Characterisation of the Met Office NWP model biases and uncertainties using the new RS41-GDP

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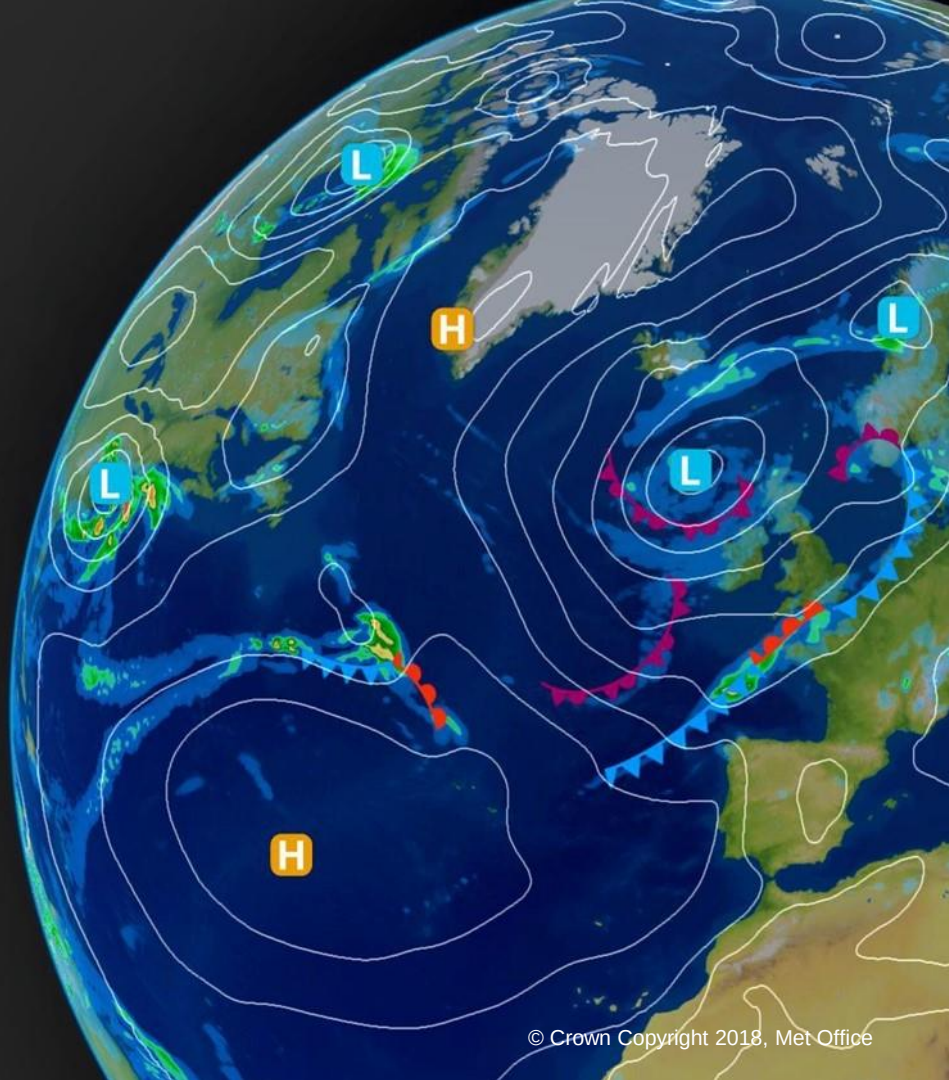

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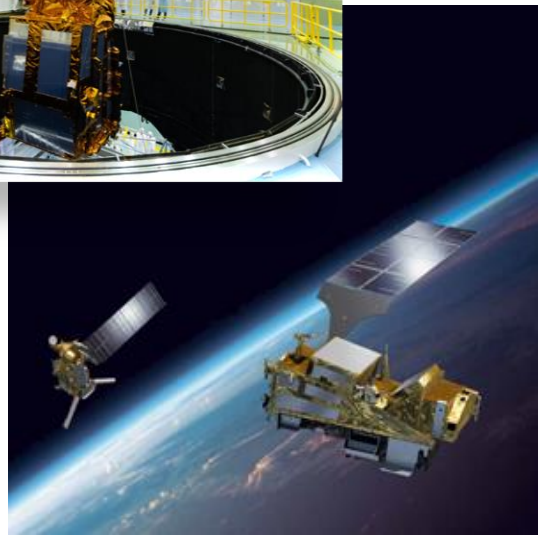
Metop-SG A is an atmospheric sounding and imaging mission (2023). It has a suite of infrared, microwave, and imaging instruments for sounding temperature, moisture and trace gases in the atmosphere, including:

- The Infrared Atmospheric Sounding Interferometer (IASI-NG) with design requirement of 0.25K absolute radiometric accuracy.
- The Microwave Sounder (MWS) with a design requirement of <1K absolute radiometric accuracy.



Is the Met Office NWP model suitable for the validation of these instruments?

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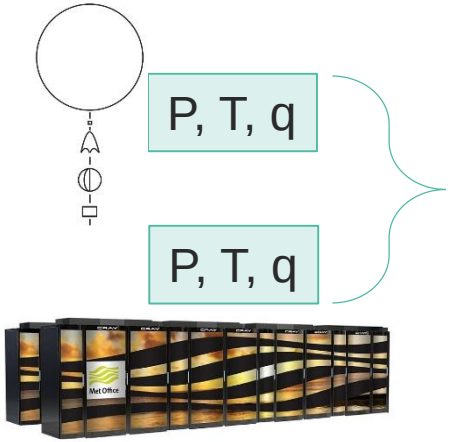
Assessing the model fields with the new RS41-GDP (beta).

This need to be done in the same space as satellite observations, i.e. in **radiance space**.



GRUAN Processor

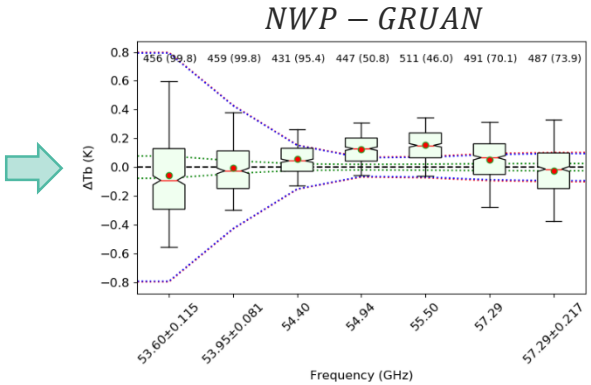
Radiance Simulator

+

RTTOV

+

GRUAN processing capability



See Carminati et al., 2019 https://www.atmos-meas-tech.net/12/83/2019/amt-12-83-2019.html

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Given the difference $\delta \boldsymbol{y} = NWP - GRUAN$ in radiance space

The total uncertainty of $\delta \boldsymbol{y}$ is expressed as the covariance matrix $\boldsymbol{S}_{\delta \boldsymbol{y}}$:

$$\boldsymbol{S}_{\delta \boldsymbol{y}} \cong \boldsymbol{H}\boldsymbol{R}\boldsymbol{H}^T + \boldsymbol{H}\boldsymbol{W}\boldsymbol{B}\boldsymbol{W}^T\boldsymbol{H}^T + \boldsymbol{H}\boldsymbol{S}_{int}\boldsymbol{H}^T$$

Expressed as a function of $\boldsymbol{B}$ and $\boldsymbol{W}$ (interpolation matrix)

$$= \boldsymbol{H}\boldsymbol{W}\boldsymbol{B}_{temp}\boldsymbol{W}^T\boldsymbol{H}^T + \boldsymbol{H}\boldsymbol{W}\boldsymbol{B}_q\boldsymbol{W}^T\boldsymbol{H}^T + \boldsymbol{h}\sigma^2_{surf}\boldsymbol{h}$$

Full model covariance matrices

$$= \boldsymbol{H}\boldsymbol{R}_{temp}\boldsymbol{H}^T + \boldsymbol{H}\boldsymbol{R}_q\boldsymbol{H}^T + \boldsymbol{H}\boldsymbol{R}_P\boldsymbol{H}^T + \boldsymbol{h}\sigma^2_{surf}\boldsymbol{h}^T$$

Diagonal matrices of GRUAN uncertainties

With $\boldsymbol{H}$ the Jacobian matrix containing the partial derivatives of $\partial y/\partial x$ (i.e. a change in radiance ∂y for a change in the state vector ∂x)

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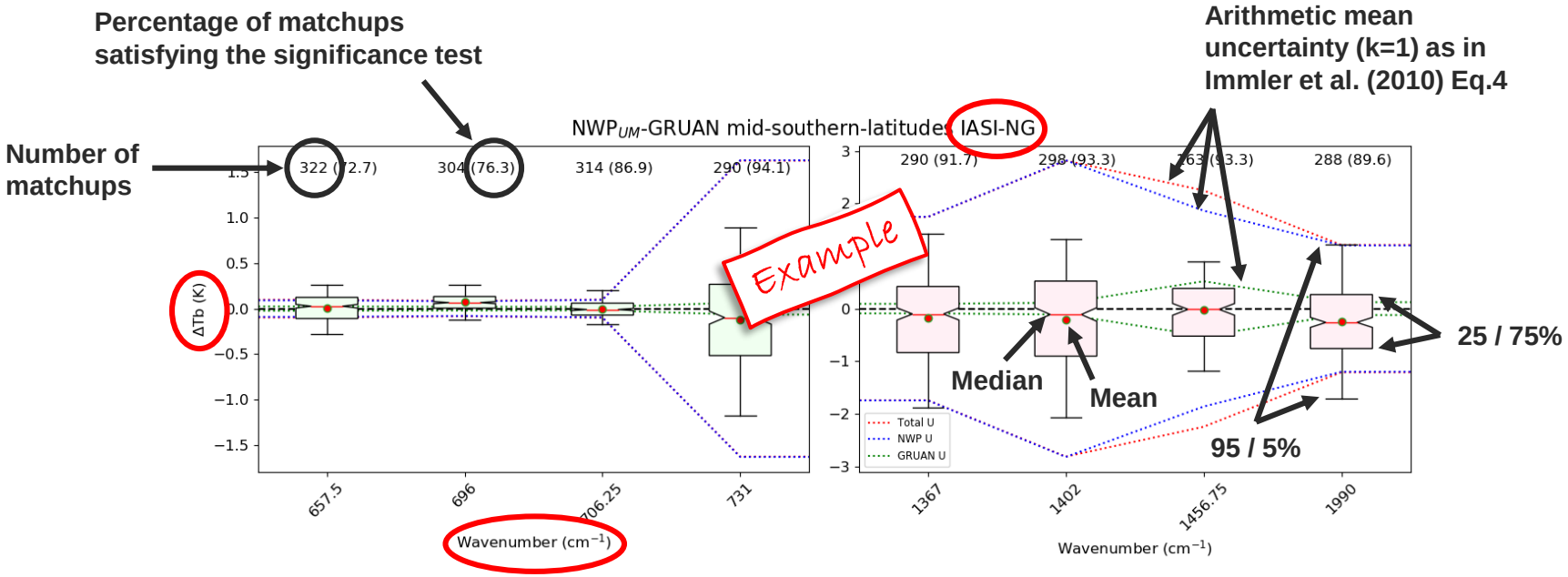
The statistical significance of $\delta \boldsymbol{y}_i$ (where i is the channel number) is assessed by testing the following:

$$|\delta \boldsymbol{y}_i| < 2\sqrt{diag(\boldsymbol{S}_{\delta \boldsymbol{y}})_i}$$

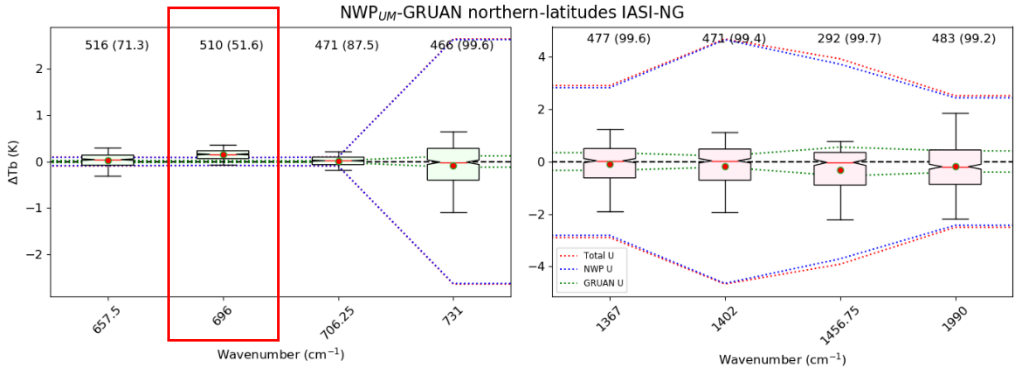
NWP and GRUAN simulated brightness temperatures satisfying this test are in agreement with a confidence interval of 95.5%. If the uncertainty is well defined then the lack of agreement is a sign of biases in either NWP or GRUAN.

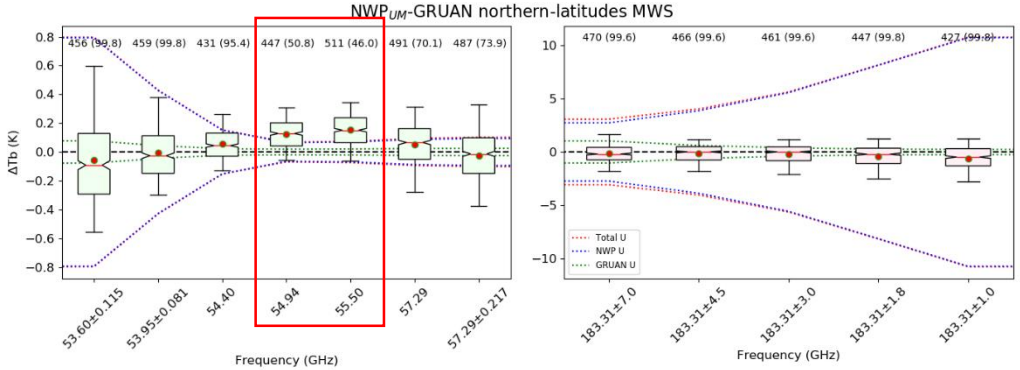
Caveat: this ignores the correlation in $\boldsymbol{S}_{\delta \boldsymbol{y}}$

Figure keys


Percentage of matchups satisfying the significance test
Arithmetic mean uncertainty (k=1) as in Immler et al. (2010) Eq.4
Number of matchups
NWP$_{UM}$-GRUAN mid-southern-latitudes IASI-NG
322 (72.7)
304 (76.3)
314 (86.9)
290 (94.1)
290 (91.7)
298 (93.3)
288 (89.6)
ΔTb (K)
Example
Median
Mean
95 / 5%
25 / 75%
Total U
NWP U
GRUAN U
657.5
696
706.25
731
1367
1402
1456.75
1990
Wavenumber (cm^{-1})
Wavenumber (cm^{-1})

SOD Jan-Jun 2020





Assuming that the uncertainty is correctly defined:

A bias is detected for half or more of the match ups at 696 cm^{-1} in the IR and 54.95 and 55.5 GHz in the MW channels.

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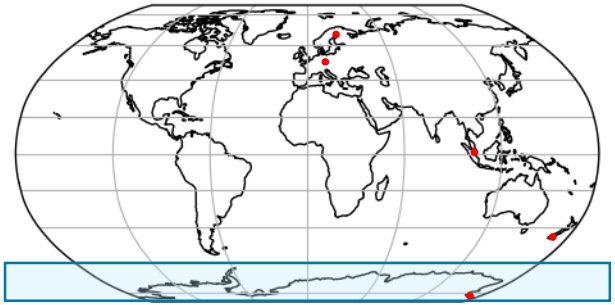

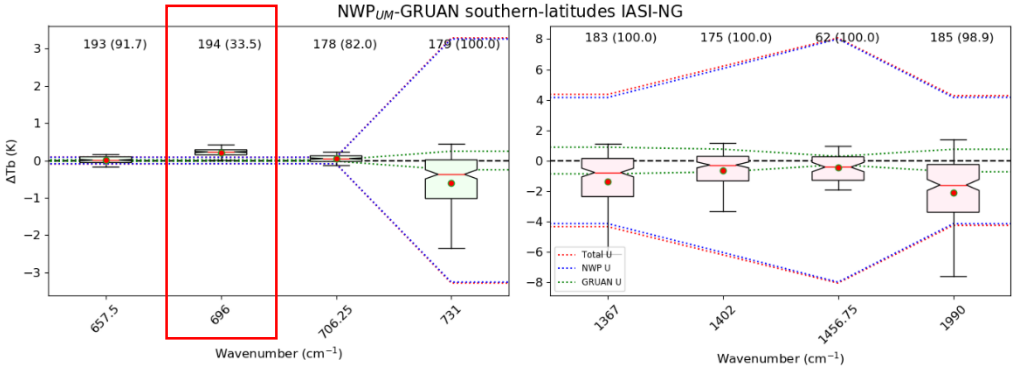

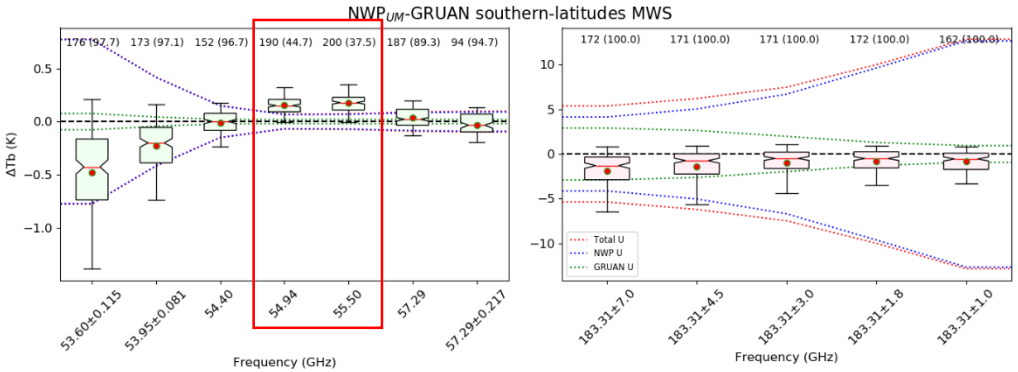

Assuming that the uncertainty is correctly defined:

A bias is detected for half or more of the match ups at 696 cm^{-1} in the IR and 54.95 and 55.5 GHz in the MW channels.

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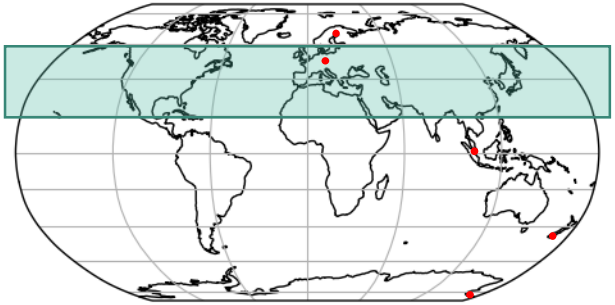
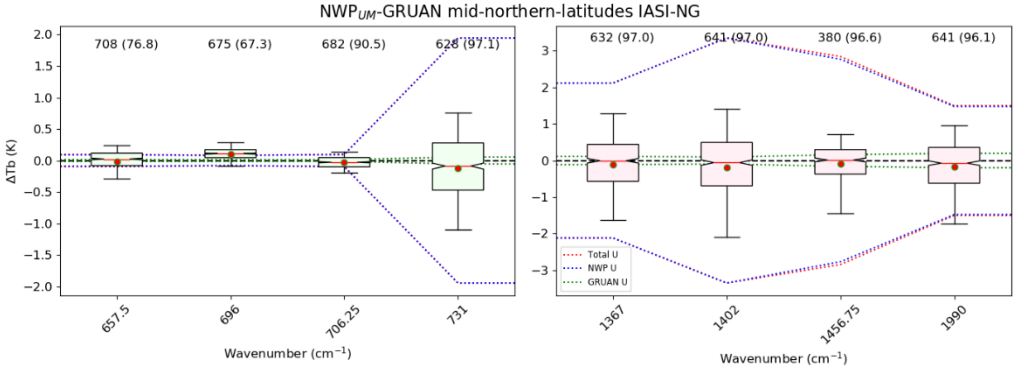
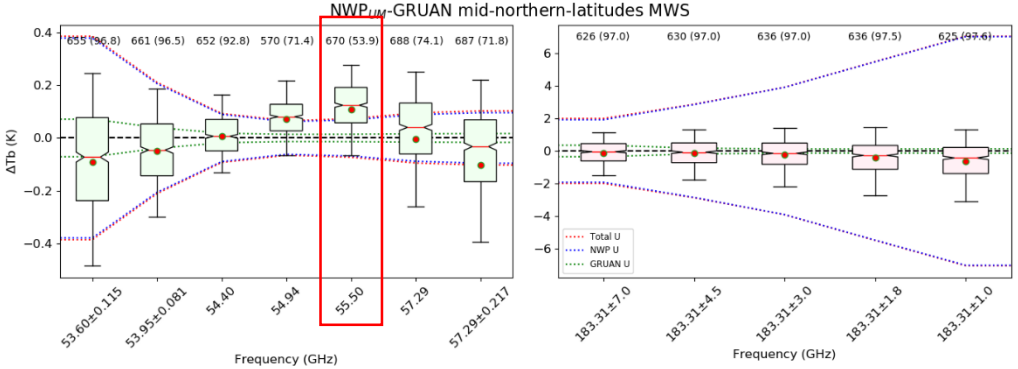




Assuming that the uncertainty is correctly defined:

A bias is detected for half or more of the match ups at 55.5 GHz in the MW channels.



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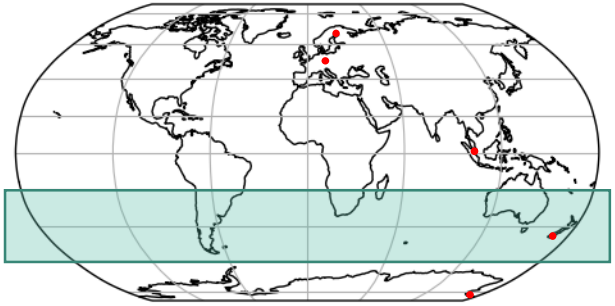
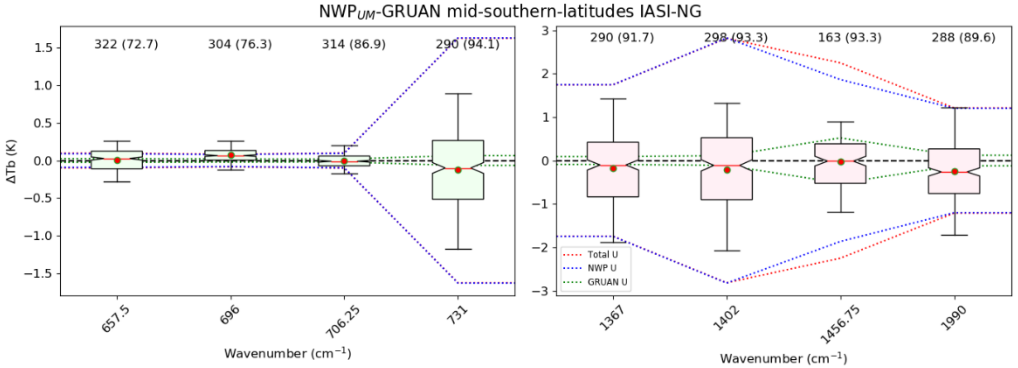
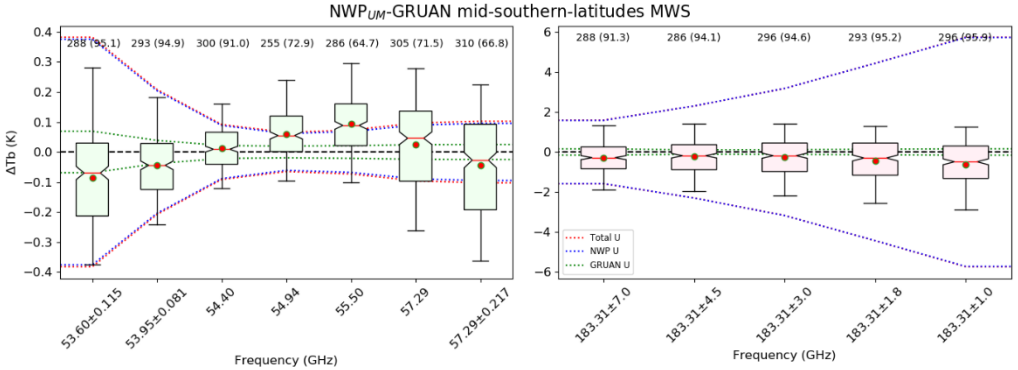


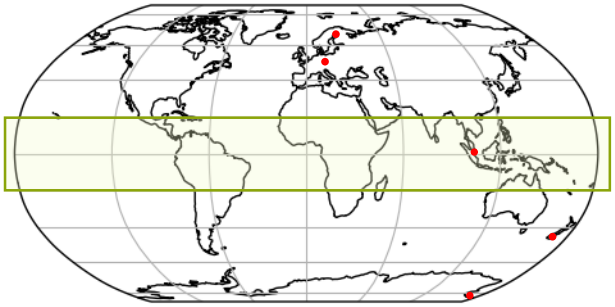


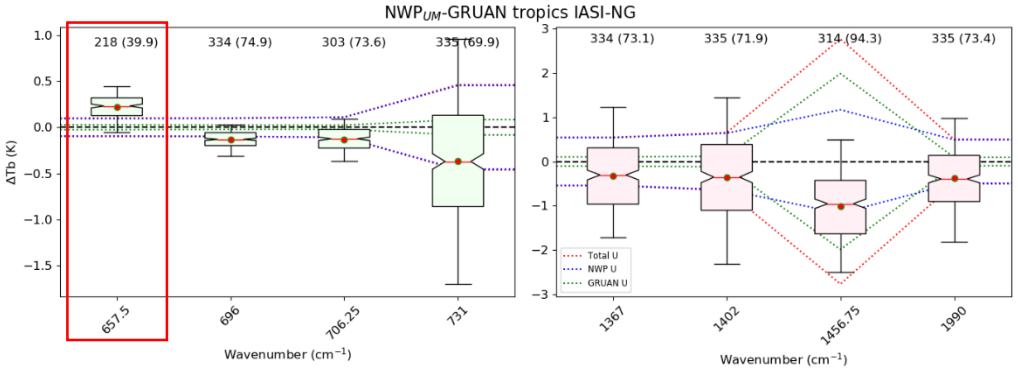
Assuming that the uncertainty is correctly defined:

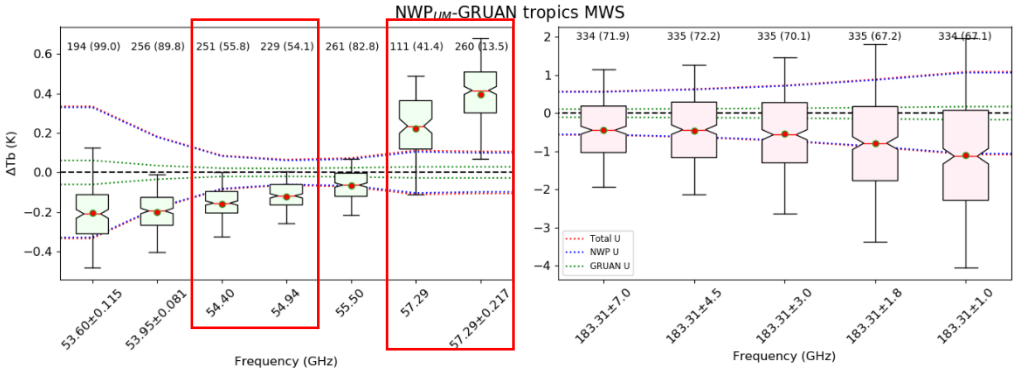
All the tested channels are in agreement for at least 64% of the match ups.



SNG Jan-Jun 2020







Assuming that the uncertainty is correctly defined:

A bias is detected for half or more of the match ups at 657.5 cm^{-1} in the IR and 54.4, 54.95, 57.29 and 57.29±0.217 GHz in the MW channels.

The reduced Chi-square test gives the overall agreement, accounting for inter-channel correlation:

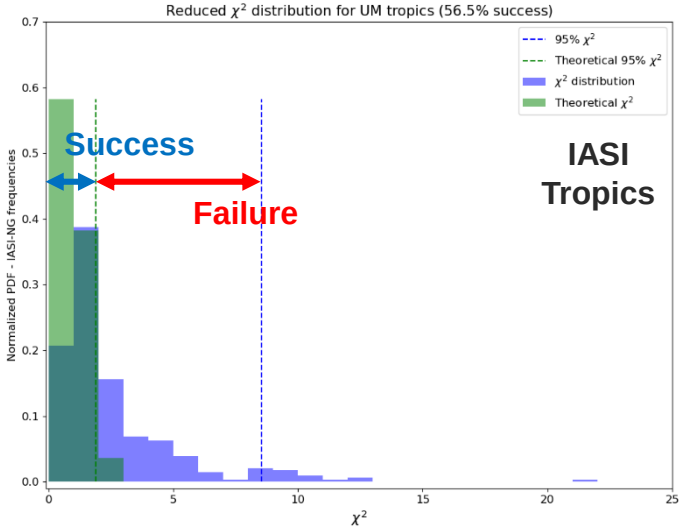
$$\tilde{\mathrm{X}}^2 = \frac{1}{c}\left(\delta \boldsymbol{y}_i - \overline{\delta \boldsymbol{y}}\right)^T \boldsymbol{S}_{\delta y}^{-1}\left(\delta \boldsymbol{y}_i - \overline{\delta \boldsymbol{y}}\right)$$

where c is the number of degrees of freedom

$\tilde{\mathrm{X}}^2_{calc}(95\%) > \tilde{\mathrm{X}}^2_{theo}(95\%)$ means:

- One (or more) component of $\boldsymbol{S}_{\delta y}$ have been underestimated, and/or
- Missing unforeseen sources of uncertainty

	Polar NH	Mid NH	Tropics	Mid SH	Polar SH
IASI-NG	83.9%	88.4%	56.5%	78.2%	91.5%
MWS	83.3%	89.4%	62.2%	81.3%	95.5%



Conclusion

IASI-NG

- NWP uncertainty for humidity sounding channels are too large to detect small uniform biases (<1K).
- For some temperature channels, the uncertainty does not exceed 0.15 K and the NWP fields are consistent with GRUAN.
- But comparison with real IASI observations will bring additional sources of uncertainty driving the total uncertainty up and it is not certain that a uniform bias of 0.25 K could be detected.

MWS

- NWP uncertainty for humidity sounding channels are too large to detect small uniform biases (<1K), except maybe in the tropics.
- For temperature channels, biases of the order of the instrument radiometric accuracy (1K) should be detectable.

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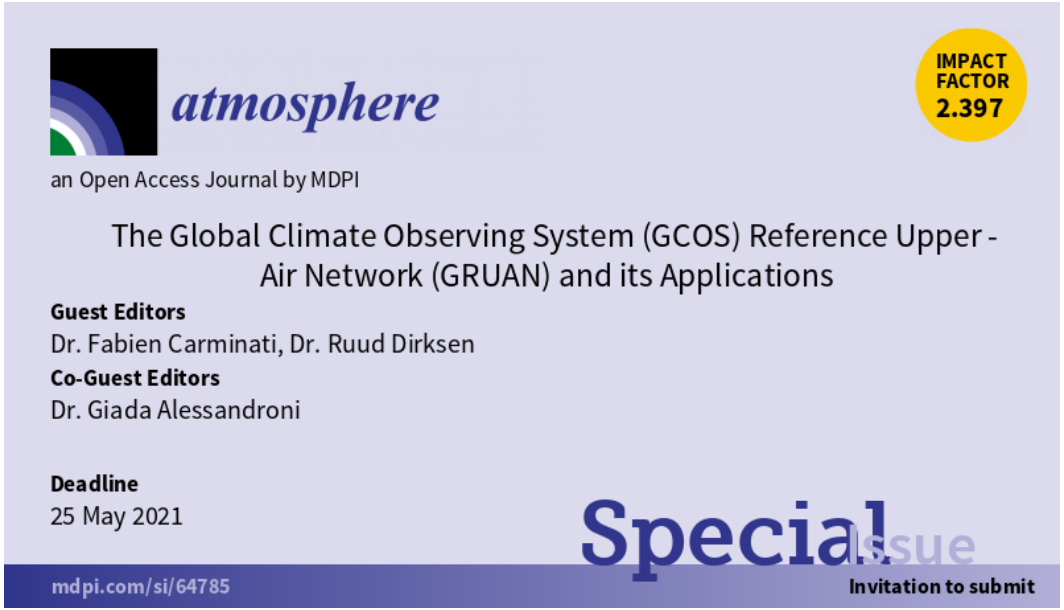

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Questions ?

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