The (GAIA-CLIM) GRUAN Processor

ICM-9 in Helsinki (FI), 2017

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The GRUAN Processor

The characterisation of biases in satellite observations using Numerical Weather Prediction (NWP) models has become a mature technique over the past decade and has successfully been employed for the validation (or recalibration) of numerous instruments.

However, although it is generally accepted that NWP uncertainties, in brightness temperature (BT) space, are about 0.1K for atmospheric temperature and 0.5-1K for humidity, no robust quantification has been conducted to date.

The characterisation of uncertainties in NWP models is a major challenge that is addressed as part of the Horizon 2020 GAIA-CLIM project and the GRUAN Processor demonstrates how reference quality radiosonde data can be used to better understand and characterise model fields uncertainties and how they can be propagated to uncertainties in simulated (L1B) radiances.

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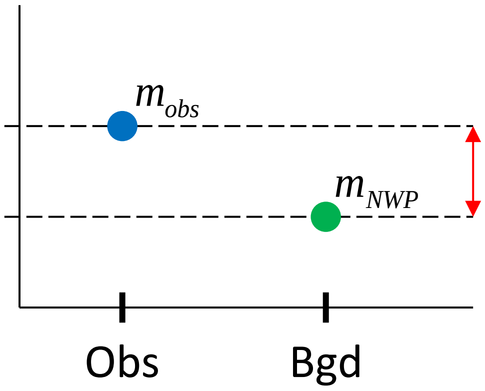
The GRUAN Processor



Current situation

NWP-based validations are typically done by comparing a set of observations to a NWP short-range forecast (i.e. $m_{obs} - m_{NWP}$).

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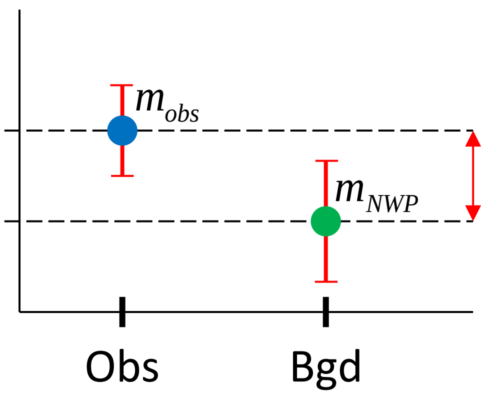

Ideal validation

Consistency is achieved when the difference satisfy :

$$\left| m_{obs} - m_{NWP} \right| < k\sqrt{\sigma^2 + u_{obs}^2 + u_{NWP}^2}$$

Where u_{obs} and u_{NWP} the uncertainties associated to m_{obs} and m_{NWP}, σ the co-location/co-incidence uncertainty, and k a coverage factor.

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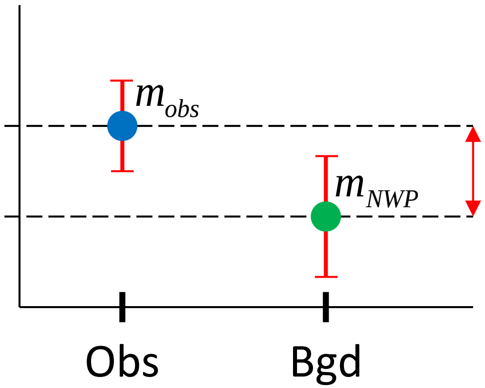

Ideal validation

Consistency is achieved when the difference satisfy :

$$|m_{obs} - m_{NWP}| < k\sqrt{\sigma^2 + u_{obs}^2 + u_{NWP}^2}$$

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Accounting for:

- Radiative transfer modelling uncertainties
- Scale mismatch uncertainties
- Interpolation uncertainties
- NWP fields uncertainties

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The GRUAN Processor

LEGACY: EUMETSAT Numerical Weather Prediction Satellite Application Facilities NWPSAF RTTOV fast radiative transfer model and Radiance Simulator (http://nwpsaf.eu/).

CAPABILITY: Simulate satellite observations (in Brightness Temperatures or Radiances) from observed or modelled geophysical parameters (Pressure, Humidity, Temperature).

OBJECTIVE: Estimate model uncertainties by comparison with GRUAN observations and uncertainties both in observation and Brightness Temperature (or Radiance) spaces.

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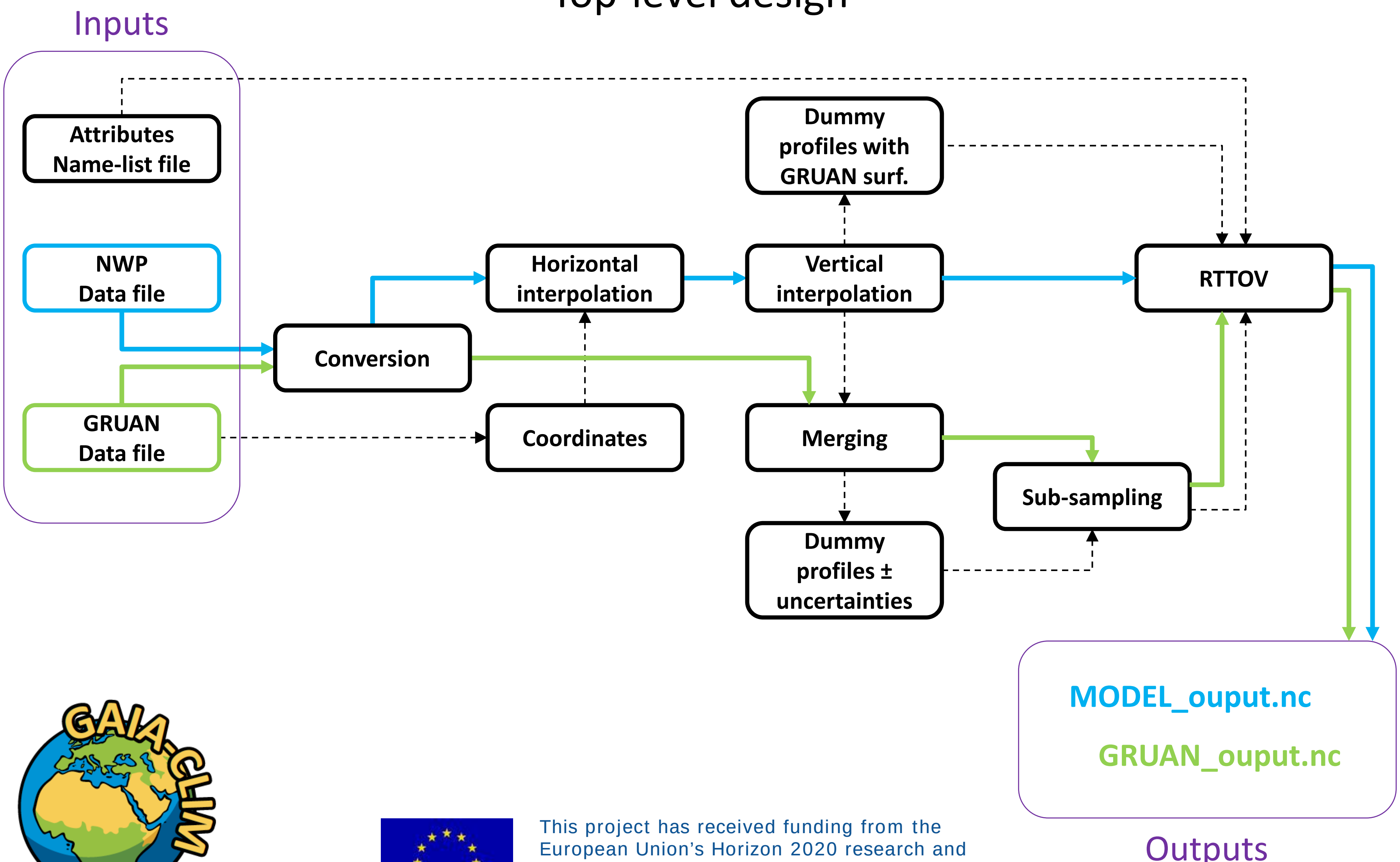
The GRUAN Processor

Top-level design



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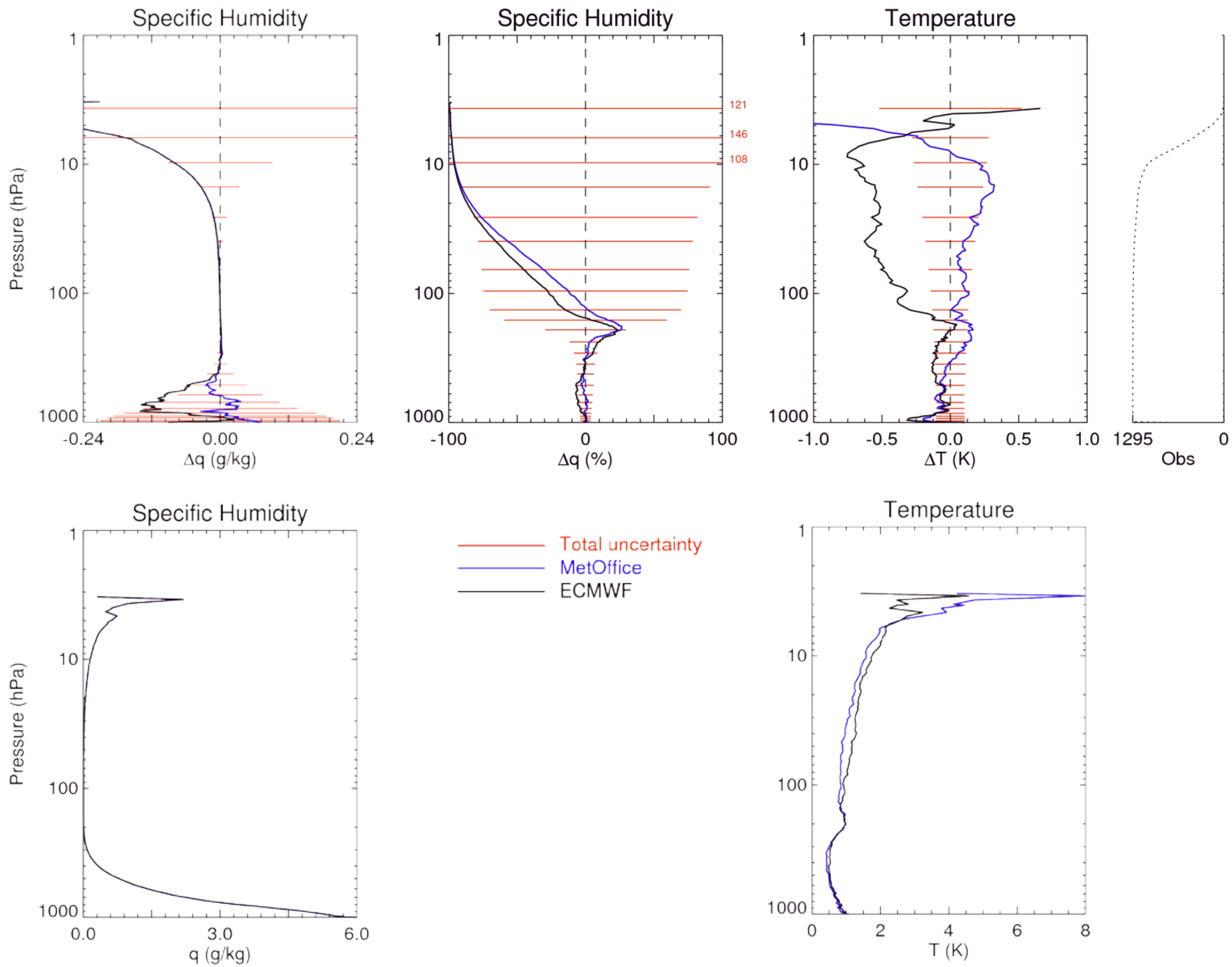
Observation Space

NWP - GRUAN
Lindenberg, 2013
1297 profiles

Standard deviation of the difference



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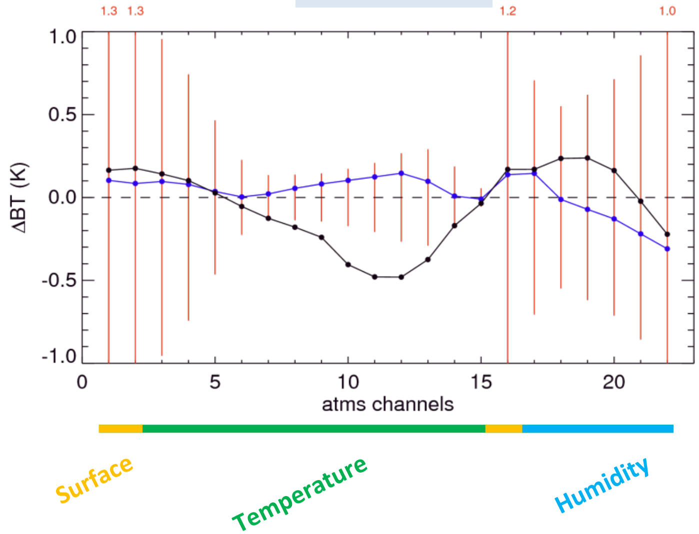
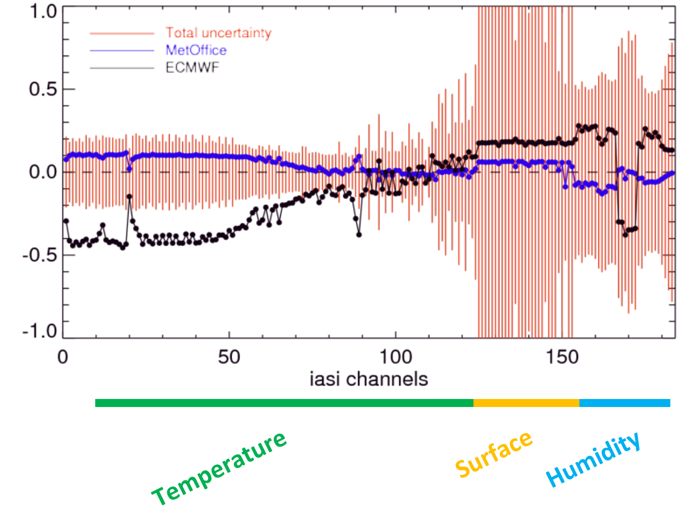
Brightness Temperature Space

ATMS

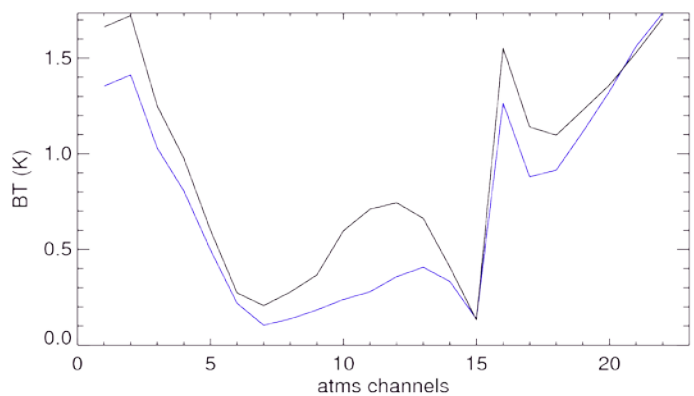
IASI

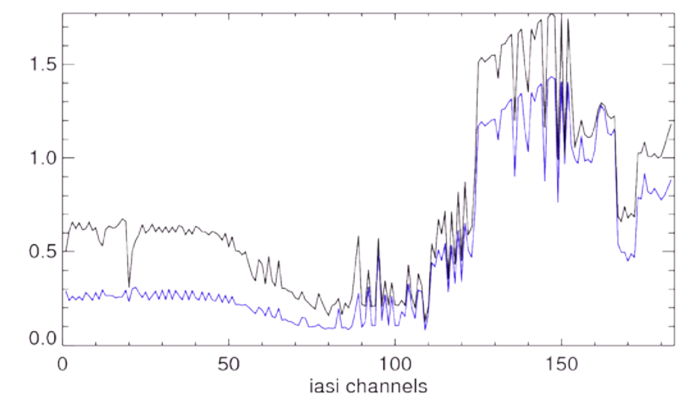
NWP - GRUAN
Lindenberg, 2013
1297 profiles





Standard deviation of the difference





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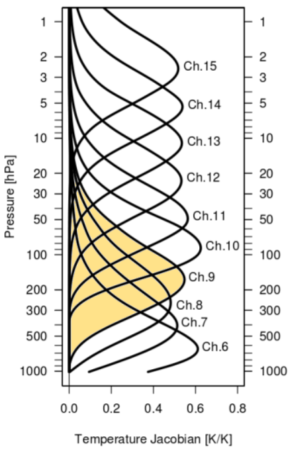
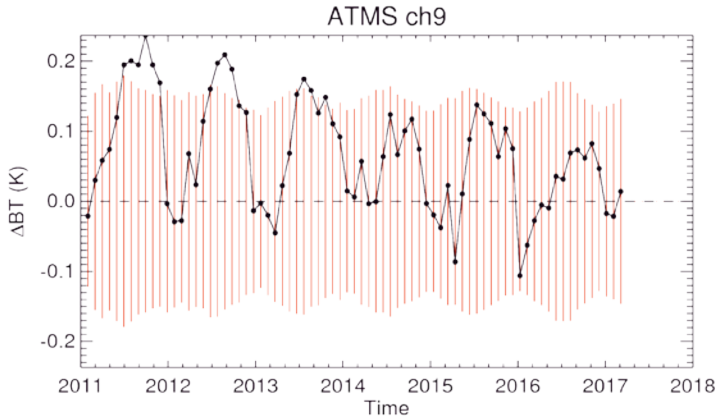
Brightness Temperature Space

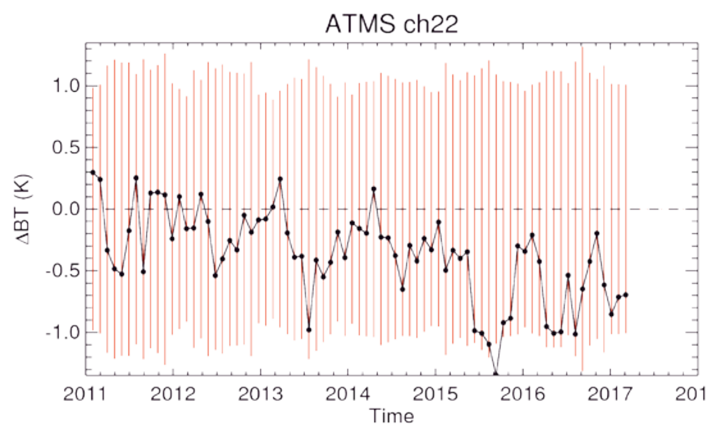
Time series

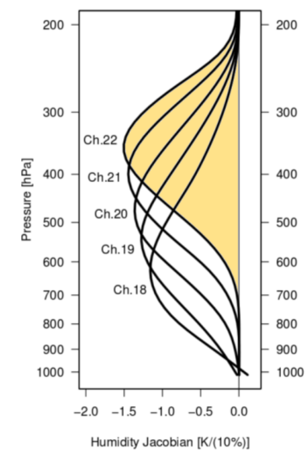




NWP$_{MO}$ - GRUAN
Lindenberg
monthly mean
ATMS channel 9 (55GHz)

NWP$_{MO}$ - GRUAN
Lindenberg
monthly mean
ATMS channel 22
(183±1GHz)





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Ongoing developments

Estimation of the vertical interpolation uncertainty such as:

$$\mathbf{S}_{\varepsilon_{\text{int}}} \equiv \text{cov}(\boldsymbol{\varepsilon}_{\text{int}}) \cong \mathbf{B}_{obs}(\mathbf{I} - \mathbf{W}(\mathbf{W}^T\mathbf{B}_{obs}^{-1}\mathbf{W})^{-1}\mathbf{W}^T\mathbf{B}_{obs}^{-1})$$

where $\mathbf{W}$ the interpolation matrix and $\mathbf{B}_{\text{obs}}$ the sonde error covariance on the processor vertical grid.

This will allow to estimate the covariance of the departure in predicted observations:

$$\mathbf{S}_{\delta y} \equiv \text{cov}(\delta\mathbf{y}) \cong \mathbf{H}\mathbf{R}_{obs}\mathbf{H}^T + \mathbf{H}\mathbf{W}\mathbf{B}_{NWP}\mathbf{W}^T\mathbf{H}^T + \mathbf{H}\mathbf{S}_{\varepsilon_{\text{int}}}\mathbf{H}^T$$

with

$$\delta\mathbf{y} \equiv \mathbf{y}_{obs} - \mathbf{y}_{NWP} \cong \mathbf{H}_{x^t_{obs}}(\mathbf{W}\boldsymbol{\varepsilon}_{NWP} + \boldsymbol{\varepsilon}_{\text{int}} - \boldsymbol{\varepsilon}_{obs})$$

where $\mathbf{y}_{\text{obs}}$ and $\mathbf{y}_{\text{NWP}}$ are the predicted sonde and model observations, $\mathbf{H}$ the observation operator, $\mathbf{R}_{\text{obs}}$ and $\mathbf{B}_{\text{NWP}}$ the sonde and Forecast error covariances on their native vertical grid.

A χ_i^2 test will be applied to the departure covariance to assess our estimation of NWP uncertainty:

$$\chi_i^2 = (\delta\mathbf{y}_i - \overline{\delta\mathbf{y}})^T \mathbf{S}_{\delta y}^{-1}(\delta\mathbf{y}_i - \overline{\delta\mathbf{y}})$$

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What next?

- Update of the GRUAN Processor webpage

  http://nwpsaf.eu/GProc_test/fab/ins.shtml.
- Estimation of GRUAN co-variance matrix.
- Separate treatment for GRUAN correlated and random uncertainties.
- Processing capability extended to reanalyses and other NWP centres.
- Manuscript in preparation.
- Semi-automatic monitoring of NWP model at the Met Office (and ECMWF ?).

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Thank you

Any questions?

Now, later, or by email at

fabien.carminati@metoffice.gov.uk

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Supplementary material

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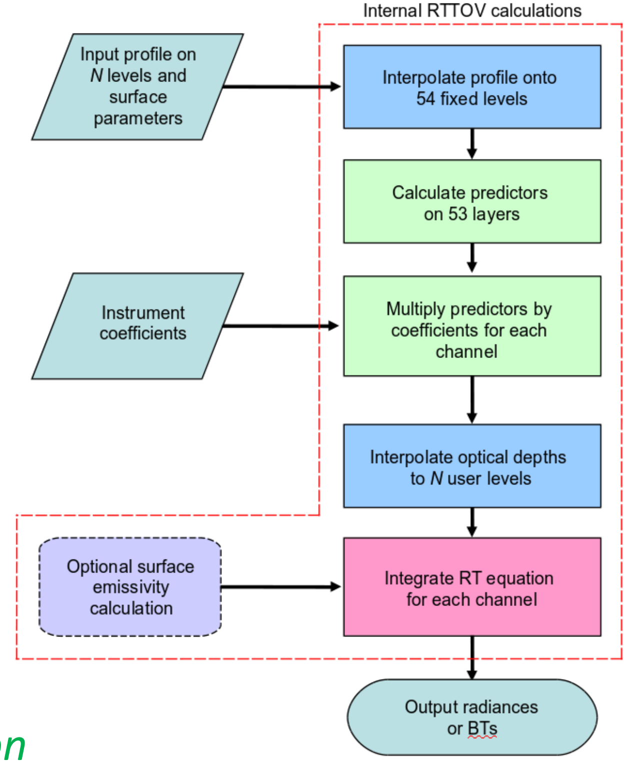
RT model

RTTOV (Radiative Transfer for TOVS (TIROS (Television Infrared Observation Satellite) Operational Vertical Sounder))

- Fast RT model that calculates top-of-atmosphere (TOA) satellite-seen radiances for passive VIS, IR and MW nadir viewing instruments.
- Funded by EUMETSAT through NWPSAF, developed by Met Office, Météo-France, and ECMWF.
- Parameterised off-line line-by-line calculations of optical depths based on 498 training profiles for each instrument channel.

RTTOV flow diagram



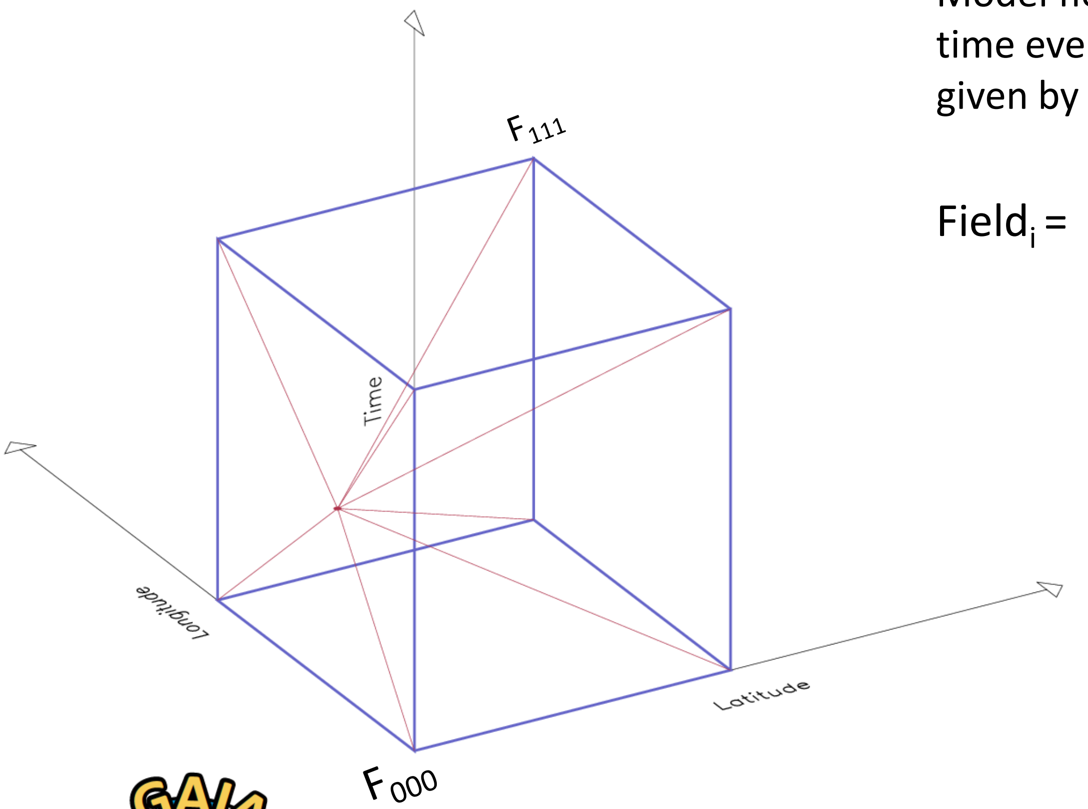
Clear sky RT Equation (ignoring scattering):

Radiance = Upwelling Atmospheric Emission + Surface Emission + Downwelling Atmospheric Emission Reflected by Surface

See http://nwpsaf.eu/site/software/rttov/documentation/ for the details.

The GRUAN Processor

Interpolations



Model fields are interpolated at observation lat-lon-time every 15s along the sonde path. Weights are given by the 8 neighbouring grid points.

$$
\begin{aligned}
\text{Field}_i = \; & F_{000}\,(1 - x_{weight})\,(1 - y_{weight})\,(1 - z_{weight}) + \\
& F_{100}\,x_{weight}\,(1 - y_{weight})\,(1 - z_{weight}) + \\
& F_{010}\,(1 - x_{weight})\,y_{weight}\,(1 - z_{weight}) + \\
& F_{001}\,(1 - x_{weight})\,(1 - y_{weight})\,z_{weight} + \\
& F_{101}\,x_{weight}\,(1 - y_{weight})\,z_{weight} + \\
& F_{011}\,(1 - x_{weight})\,y_{weight}\,z_{weight} + \\
& F_{110}\,x_{weight}\,y_{weight}\,(1 - z_{weight}) + \\
& F_{111}\,x_{weight}\,y_{weight}\,z_{weight}
\end{aligned}
$$

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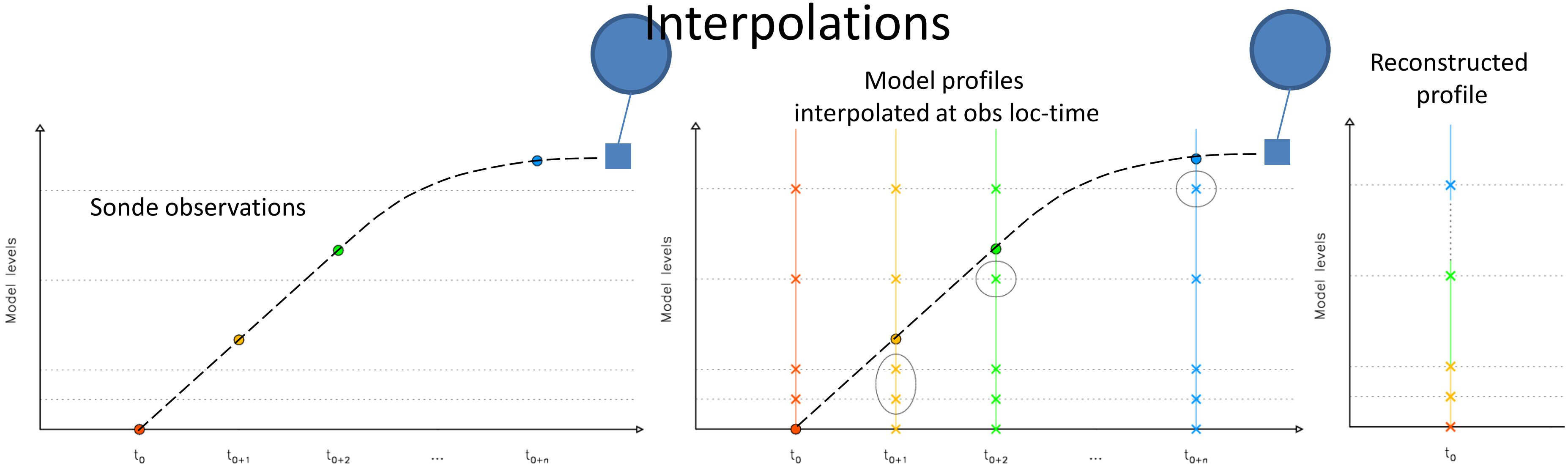
Interpolations



1. A single set of reconstructed model profiles is generated by combining model levels crossed by the sonde between two observations.
2. The top of the reconstructed profiles is merged to the GRUAN profiles to compensate for the lack of information in the stratosphere.
3. Reconstructed model profiles are vertically interpolated on the processor fixed vertical grid (278 levels), while GRUAN profiles are sub-sampled on the same grid.

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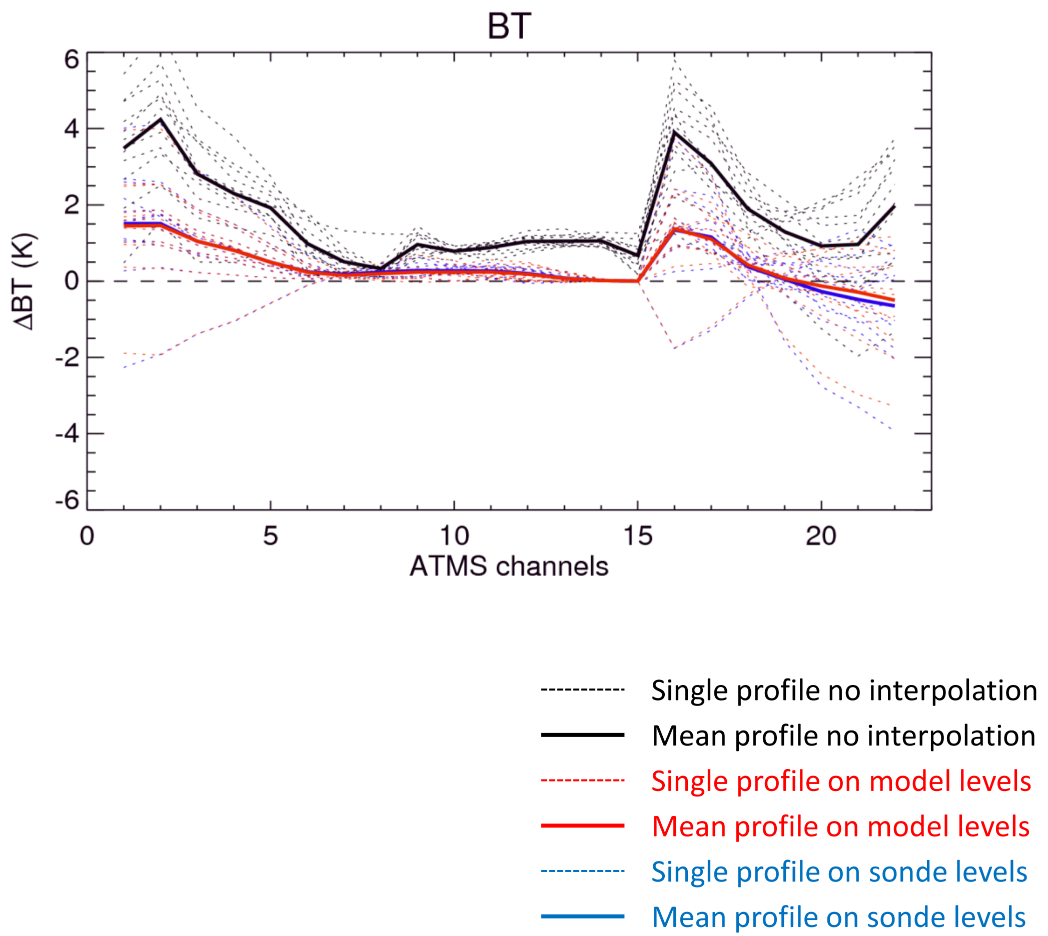
BT simulated using native vertical resolution leads to ΔBT larger than expected given ΔQ and ΔT.

This has been traced back to the RT equation applied to highly different vertical grid (coarse for model, very fine for GRUAN).

→ Profiles need to be on the same vertical grid for consistent comparison on BT space.



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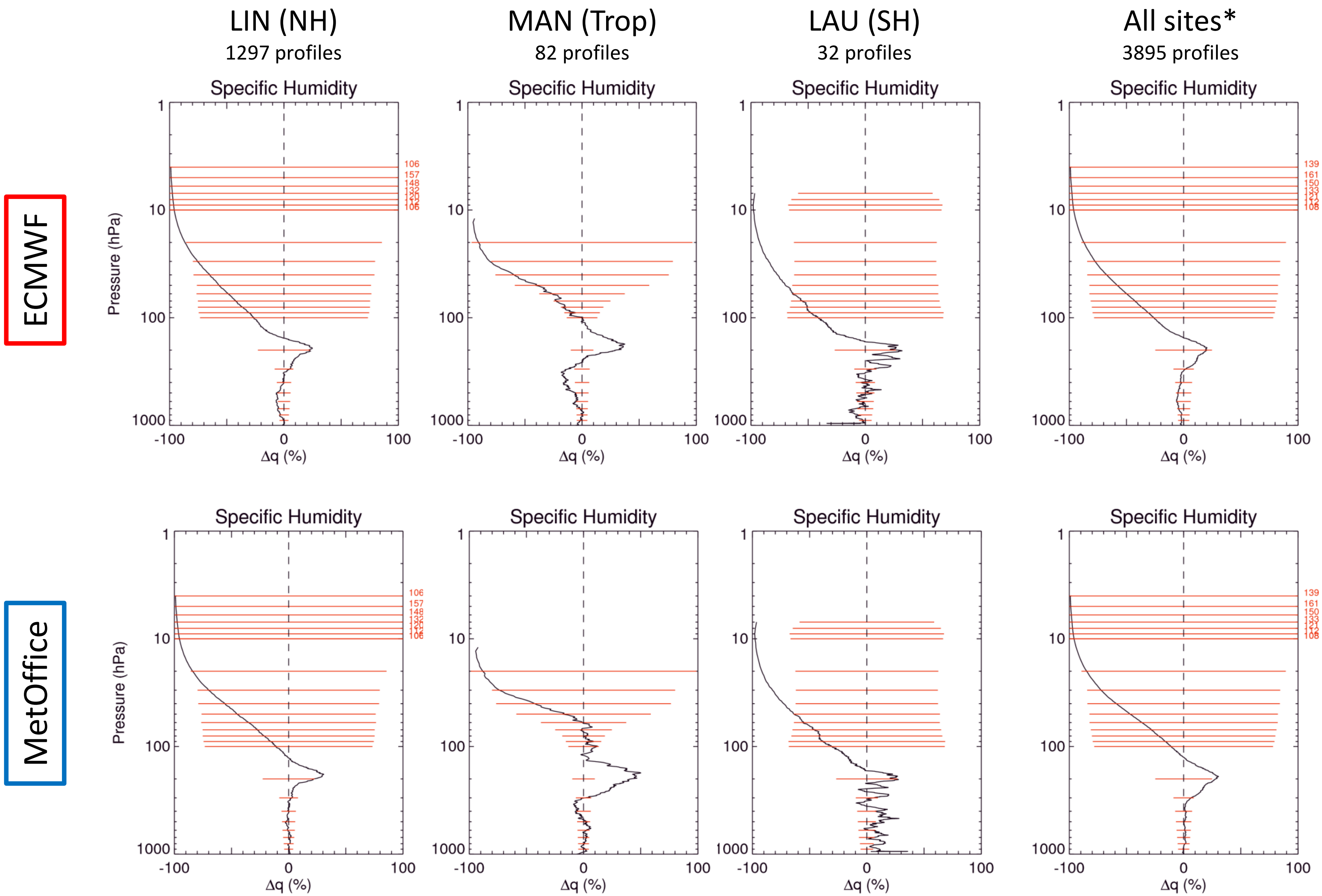
NWP-GRUAN

– Mean total uncertainty



NWP-GRUAN

– Mean total uncertainty