Characterisation of Numerical Weather Prediction model biases for improved satellite Cal/Val

ITSC XXI, Darmstadt, November 2017

Fabien Carminati (MO), Stefano Migliorini (MO), Bill Bell (ECMWF), Bruce Ingleby (ECMWF), Heather Lawrence (ECMWF)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 640276.

Rationale

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 [1] [2] [3] [4] [5].

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, **but no robust quantification has been conducted to date**.

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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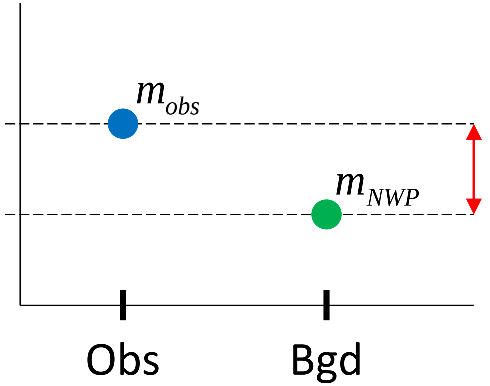
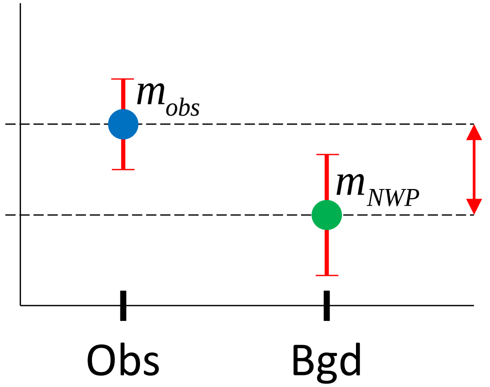
Rationale



Current situation

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



Ideal validation

Consistency is achieved when the difference satisfy [6]:

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

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

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Rationale

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

Fiduceo

www.fiduceo.eu

Uncertainties in RT modelling

- Line-by-line to fast model
- Spectroscopic uncertainty
- Surface emissivity

Uncertainties due to residual cloud after screening

$$u_{NWP} = f(u(x_{NWP}), u(H), u(\Delta x), u(z, z'), u(cloud))$$

Uncertainties due to vertical interpolation

- GRUAN processor

Uncertainties in NWP T, q mapped to brightness temperature

- Estimate from NWP-GRUAN

Uncertainties due to scale mismatch

- Observation scale ≠ model scale
- Natural scale << obs and model

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Outline

- **Introduction to the GRUAN Processor**
  - Top level design
- **Preliminary results**
  - Observation space
  - Brightness temperature space
  - Time series
- **Outlook**

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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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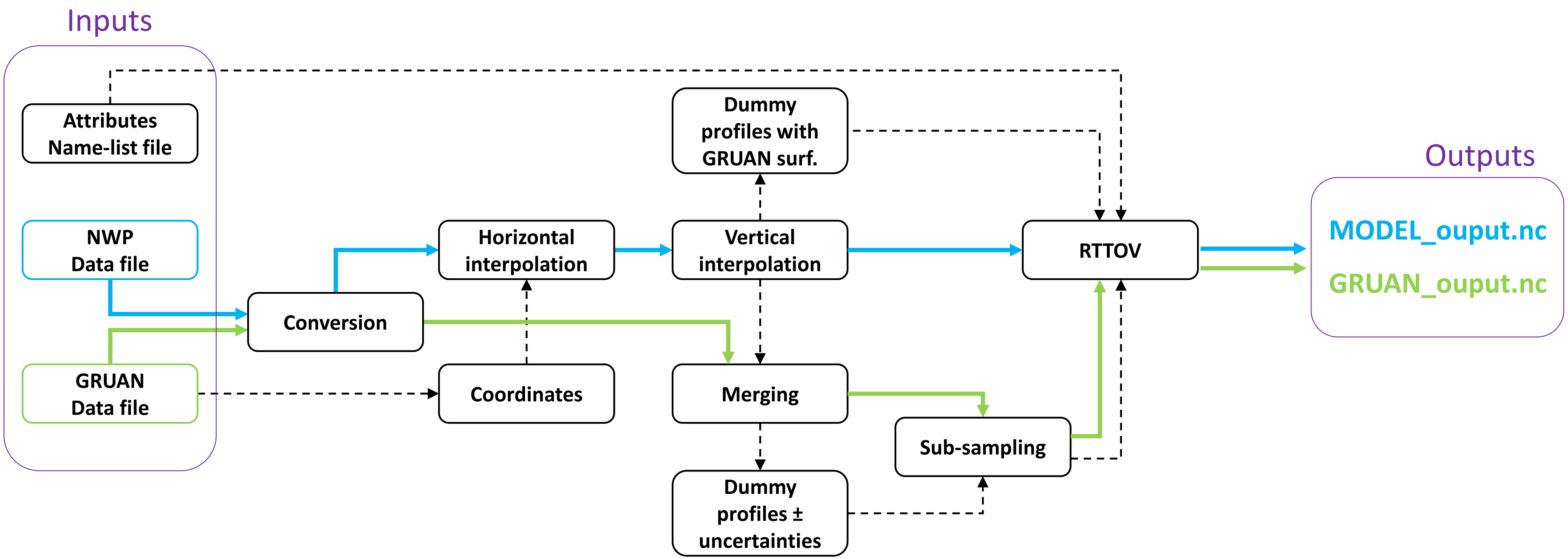
The GRUAN Processor

Top-level design



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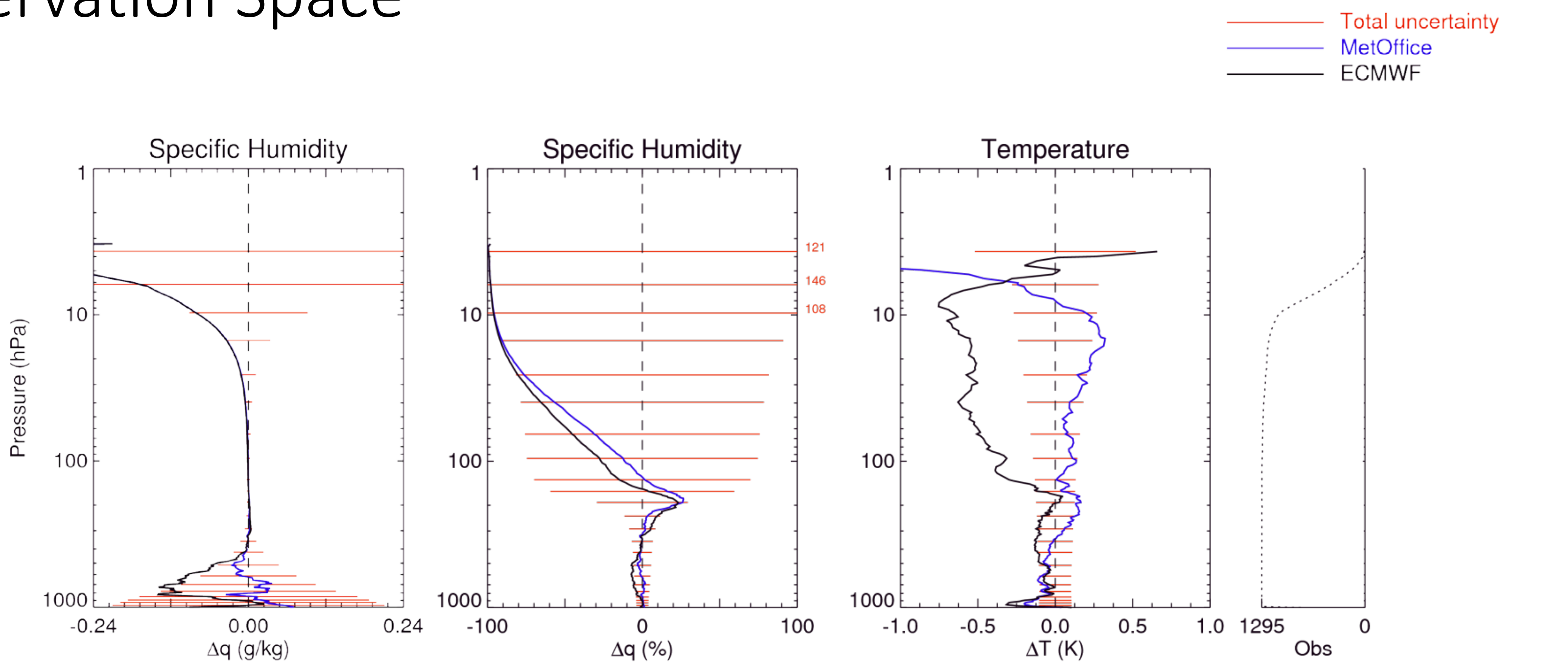
Observation Space



NWP – GRUAN, Lindenberg, 2013, 1297 profiles

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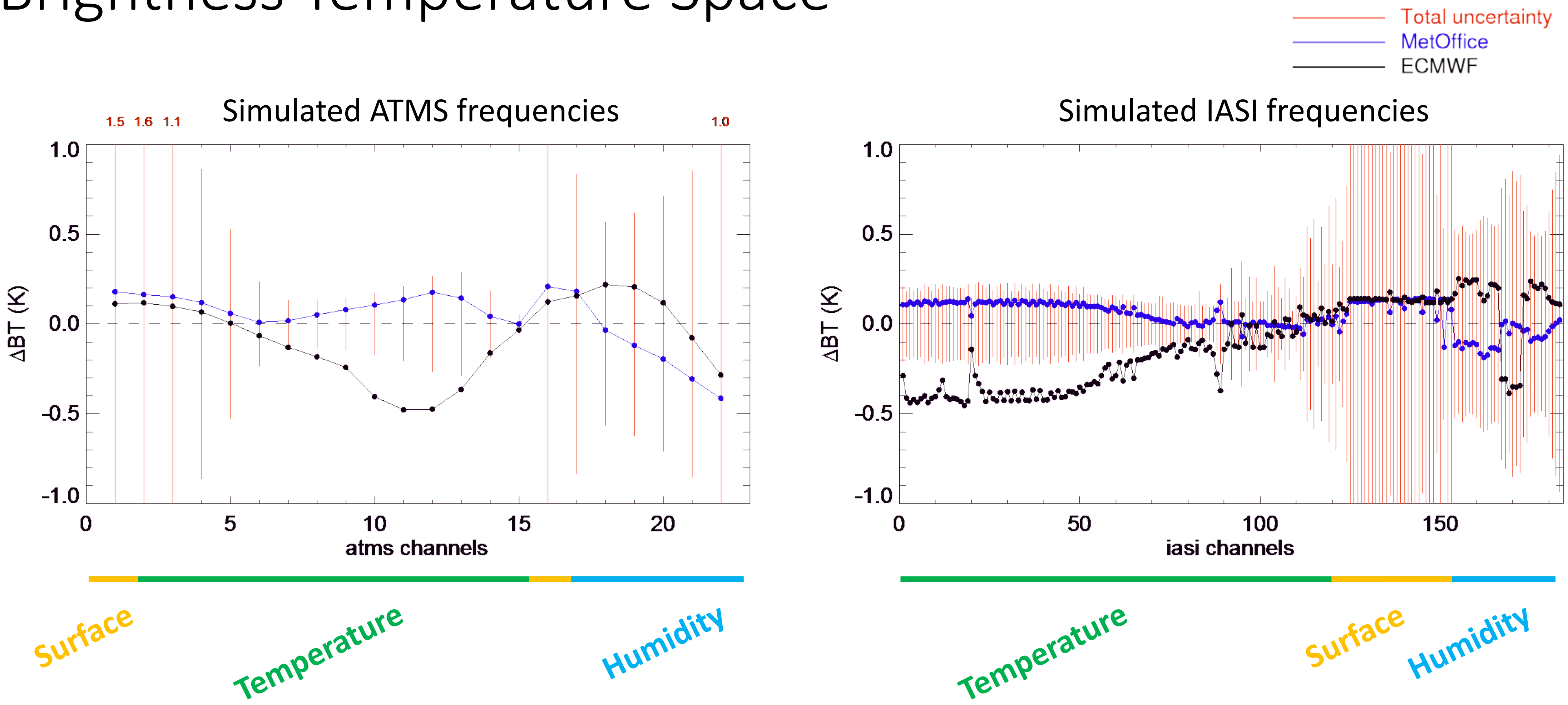
Brightness Temperature Space



NWP – GRUAN, Lindenberg, 2013, 1297 profiles

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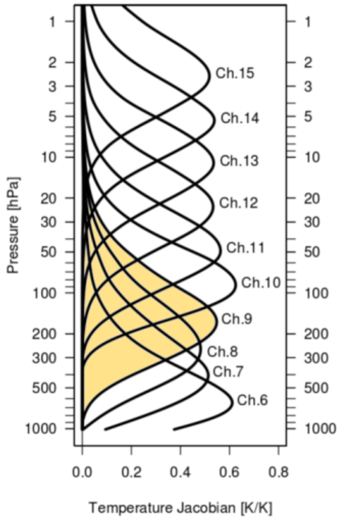
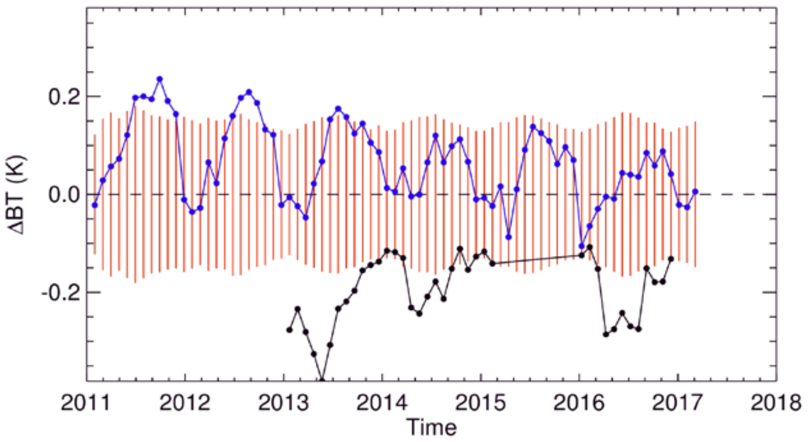
Time series

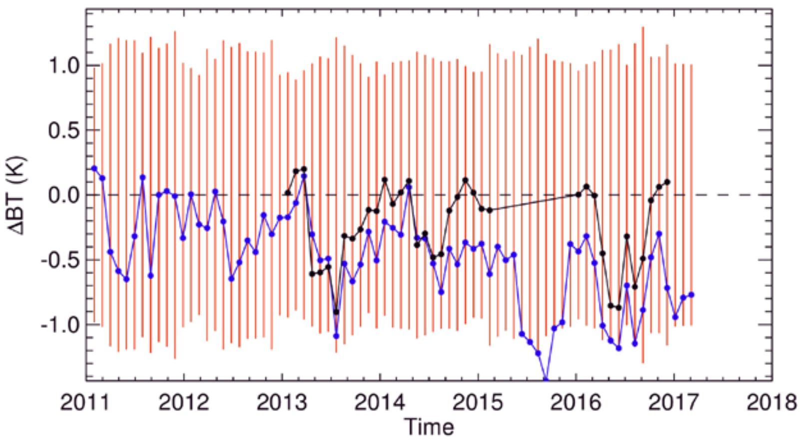
Total uncertainty
MetOffice
ECMWF

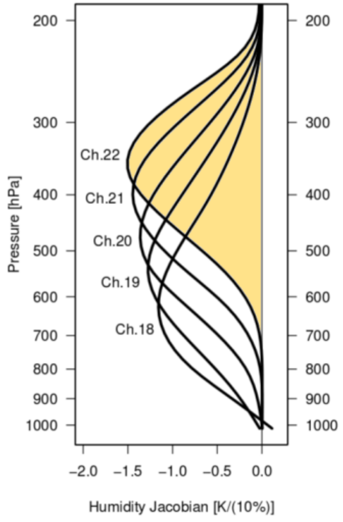


NWP – GRUAN, Lindenberg, monthly mean
ATMS channel 9 (55GHz)



NWP – GRUAN, Lindenberg, monthly mean
ATMS channel 22 (183±1GHz)





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Interpolation uncertainty

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.

Estimation of 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 $\delta\mathbf{y} \equiv \mathbf{y}_{obs} - \mathbf{y}_{NWP} \cong \mathbf{H}_{x_{obs}^t}(\mathbf{W}\boldsymbol{\varepsilon}_{NWP} + \boldsymbol{\varepsilon}_{\text{int}} - \boldsymbol{\varepsilon}_{obs})$

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 background error covariances.

see
Stefano Migliorini
Poster 3p.02
Session 3b: Calibration, validation and uncertainty

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Outlook

- Update GRUAN Processor webpage http://nwpsaf.eu/GProc_test/ins.shtml.
- Full integration in the GAIA-CLIM Virtual Observatory and tool box (Copernicus?).
- Best channel-by-channel estimation of NWP uncertainty for selected instruments.
- MHS closure analysis with FIDUCEO.
- Processing capability extended other NWP centres.
- Semi-automatic monitoring of NWP model at the Met Office (and ECMWF?).
- Manuscripts (technical & scientific) in preparation (expected early 2018).

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Thank you

Please do not forget

Thursday, 30 November 2017, 18:45-20:45

GAIA-CLIM workshop on satellite validation with NWP

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References

[1] Bell, W., Candy, B., Atkinson, N., Hilton, F., Baker, N., Bormann, N., Kelly, G., Kazumori, M., Campbell, W.F. and Swadley, S.D., 2008. The assimilation of SSMIS radiances in numerical weather prediction models. IEEE Transactions on Geoscience and Remote Sensing, 46(4), pp.884-900.

[2] Bormann, N., Fouilloux, A. and Bell, W., 2013. Evaluation and assimilation of ATMS data in the ECMWF system. Journal of Geophysical Research: Atmospheres, 118(23).

[3] Doherty, A., Atkinson, N., Bell, W. and Smith, A., 2015. An Assessment of Data from the Advanced Technology Microwave Sounder at the Met Office, Advances in Meteorology, vol. 2015, Article ID482 956920, 16 pages, 2015. doi:10.1155/2015/956920.

[4] Lu, Q. and Bell, W., 2014. Characterizing channel center frequencies in AMSU-A and MSU microwave sounding instruments. Journal of Atmospheric and Oceanic Technology, 31(8), pp.1713-1732.

[5] Saunders, R.W., Blackmore, T.A., Candy, B., Francis, P.N. and Hewison, T.J., 2013. Monitoring satellite543 radiance biases using NWP models. IEEE Transactions on Geoscience and Remote Sensing, 51(3),544 pp.1124-1138.

[6] Immler, F.J., Dykema, J., Gardiner, T., Whiteman, D.N., Thorne, P.W. and Vömel, H., 2010. Reference Quality Upper-Air Measurements: guidance for developing GRUAN data products. *Atmospheric Measurement Techniques*, *3*(5), pp.1217-1231.

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