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DMI

ROM SAF tropospheric specific humidity CDR, based on GNSS Radio Occultations

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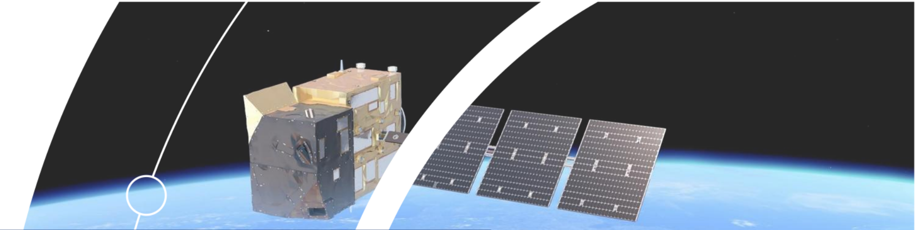

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RADIO OCCULTATION METEOROLOGY

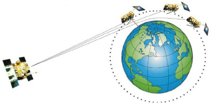
Outline

- GNSS radio occultations brief
- The ROM SAF humidity products
  - ROM SAF CDR v1 + ICDR v1
  - ROM SAF CDR v2 + ICDR v2
  - ROM SAF CDR v3
  - Stability
- G-VAP discussion: Multiple RO CDR products?

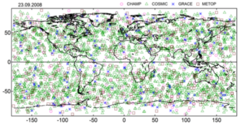
GNSS radio occultations brief

GNSS radio occultations brief

Ray bending due to refractivity gradient:



Daily global coverage

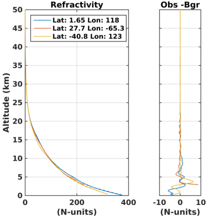


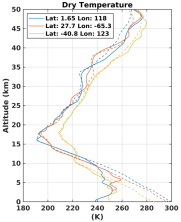
Bending angle $\rightarrow$ refractivity, N

$N \equiv 10^6$(refractive index $-$ 1), depends on temperature, humidity and pressure:

$$\mathbf{N} = \mathbf{H}(\mathbf{x}),\ \mathbf{x} = (\mathbf{T}, \mathbf{q}, p_{\text{sfc}})$$

$\mathbf{N} \rightarrow$

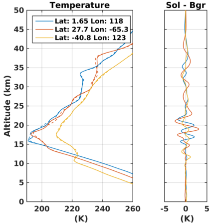


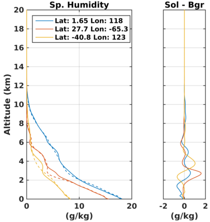


$\leftarrow \mathbf{T}_{\text{dry}}$

With obs. $\mathbf{N}$ and background $\mathbf{x}^b$: Minimize $J(\mathbf{x}) = \frac{1}{2}(\mathbf{x}-\mathbf{x}^b)^T\mathbf{B}^{-1}(\mathbf{x}-\mathbf{x}^b)+\frac{1}{2}(\mathbf{N}-\mathbf{H}(\mathbf{x}))^T\mathbf{R}^{-1}(\mathbf{N}-\mathbf{H}(\mathbf{x}))$

$\mathbf{T} \rightarrow$





$\leftarrow \mathbf{q}$

The ROM SAF humidity products

ROM SAF CDR v1 + ICDR v1

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CDR v1: Spans 2001 to 2016, released 2019

CHAMP, GRACE, COSMIC-1, Metop A/B

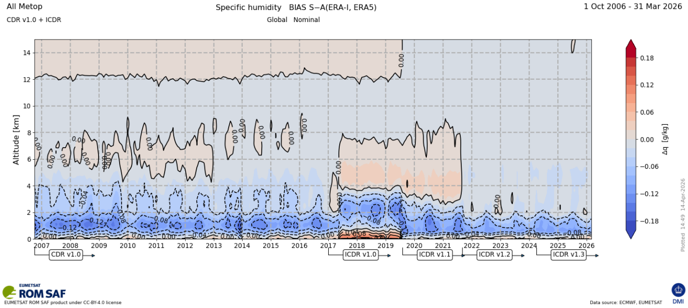
I-CDR v1: Spans 2017 to 2026-03 Metop A/B/C

Level 2 (profiles) and Level 3 gridded by latitude → Copernicus C3S

ERA-I + ERA5 background, ECMWF background uncertainty

2% refractivity uncertainty assumption

Vinicius Barbosa is going to say more about ROM SAF CDR1



EUMETSAT ROM SAF GRM-29-R1
doi:10.15770/EUM_SAF_GRM_0002
doi:10.15770/EUM_SAF_GRM_0006

ROM SAF CDR v2 + ICDR v2

To be released in 2026 Q3/Q4

CHAMP, GRACE, COSMIC-1, Metop A, B and C

Reduced smoothing in troposphere

3CH empirical estimation of refractivity uncertainty and error correlation

ERA5 background

Empirical estimation of background uncertainty and error correlation.

Empirical error covariance estimation

RO refractivity profiles | GRUAN refractivity | ERA5 forecast refractivity

↘ ↓ ↙

Generalized Three Cornered Hat

↓

Refractivity error covariance matrix, **R**

↓

Iterative background error covariance, **B**, estimate

↑ ↑ ↑

Background ($\mathbf{T}$, $\mathbf{q}$, p_{sfc}) | GRUAN ($\mathbf{T}$, $\mathbf{q}$) | RO ($\mathbf{T}_{dry}$)

R ↘ Consistent **R** and **B** ↗ **B**

Empirical error covariance estimation

- choice of background profiles, $\mathbf{x}_b = (\mathbf{T}, \mathbf{q}, p_{\mathrm{sfc}})$, defines the 1D-Var algorithm
- generalized three cornered hat (3CH) is used to estimate refractivity and background temperature error covariance matrices: amt.copernicus.org/articles/15/6243/2022/
- the procedure includes extrapolation of the temperature uncertainty in lower troposphere when 3CH fails
- empirical error covariance estimation closes the uncertainty budget

The averaging kernels are derived from **R**, **B** and **H**

$$\mathbf{A} = \begin{pmatrix} \mathbf{A}_{TT} & \mathbf{A}_{Tq} \\ \mathbf{A}_{qT} & \mathbf{A}_{qq} \end{pmatrix}$$

Specific humidity trend expanded on averaging kernel:

$$\frac{d\hat{\mathbf{q}}}{dt} = \mathbf{A}_{qq}\frac{d\mathbf{q}}{dt} + \mathbf{A}_{qT}\frac{d\mathbf{T}}{dt} - \mathbf{A}_{qT}\frac{d\mathbf{T}_{\mathrm{bg}}}{dt} + (I - \mathbf{A})_{qq}\frac{d\mathbf{q}_{\mathrm{bg}}}{dt}.$$

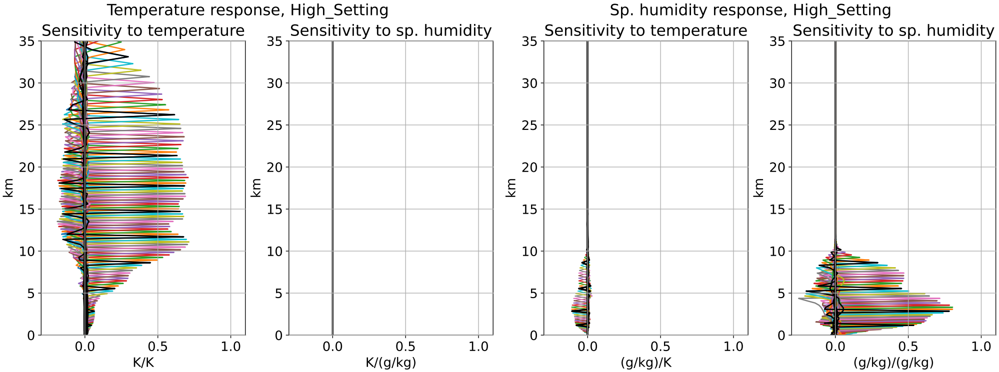
$\mathbf{A}_{qq}\frac{d\mathbf{q}}{dt}$: geophysical **q** trend projected on averaging kernels

$\mathbf{A}_{qT}\frac{d\mathbf{T}}{dt}$: geophysical **T** trend bleeding into **q** trend through averaging kernels

$-\mathbf{A}_{qT}\frac{d\mathbf{T}_{\mathrm{bg}}}{dt}$: background **T** trend bleeding into **q** trend through averaging kernels

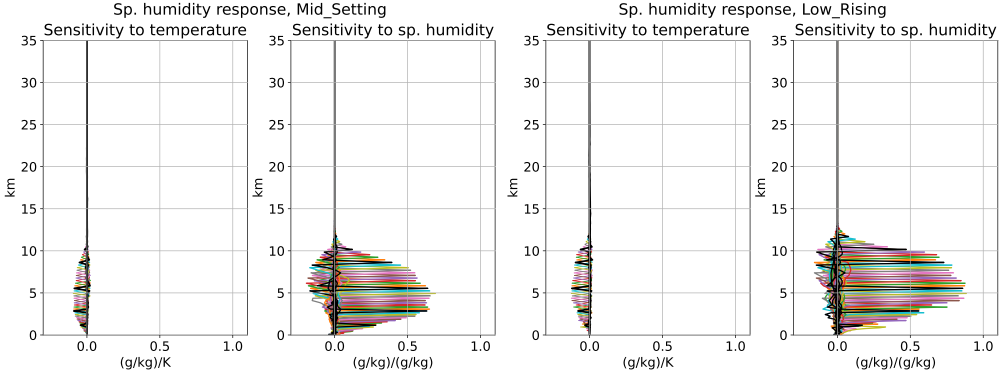
$(I - \mathbf{A})_{qq}\frac{d\mathbf{q}_{\mathrm{bg}}}{dt}$: background **q** trend bleeding into **q** trend through averaging kernels

Averaging Kernels



Averaging Kernels for high latitudes, setting occultations.

Averaging Kernels



Averaging Kernels for mid and low latitudes.

RO specific humidity versus GRUAN

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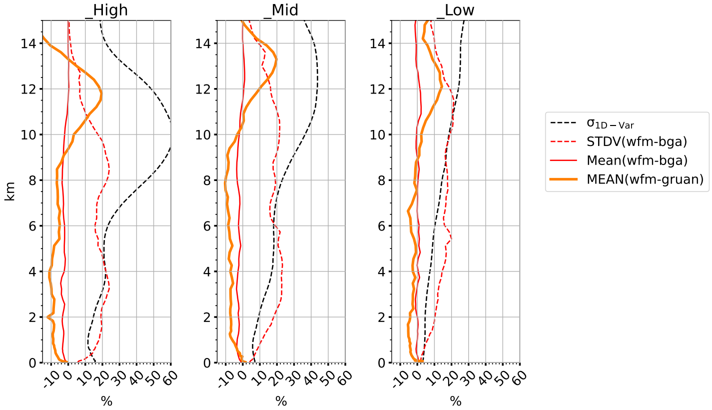

(RS92 and RS41)

RO is 0-10% dry where 1D-Var has sensitivity

ROM SAF CDR v3

Scheduled for 2030

Under development

CHAMP, GRACE, COSMIC-1, Metop A B C, EPS SG, Sentinel 6, COSMIC-2, commercial missions

ERA de-trended background, to enable trend detection

Same procedure as in CDR v2, for empirical error covariance matrix estimation

To avoid background trends to bleed into the retieval we apply a correction to x^b, such that there is no drift in monthly averages throughout the time series:

$$\mathbf{x}_D^b = \mathbf{x}^b + \text{monthly mean (all years)} - \text{mean of month (in the particular year of } \mathbf{x}^b\text{)}$$

$\mathbf{x}_D^b$ is then used as background.
Unfortunately this will lead to an attenuation of the geophysical trend in the retrieval.

$$\frac{d\hat{\mathbf{q}}}{dt} = (1-\alpha)\frac{d\mathbf{q}}{dt}$$

The intention to (try to) estimate α at GRUAN sites.

Status of ROM SAF specific humidity CDR

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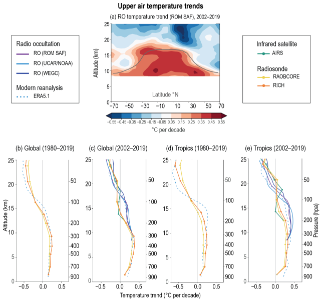
- ☑ Correction for sampling errors in Level 3 production (CDR v1)
- ☑ Empirical estimation of error covariance matrices (CDR v2)
- ☐ De-trending background fields before 1D-Var (CDR v3)
- ☐ Understand boundary layer biases (CDR v3 ?)

G-VAP discussion: Multiple RO CDR products?

- centres differs in choice of method
- should we choose on a “canonical” data-set?
- the algorithms can be designed with different purposes
- for IPCC AR6 multiple temperature trends were reported:



- ROMSAF CDR v2 is based on empirically determined error covaraince estimates
- Radio occultations are dry (0-10%), compared to GRUAN, at all altitudes
- ROM SAF CDR v 3 is being developed out of a strategy for trend-detection
- RO humidity has matured to be a CDR candidate
- There is some work to do with evaluating and presenting outputs from multiple centres in a coherent way

Thanks