shows the positive bias arising if negative sp. hum. values are set to zero.

Summary

- Error covariance matrices for 1D-Var can be calculated empirically by G3CH
- The RO humidity sensitivity is largest polar latitudes
- Positive bias in specific humidity is to some extent removed by allowing negative humidity
- RO specific is negatively biased with respect to GRUAN

Future

Two major outstanding actions to be addressed in next reprocessing:

- De-trended background (a priori) data
- Better understanding of the constant negative bias.

[1] J. K. Nielsen, H. Gleisner, S. Syndergaard, and K. B. Lauritsen. Estimation of refractivity uncertainties and vertical error correlations in collocated radio occultations, radiosondes and model forecasts. *Atmos. Meas. Tech. Discuss.*, 2022:1–28, 2022.