GAIA-CLIM – Fiduceo joint session

Water vapour error budget closure

Bill Bell, Stefan Buehler,
Fabien Carminati, Stu Newman, Stefano Migliorini,
Emma Turner, Ed Pavelin, Heather Lawrence

Outline

- Aims of GAIA-CLIM WP4 & Fiduceo
- ‘Water vapour error budget closure’ - defining the problem
- Estimating key uncertainties:
  - in NWP fields
  - in radiative transfer modelling
  - due to scale mismatch / errors of representativeness
  - in satellite radiances

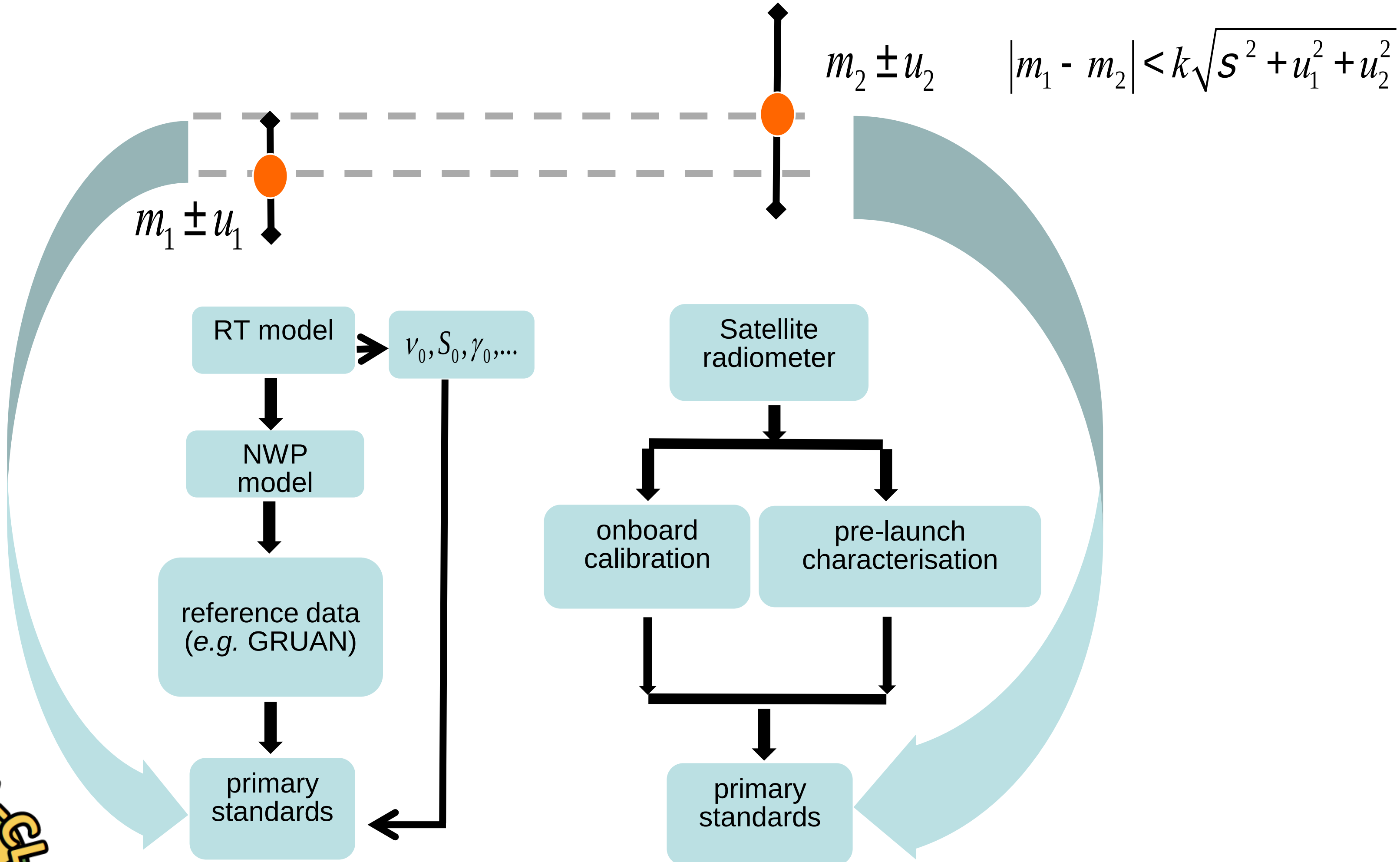
GAIA-CLIM (in NWP fields; in radiative transfer modelling; due to scale mismatch / errors of representativeness)

FIDUCEO (in satellite radiances)

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

GAIA-CLIM (WP4)

Idealised validation of EO data

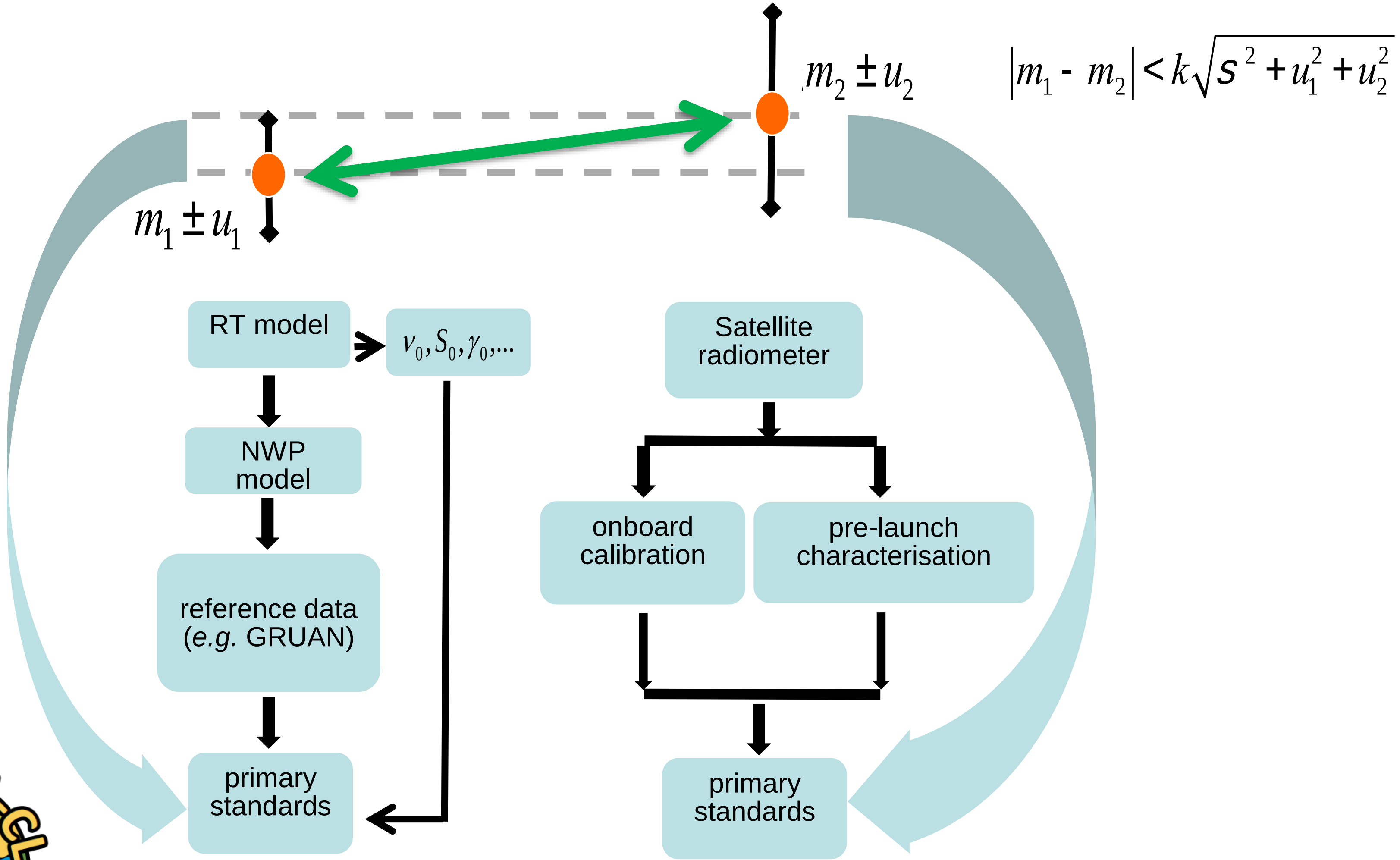


This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 640276.

www.gaia-clim.eu

GAIA-CLIM (WP4)

Current status on validation of EO data

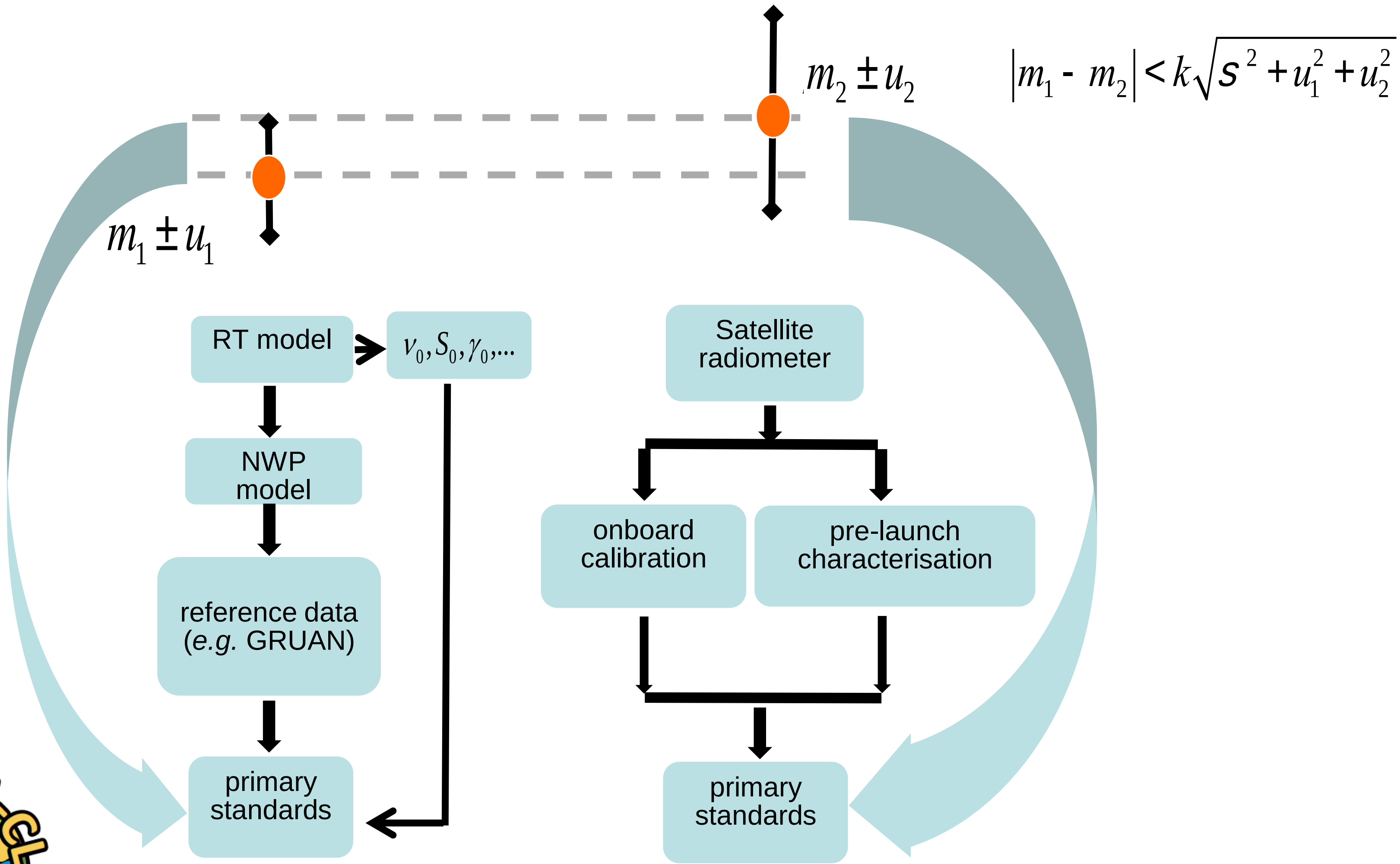


This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 640276.

www.gaia-clim.eu

GAIA-CLIM (WP4)

Aims



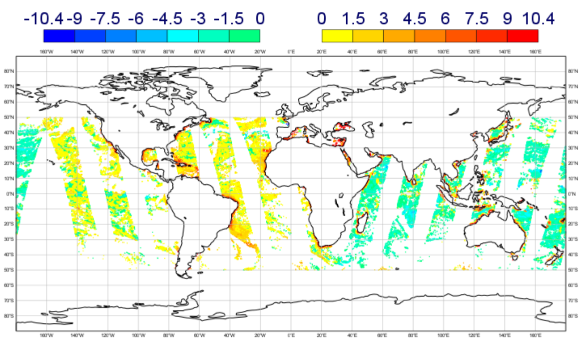
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 640276.

www.gaia-clim.eu

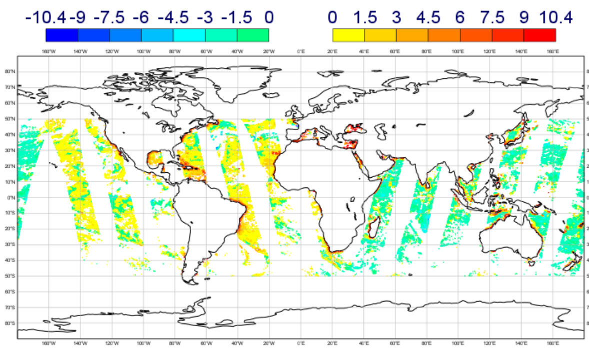
GAIA-CLIM WP4: Demonstrating the value of NWP for EO validation

FY-3C MWRI 10H channel

ECMWF O – B (minus global average)



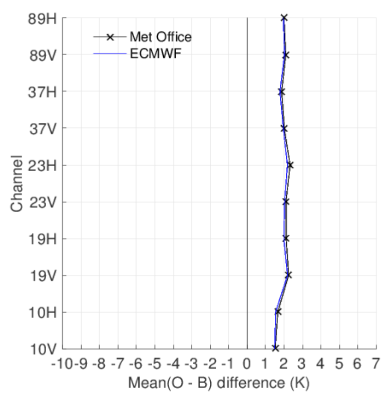
Met Office O – B (minus global average)



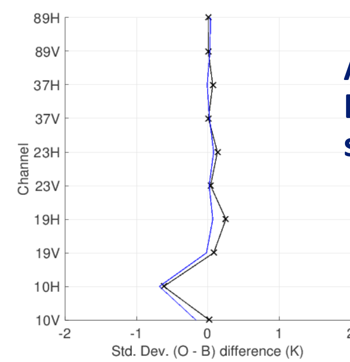
N.B. collocated data to get exactly the same sample (12 hour period)

2 K bias difference for both ECMWF and Met Office data:

Ascending mean(O – B) minus Descending mean(O – B):



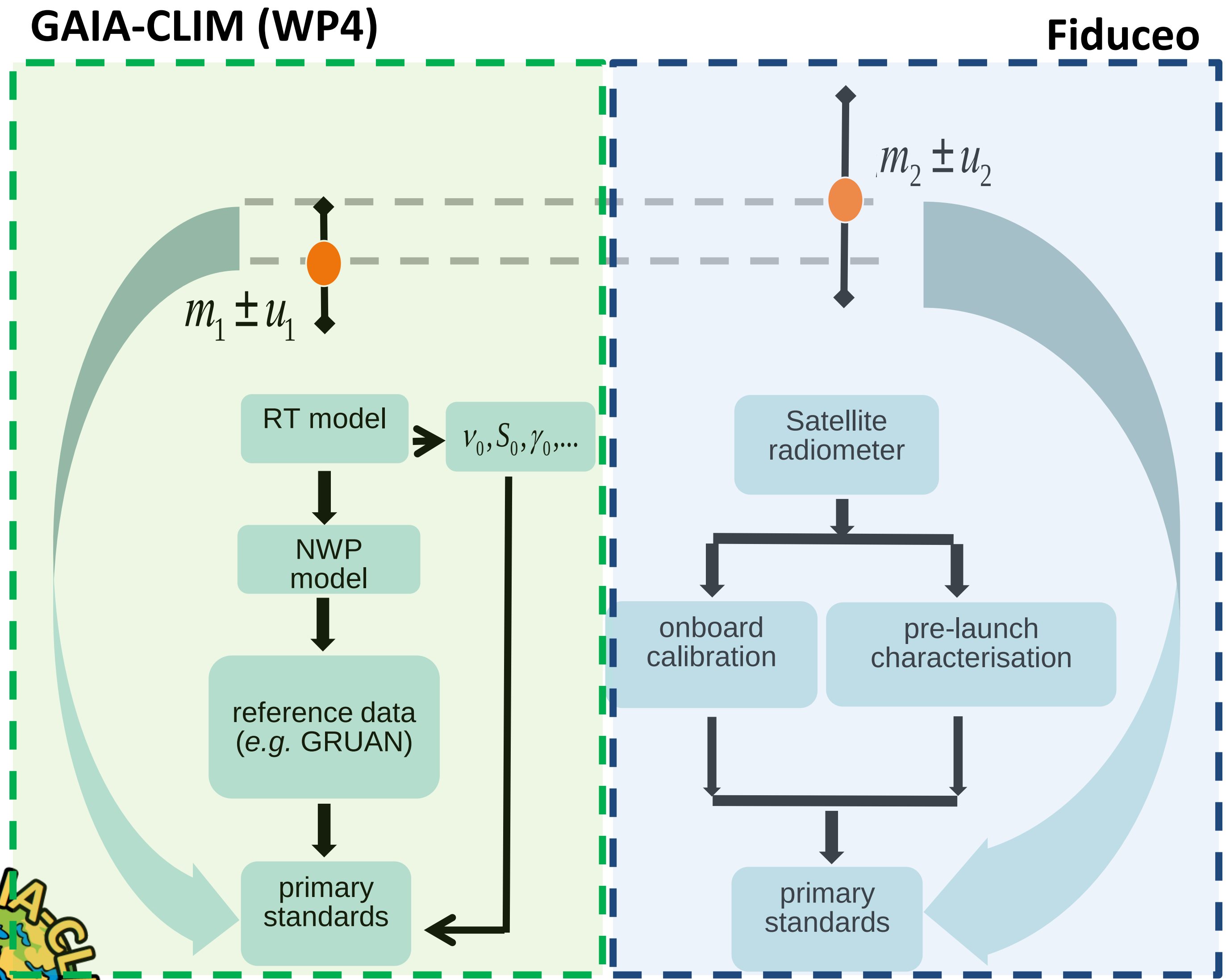
Ascending stdev(O – B) minus Descending stdev(O – B):



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

www.gaia-clim.eu

GAIA-CLIM (WP4) & Fiduceo



- FCDRs by: Nov 2017

(for both AMSU-B & HIRS)

IR: 1982-2016
MW: 1992-2016

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

www.gaia-clim.eu

Uncertainties in simulated TOA brightness temperatures $U(T_B)$

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

Uncertainties in NWP T & q (in brightness temperatures)

- Estimated from (NWP-GRUAN)
- Consistency check: **~ √(HBH^T)** ?

Uncertainties in RT modelling

- *Line-by-line* to *fast* model
- Spectroscopic uncertainties

Uncertainties due to vertical interpolation

- GRUAN-processor

Uncertainties due to scale mismatch

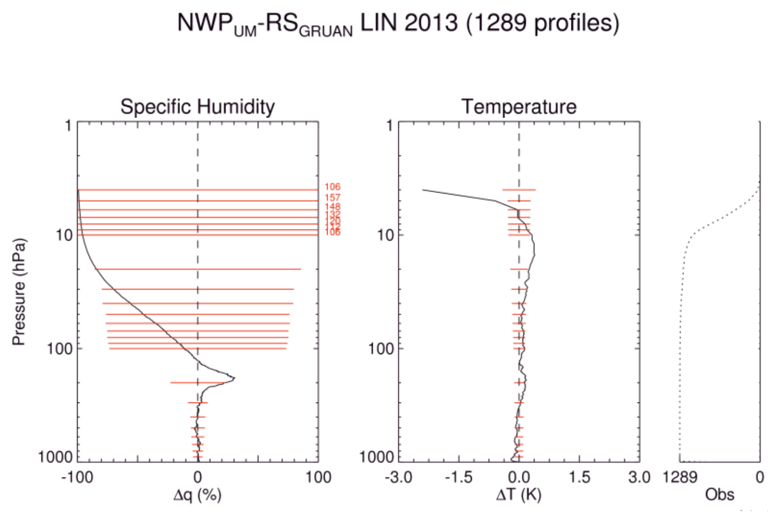
- Observation scale ≠ model scale

AND

- Natural scale << obs & model

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

NWP uncertainties
e.g. Lindenburg data

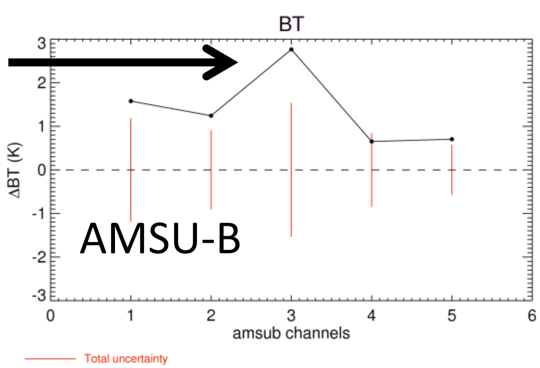


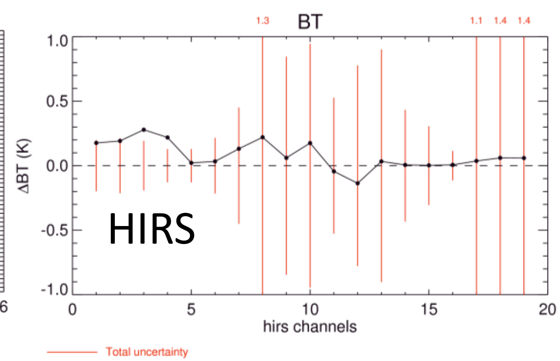
- GAIA-CLIM WP4 GRUAN PROCESSOR
- (NWP – GRUAN) used to determine NWP uncertainties

To do (Yr 3 of GAIA-CLIM):

- Improved interpolation (to reduce biases)
- Estimate correlated errors for GRUAN sondes
  - Desroziers diagnostics (GUAN)
  - Physically based modelling
- Estimate (bounds on?) NWP uncertainties

$H(x_{NWP}) - H(x_{GRUAN})$



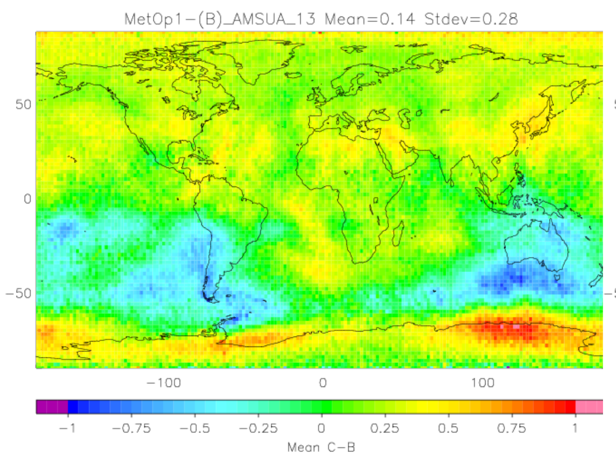


This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 640276.

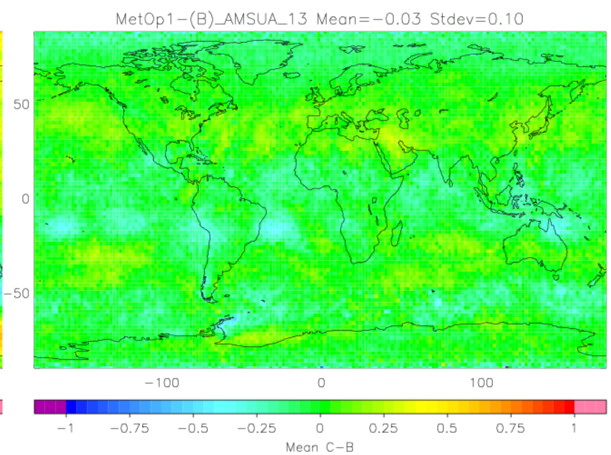
www.gaia-clim.eu

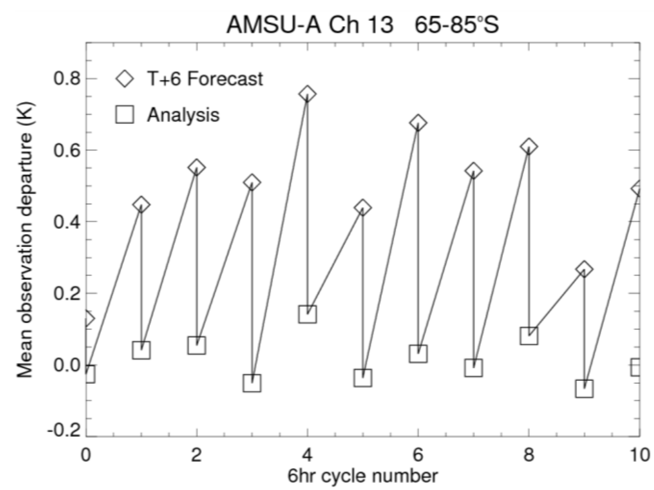
NWP uncertainties:
Model errors - AMSU-13 & errors in T+6hr temperatures at 5 hPa

Obs – T+6 forecasts



Obs – Analyses





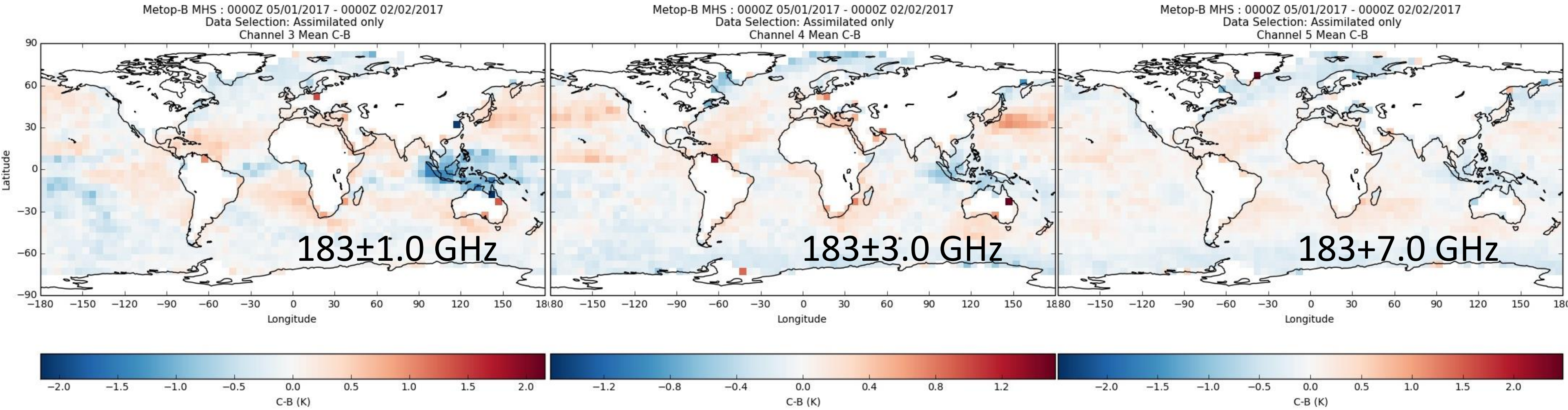
Departures (FG and analysis) averaged over 1 month

(Ed Pavelin)

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

www.gaia-clim.eu

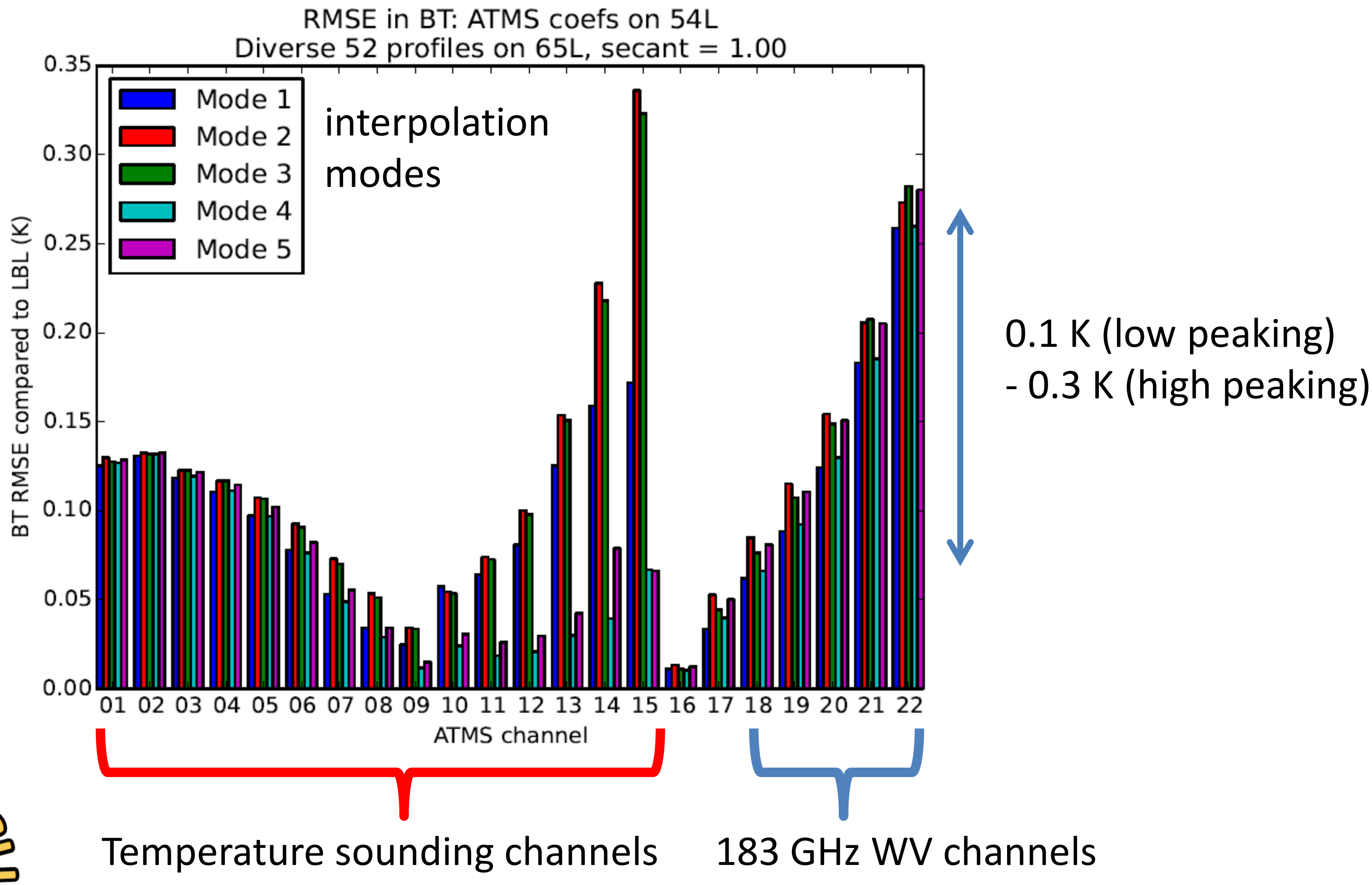
NWP uncertainties: Model errors - MHS 183 GHz humidity sounding channels



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

www.gaia-clim.eu

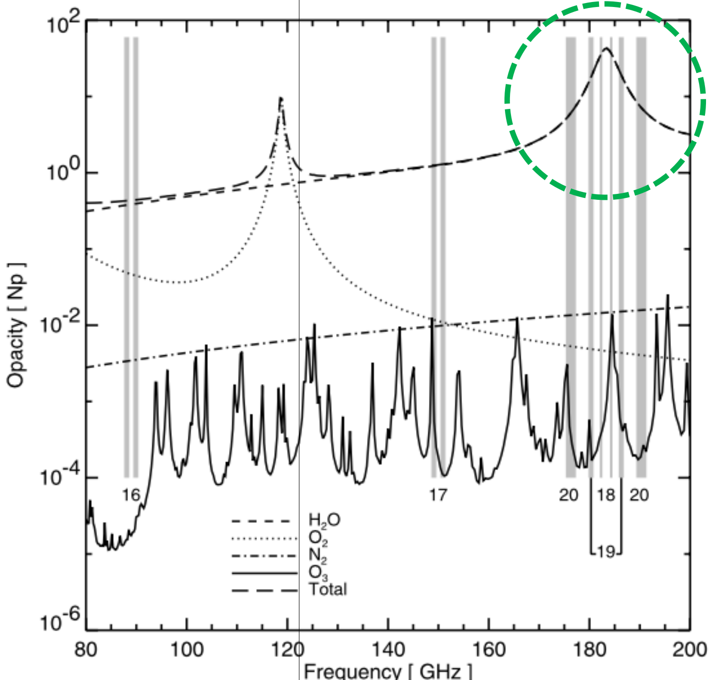
Uncertainties in radiative transfer modelling: line-by-line to fast model uncertainties



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

www.gaia-clim.eu

Uncertainties in radiative transfer modelling: Spectroscopic uncertainties



f

H_2O line absorption

$$N_L = SF(f)$$

$$F''(f) = \frac{A}{X} + \frac{A}{Y} - \delta(f/\nu_0)\left[\frac{(\nu_0 - f)}{X} + \frac{(\nu_0 + f)}{Y}\right]$$

$$A = \frac{\gamma f}{\nu_0}$$

$$X = (\nu_0 - f)^2 + \gamma^2$$

$$Y = (\nu_0 + f)^2 + \gamma^2$$

$$S = b_1 e \theta^{3.5} \exp^{b_2(1-\theta)}$$

$$\gamma = b_3 10^{-3}(p\theta^{b_4} + b_5 e \theta^{b6})$$

$$\delta = 0$$

$$\theta = \frac{300}{T}$$

$$RH = 100\left(\frac{e}{e_s}\right)$$

H_2O continuum absorption

$$N_C''(f) = f\left(b_s e + b_f p\right)10^{-5} e \theta^3$$

$$b_s = 3.57\theta^{7.5}$$

$$b_f = 0.113$$

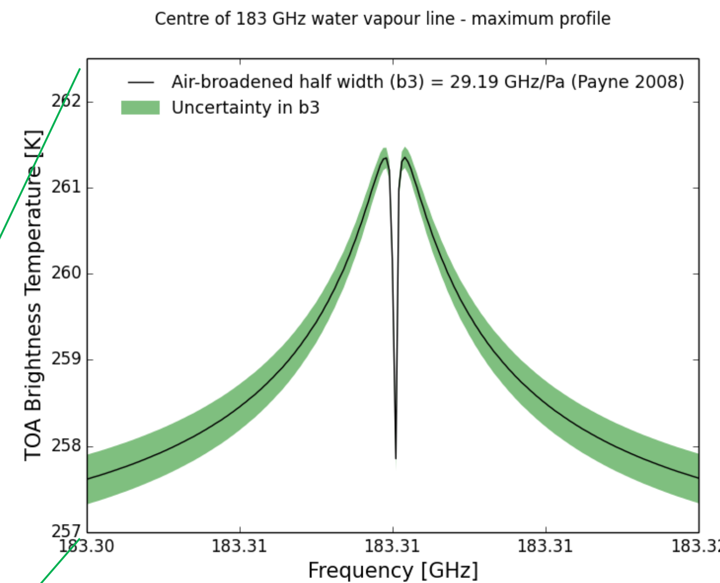
From Liebe (1989)

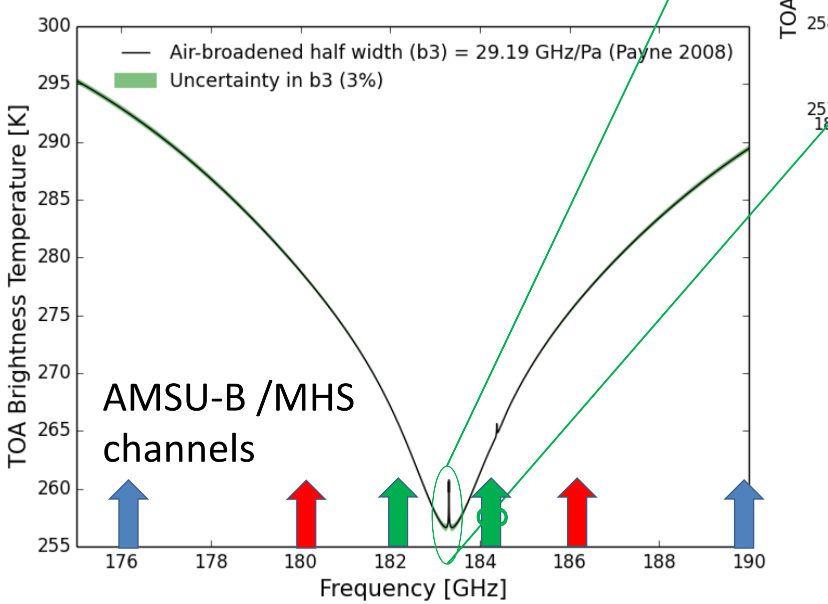
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 640276.

www.gaia-clim.eu

Spectroscopic uncertainties

Spectroscopic Parameter	Value	Uncertainty (±%)
b_1 (line strength)	2.3	0.5
b_2 (T-dependence of line strength)	0.668	-
b_3 (air-broadened half-width [ABHW])	29.19	3
b_4 (T-dependence of ABHW)	0.77	15
b_5 (self-broadened half-width [SBHW])	5.3	15
b_6 (T-dependence of SBHW)	0.85	15

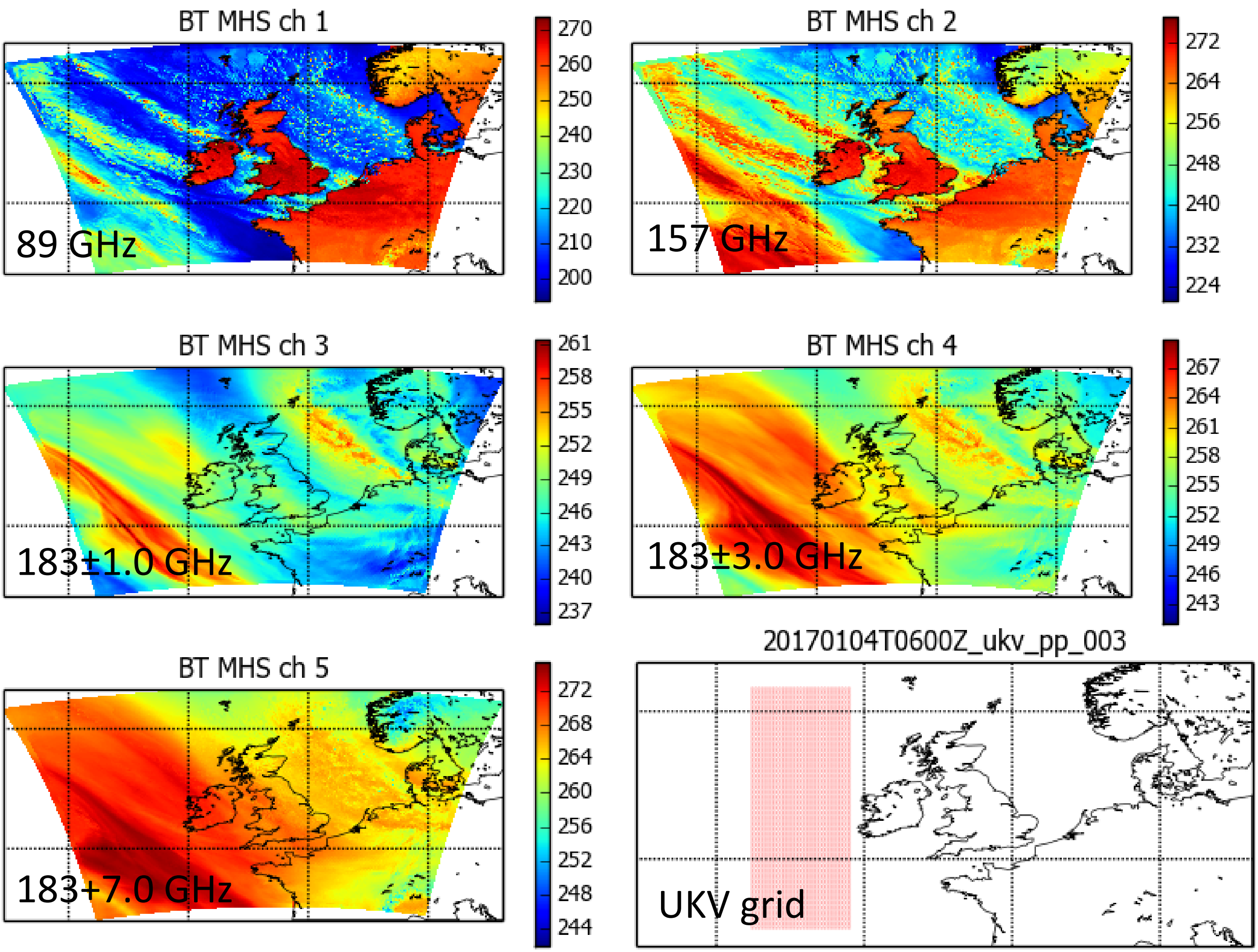




This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 640276.

www.gaia-clim.eu

Quantifying uncertainties due to scale mismatch

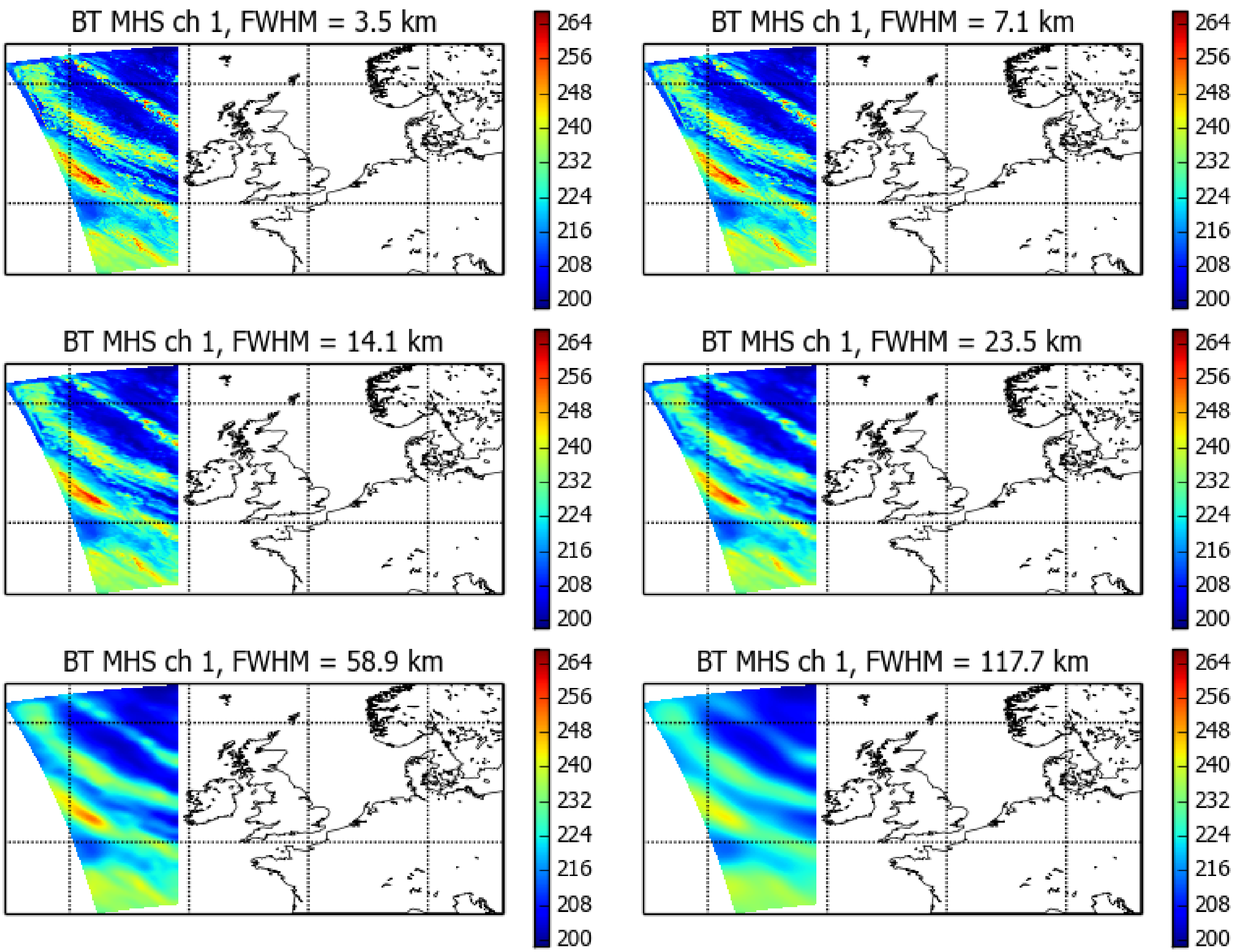


simulations based on UKV 1.5 km model

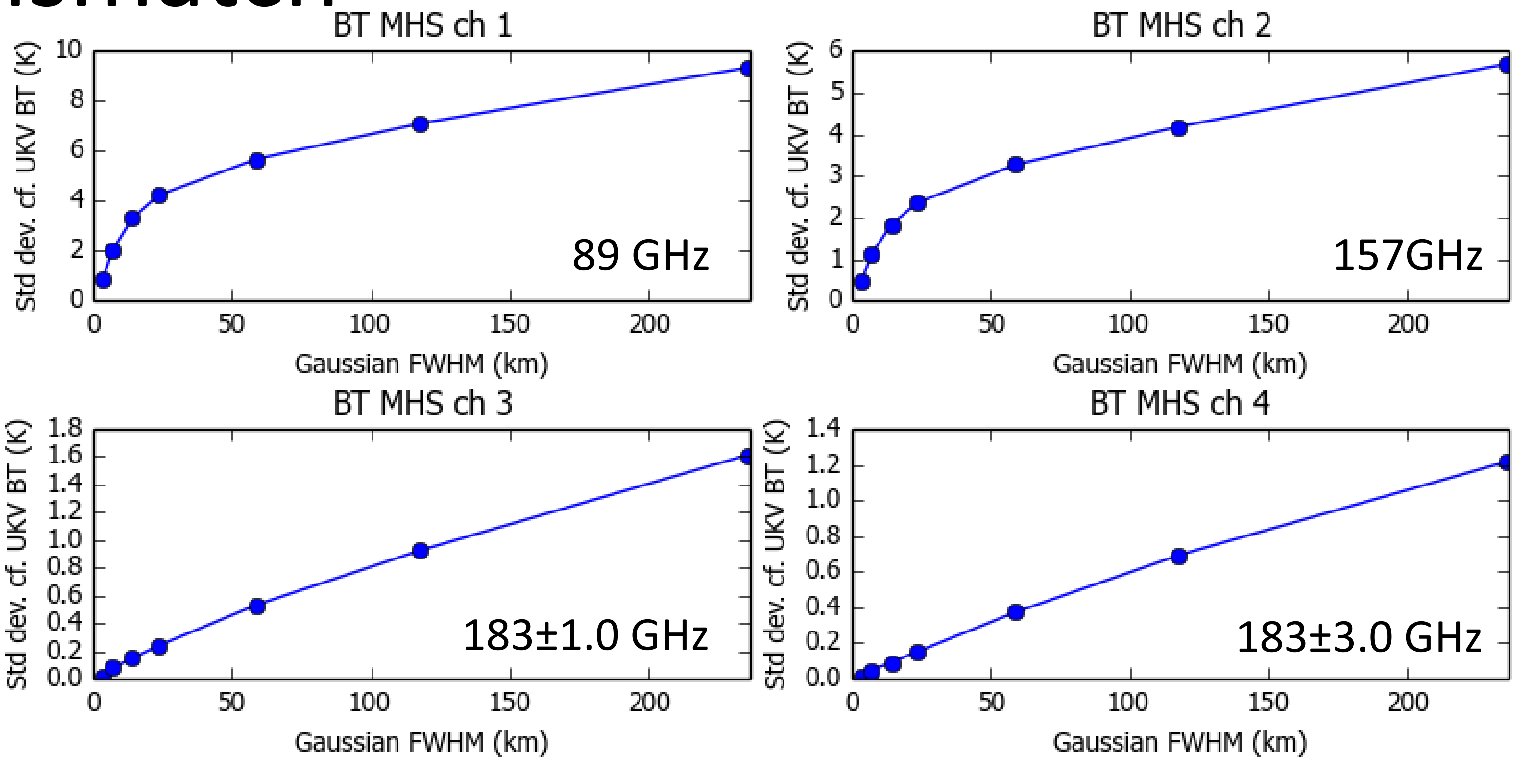
Take these as a *proxy* for the true brightness temperature scene …

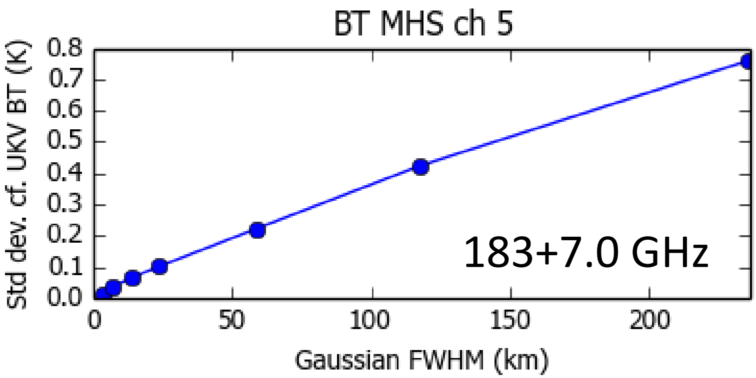
..and degrade using a 2D convolution

Quantifying uncertainties due to scale mismatch



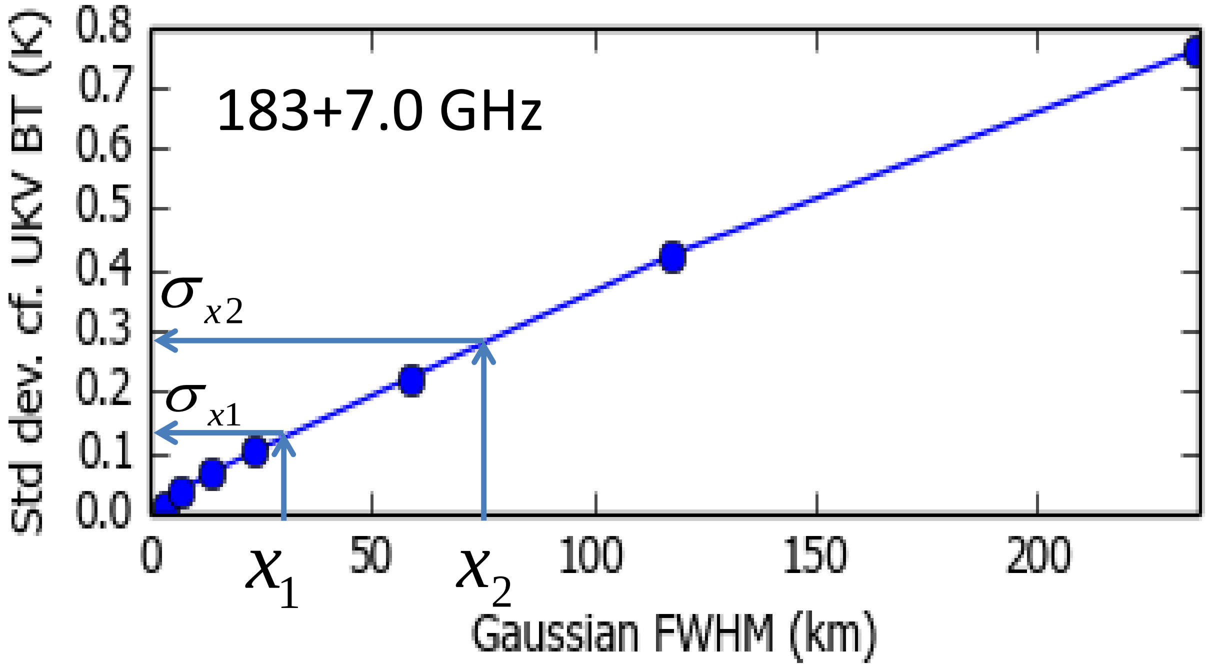
Quantifying uncertainties due to scale mismatch





- *For sounding channels* – linear increase of representativeness error with scale
- *For surface-viewing channels* – sharp initial rise to higher values
- *nb* Based on single illustrative case

Quantifying uncertainties due to scale mismatch



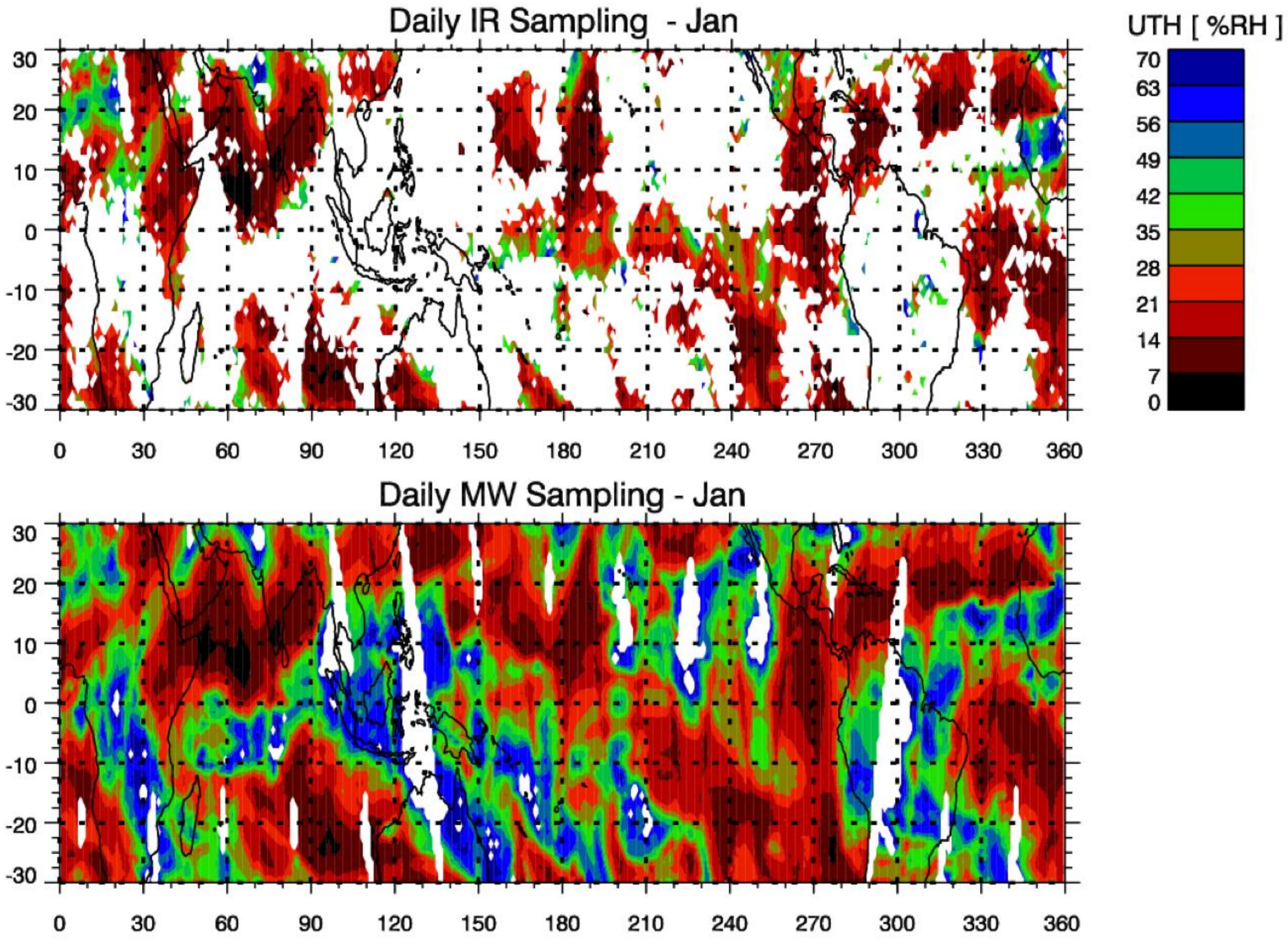
Estimate scale-mismatch / representativeness errors ($\sigma_{\Delta x}$) comparing estimate at scale x_1, with estimate at scale x_2 from:

$$\sigma_{\Delta x} = \left(\sigma_{x2}^2 - \sigma_{x1}^2\right)^{\frac{1}{2}}$$

Fiduceo: Radiometric calibration and inter-calibration of IR (HIRS) & MW (MHS) sensors

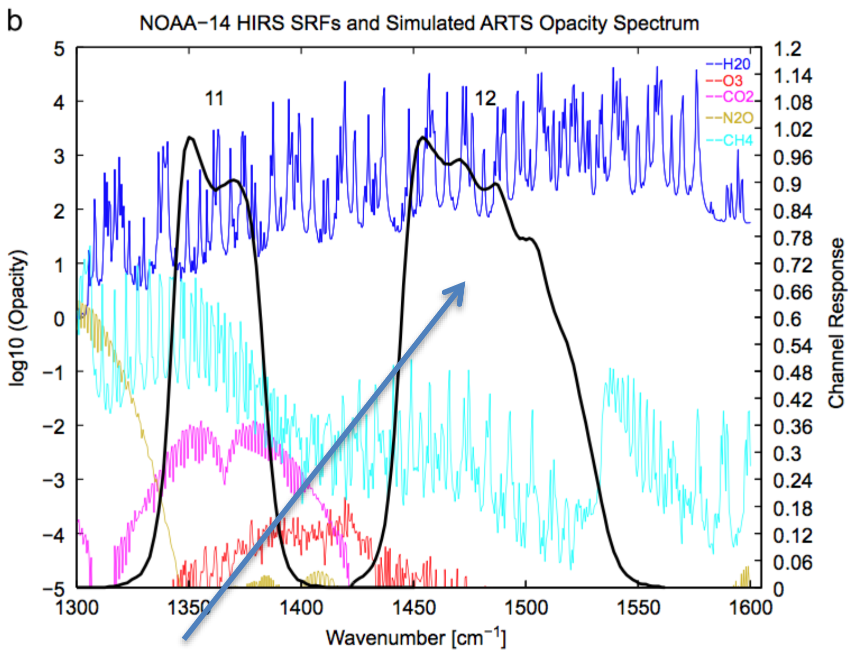
- **How different are AMSU-B and HIRS radiometrically?**
- How to intercalibrate satellite sounding sensors?

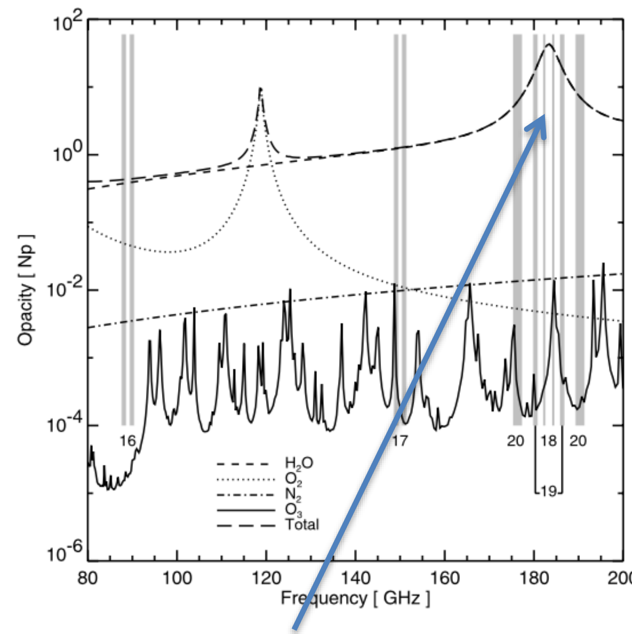
Fiduceo: IR / MW sampling



John, V. O., G. Holl, R. P. Allan, S. A. Buehler, D. E. Parker, and B. J. Soden (2011), **Clear-sky biases in satellite infra-red estimates of upper tropospheric humidity and its trends**, *J. Geophys. Res.*, ***116***, D14108, doi:10.1029/2010JD015355.

IR / MW Spectral characteristics





HIRS Channel 12 ⟵ almost matches ⟶ **AMSU-B Channel 18**

Many water vapor lines.

Buehler, S. A., V. O. John, A. Kottayil, M. Milz, and P. Eriksson (2010), **Efficient Radiative Transfer Simulations for a Broadband Infrared Radiometer — Combining a Weighted Mean of Representative Frequencies Approach with Frequency Selection by Simulated Annealing**, *J. Quant. Spectrosc. Radiat. Transfer*, *111*(4), 602–615, doi:10.1016/j.jqsrt.2009.10.018.

Only wing of one water vapor line.

John, V. O. and S. A. Buehler (2004), **The impact of ozone lines on AMSU-B radiances**, *Geophys. Res. Lett.*, *31*, L21108, doi:10.1029/2004GL021214.

IR & MW Jacobians

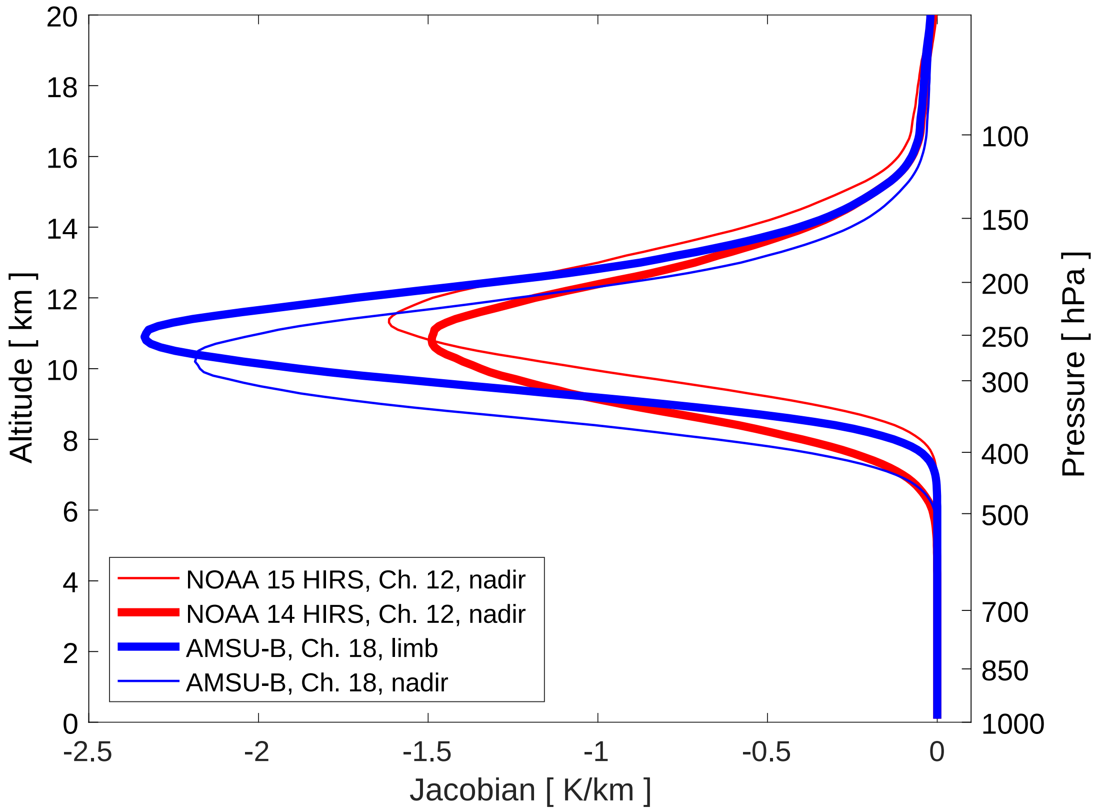


Figure by Oleksandr Bobryshev, for mean atmosphere of tropical GRUAN radiosonde stations Manus and Nauru, standard
ARTS instrument setups.

- Nadir view of Channel 12 of HIRS 2 is quite similar to most off-nadir view of Channel 18 of AMSU-B.
- For HIRS 3 (from NOAA 15 on) the sounding altitude moved up by a kilometer or so.
- For nadir view, AMSU-B sounds about a kilometer lower.

IR & MW Jacobians

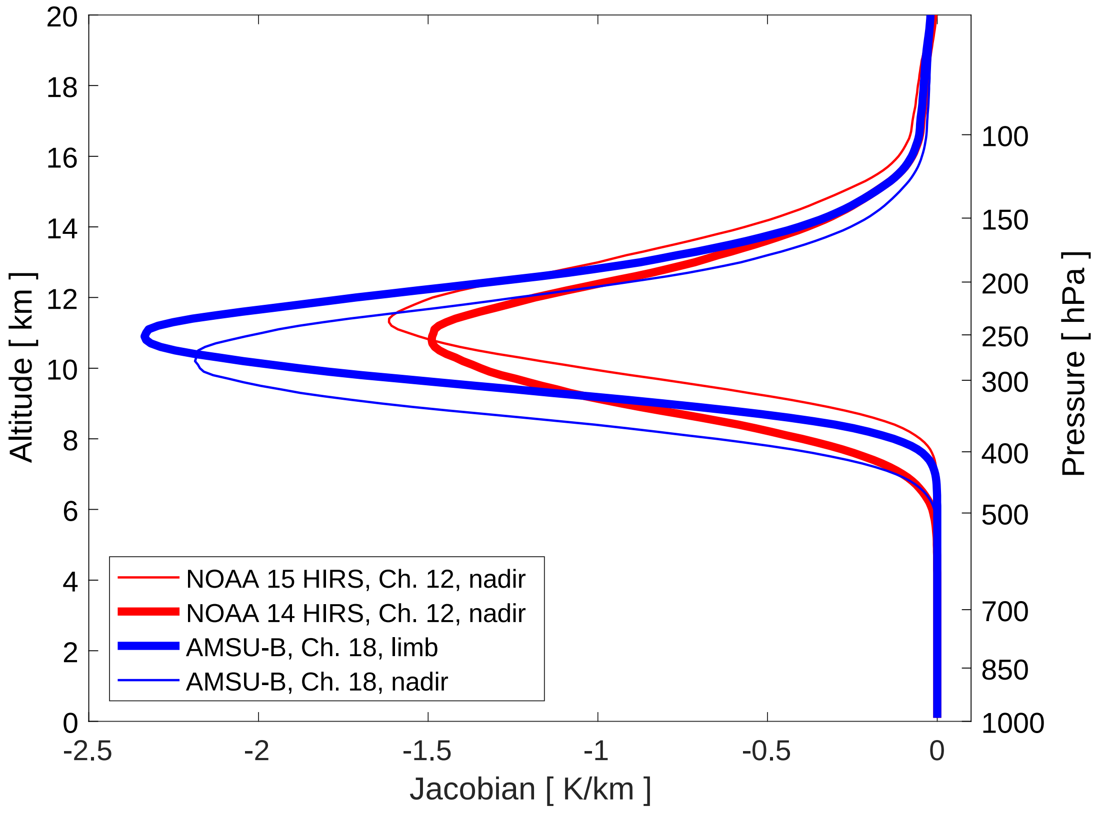
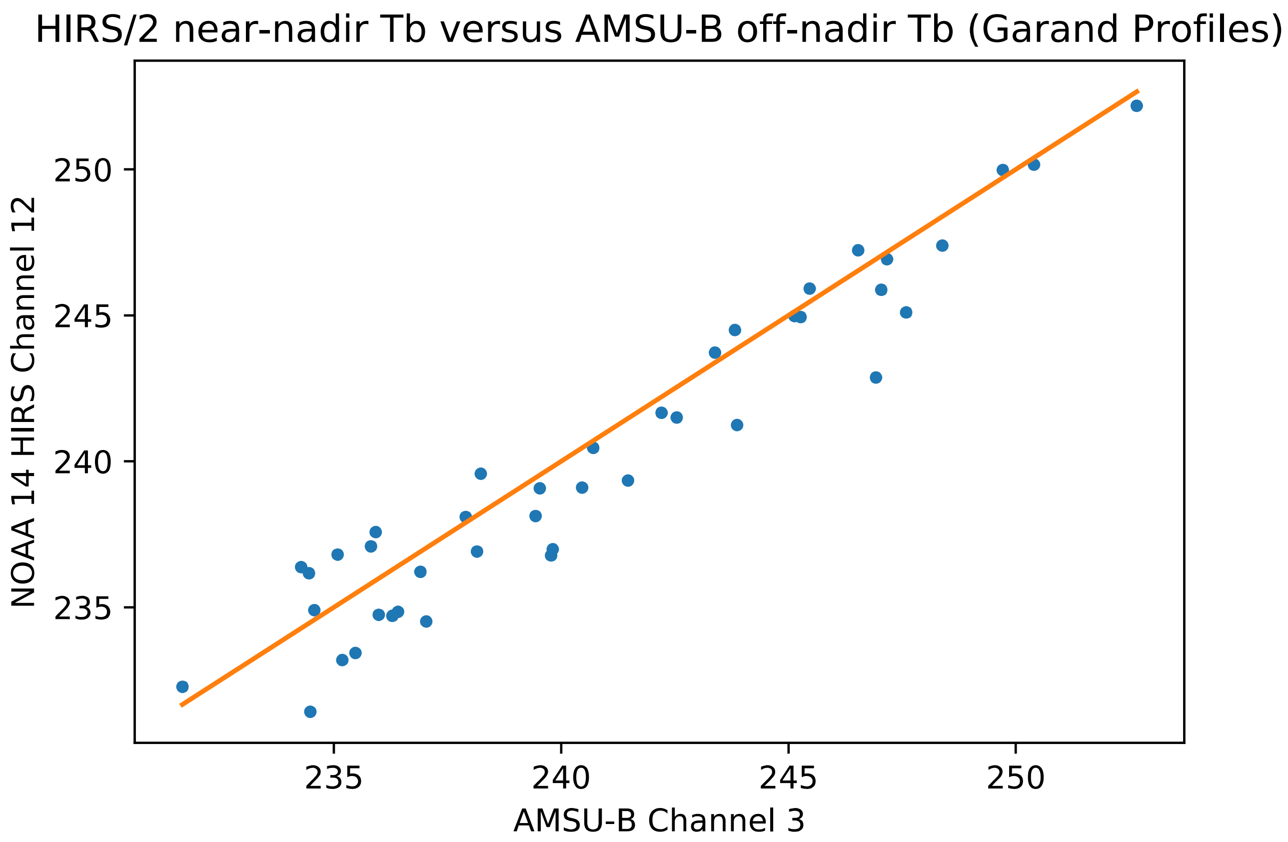


Figure by Oleksandr Bobryshev, for mean atmosphere of tropical GRUAN radiosonde stations Manus and Nauru, standard
ARTS instrument setups.

- Due to the larger spectral variability inside the band, HIRS Jacobian is wider (larger FWHM).
- HIRS is also slightly less sensitive to humidity changes.
- There will be a variable difference between the two instruments that is a function of the humidity itself and of the vertical atmospheric structure.

Brightness temperature comparison



- Tb simulation confirms that nadir view of HIRS/2 is quite similar to most off-nadir view of AMSU-B. (Simulation: ARTS, www.radiativetransfer.org, clear-sky setup)

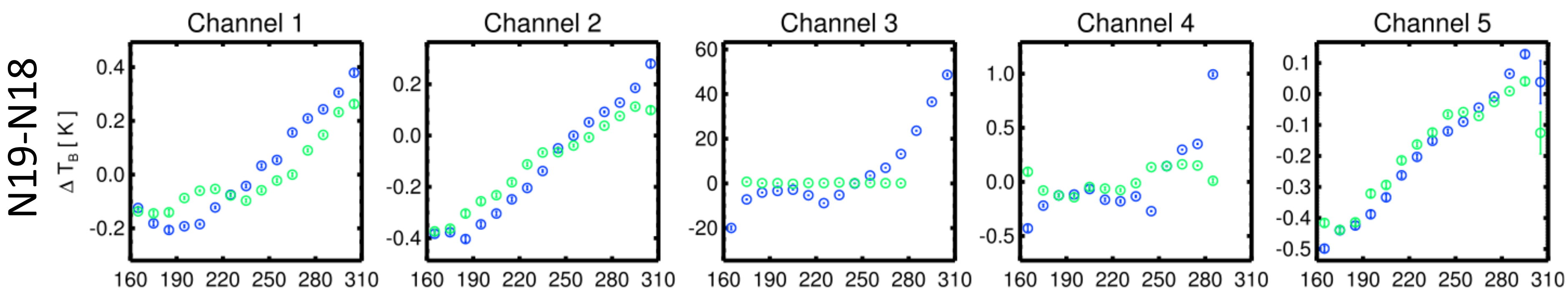
The intercalibration problem

- Instruments on different satellites can have biases
- Intercalibration requires to
  - observe the same constant target, or
  - observe the same variable target at the same time

- For the latter strategy:
  Simultaneous Nadir Overpasses (SNOs)

Simultaneous nadir overpasses (SNOs)

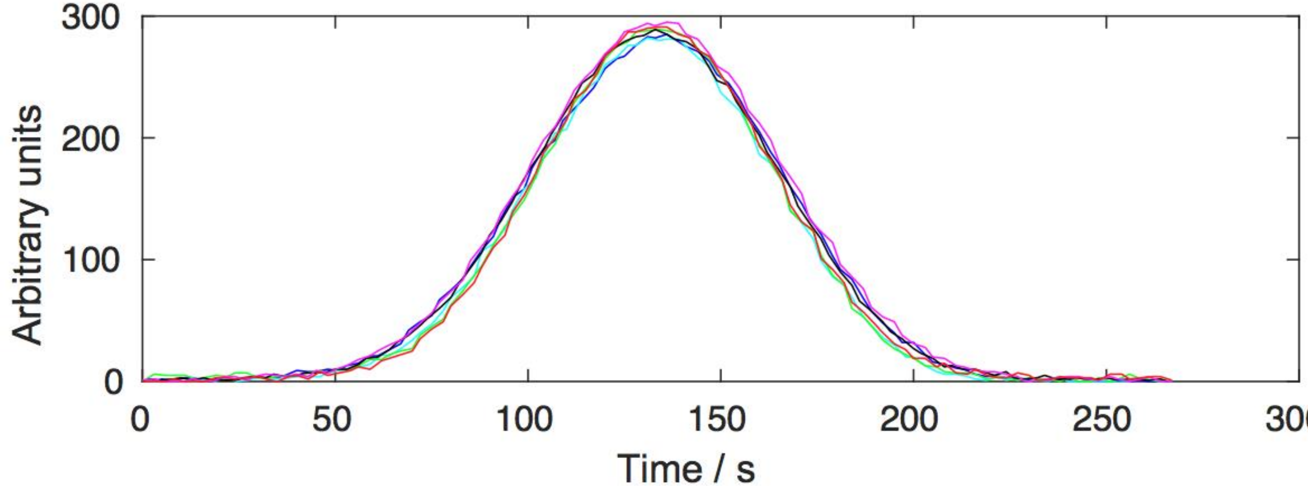
- Simultaneous nadir overpasses (SNOs) typically occur only at high latitudes, but when orbits meet due to drift they occur globally.
- There are scene radiance dependent biases. (But these can not be studied with “normal” SNOs.)
- For most satellite pairs, SNOs can only provide a “cold” calibration target. For proper calibration, we would need also a warm target.



John, V. O., G. Holl, S. A. Buehler, B. Candy, R. W. Saunders, and D. E. Parker (2012), **Understanding inter-satellite biases of microwave humidity sounders using global simultaneous nadir overpasses**, *J. Geophys. Res.*, ***117***(D2), D02305, doi:10.1029/2011JD016349.
Blue and green symbols mean that different satellites are put on the x-axis.

Observing a constant target

Strategy 1: Look at the moon

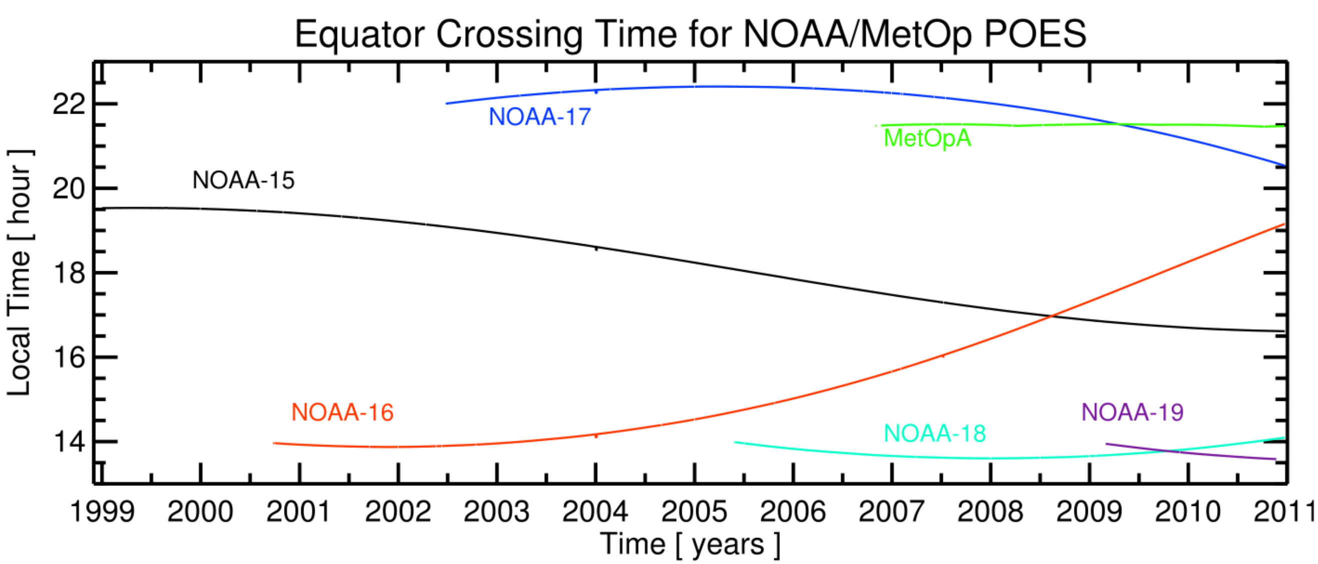


+ Very stable target
- Even colder than the SNOs at high latitude, so cannot provide "warm" calibration point
- For current missions only observed accidentally in cold space view

Burgdorf, M., S. A. Buehler, T. Lang, S. Michel, and I. Hans (2016), **The Moon as a photometric calibration standard for microwave sensors**, *Atmos. Meas. Tech.*, *9*, 3467–3475, doi:10.5194/amt-9-3467-2016.

Strategy 2: Find constant targets on earth

- This has proven quite difficult.
- Problem: Orbit drift leads to aliasing of diurnal cycle.
- Can be mitigated by avoiding convective areas.



John, V. O., G. Holl, S. A. Buehler, B. Candy, R. W. Saunders, and D. E. Parker (2012), **Understanding inter-satellite biases of microwave humidity sounders using global simultaneous nadir overpasses**, *J. Geophys. Res.*, ***117***(D2), D02305, doi:10.1029/2011JD016349.

Summary

- Aims of :
  - **GAIA-CLIM WP4** – assessing and developing NWP for EO (L1) validation; and
  - **Fiduceo** - FCDRs for real observations (HIRS & MHS)

  are highly complementary.

- Prospects for estimating key uncertainties (in Yr3) are good:
  - NWP fields
  - Radiative transfer modelling
  - Scale mismatch & vertical interpolation
  - For satellite radiances (Fiduceo)

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