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

F. Carminati; S. Newman
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?
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.

See Carminati et al., 2019 [https://www.atmos-meas-tech.net/12/83/2019/amt-12-83-2019.html](https://www.atmos-meas-tech.net/12/83/2019/amt-12-83-2019.html)
Given the difference $\delta y = NWP - GRUAN$ in radiance space

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

$$S_{\delta y} \cong HRH^T + HWBW^TH^T + HS_{int}H^T$$

Expressed as a function of $B$ and $W$ (interpolation matrix)

$$= HWB_{temp}W^TH^T + HWB_q W^TH^T + h\sigma^2_{surf}h$$

Full model covariance matrices

$$= HR_{temp}H^T + HR_q H^T + HR_p H^T + h\sigma^2_{surf}h^T$$

Diagonal matrices of GRUAN uncertainties

With $H$ the Jacobian matrix containing the partial derivatives of $\delta y/\delta x$ (i.e. a change in radiance $\delta y$ for a change in the state vector $\delta x$)
The statistical significance of $\delta y_i$ (where $i$ is the channel number) is assessed by testing the following:

$$|\delta y_i| < 2 \sqrt{\text{diag}(S_{\delta y})_i}$$

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 $S_{\delta y}$
A bias is detected for half or more of the matchups at 696 cm\(^{-1}\) in the IR and 54.95 and 55.5 GHz in the MW channels.

Assuming that the uncertainty is correctly defined:
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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.

Assuming that the uncertainty is correctly defined:
All the tested channels are in agreement for at least 64% of the match ups.

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.

Assuming that the uncertainty is correctly defined:
The reduced Chi-square test gives the overall agreement, accounting for inter-channel correlation:

$$\bar{X}^2 = \frac{1}{c} \left( \delta y_i - \bar{\delta y} \right)^T S_{\delta y}^{-1} \left( \delta y_i - \bar{\delta y} \right)$$

where $c$ is the number of degrees of freedom.

\[ \bar{X}_{calc}^2 (95\%) > \bar{X}_{theo}^2 (95\%) \] means:

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

<table>
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<th>Polar NH</th>
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<th>Tropics</th>
<th>Mid SH</th>
<th>Polar SH</th>
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<tbody>
<tr>
<td>IASI-NG</td>
<td>83.9%</td>
<td>88.4%</td>
<td>56.5%</td>
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<td>91.5%</td>
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<tr>
<td>MWS</td>
<td>83.3%</td>
<td>89.4%</td>
<td>62.2%</td>
<td>81.3%</td>
<td>95.5%</td>
</tr>
</tbody>
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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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Questions?

For more information please contact

🌐 www.metoffice.gov.uk

✉️ fabien.carminati@metoffice.gov.uk

📞 +44 (0) 3301 350824