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Characterisation of NWP Model Biases and Uncertainties in the Microwave and Infrared Spectral Domains

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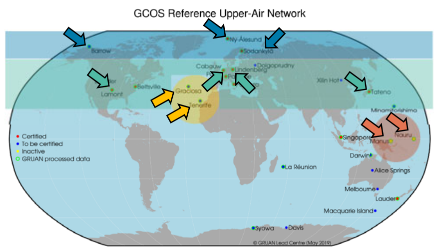
Introduction

Biases and uncertainties in NWP temperature and humidity fields mapped to radiance space have been estimated from comparisons with radiosondes of the GCOS Reference Upper-Air Network (GRUAN). Top-of-atmosphere brightness temperatures simulated from over 23000 GRUAN profiles of temperature, humidity, and pressure - and their associated uncertainties - from 11 sites in 4 geographic areas obtained over the period 2011-2017 and collocated NWP fields from both the Met Office and ECMWF global models, have been compared at key frequencies spanning both the microwave and infrared spectrums.

Sub-Tropics
GRA; TEN
~1200 matchups
2016-2017

Tropics
MAN; NAU
~600 matchups
2011-2014



Northern Latitudes
BAR; NYA; SOD
~7000 matchups
2011-2017

Mid-Latitudes
SGP; CAB; LIN; TAT
~15000 matchups
2011-2017

Figure 1: GRUAN sites and geographical areas used in the study.

Biases

Prior to estimate δy, a model-based radiative correction is applied to day time differences to correct for the residual solar radiative heating bias, such as: $\delta y_{day}^{cor} = \delta y_{day} - (\overline{\delta y_{day}^{ecmwf}} - \overline{\delta y_{night}^{ecmwf}})$. Uncertainty related to this correction is accounted for in the total uncertainty. Additionally, channels whose Jacobian peaks within 1000 m of a cloud top are removed from the statistics to avoid contamination by wet bulb effect. The statistical significance of δy is assessed as in [2], by testing the following:

$$S_{\delta y}^{-1/2} . |\delta y| < 2$$

NWP and GRUAN brightness temperatures satisfying the above test are in agreement with a confidence interval of 95.5%. Fig. 3 shows time series of 3-month average of δy at mid-latitudes for microwave frequencies and the success rate to the significance test.

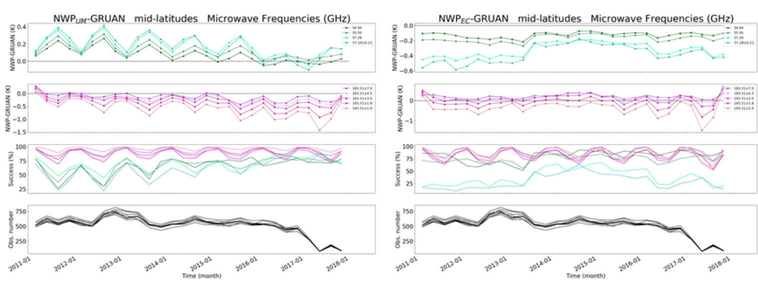


Figure 3: (From top to bottom) time series of δy (Met Office left, ECMWF right) at mid-latitudes for microwave temperature sensitive frequencies, humidity sensitive frequencies, success rate of the significance test, and number of collocations per 3-month bins.

Uncertainties

The total uncertainty of the difference $\delta y = NWP - GRUAN$ is expressed as the covariance matrix $S_{\delta y}$, as in [1], which accounts for GRUAN uncertainties in T, q, and P, NWP model T and q covariances interpolated on a fixed grid with the interpolation matrix W, and the covariance of this interpolation S_{int}, mapped to radiance space with the observation operator H, such as:

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

where

$$HRH^T = HR_{temp}H^T + HR_q H^T + HR_P H^T + h\sigma_{surf}^2 h^T$$

and

$$HWBW^T H^T = HWB_{temp}W^T H^T + HWB_q W^T H^T + h\sigma_{surf}^2 h$$

and S_{int} is function of B and W.

Fig. 2 shows the total uncertainty (square root of $S_{\delta y}$ diagonal, solid green line) and its NWP-based (incl. interpolation, dashed) and GRUAN-based components (dotted) for mid-latitudes at microwave frequencies. Note that the total uncertainty is the root sum square of the components.

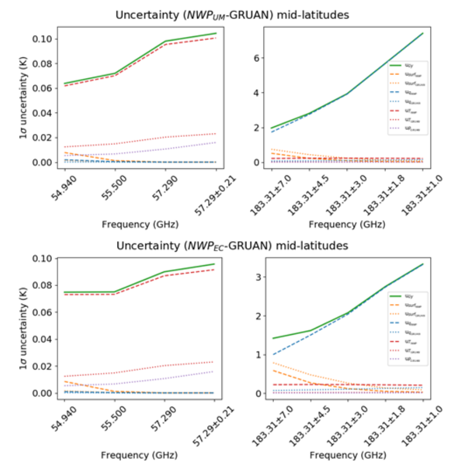


Figure 2: Total uncertainty on δy (green) with contribution from surface (orange), humidity (blue), temperature (red), and pressure (purple) at mid-latitudes in the microwave.

Summary

Tables 1 and 3 summarise the statistics obtained for the Met Office model at mid-latitudes and key microwave (top) and infrared (bottom) frequencies. Tables 2 and 4 are for ECMWF. Owing to the large model-driven uncertainty in humidity, both NWP models and GRUAN are often found in agreement (64-97%). The much smaller model and overall uncertainty in temperature however result in a drop in the agreement between NWP and GRUAN (29-98%). These results may help understand geographical distribution of model biases and uncertainties, refine model covariance uncertainties, or improve bias corrections.

It is worth noting that this analysis ignores the (unknown) uncertainty due to the scale mismatch between coarse model resolution and fine radiosonde measurements. It is expected to be more significant for humidity than temperature as the former variable varies at scales generally smaller than global model resolutions. This will be the object of a future study.

Table 1: Microwave, mid-latitudes, Met Office

Frequency (GHz)	Instrument (chan)	Matchups	Mean (K)	StDv (K)	Kurtosis	Skew	Uncertainty (K)	Success rate (%)
54.94	AMSU-A (7)	13446	0.08	0.15	1.69	0.01	0.06	63.26
55.50	AMSU-A (8)	14911	0.13	0.17	1.12	0.02	0.07	68.28
57.29	AMSU-A (9)	15647	0.19	0.23	1.23	-0.06	0.10	66.99
57.29±0.21	AMSU-A (10)	14795	0.19	0.25	2.08	-0.27	0.10	57.41
183.31±1.0	ATMS (22)	13501	-0.54	1.98	5.96	-0.78	6.32	97.01
183.31±1.8	ATMS (21)	13914	-0.38	1.78	5.49	-0.64	4.86	94.82
183.31±3.0	ATMS (20)	14181	-0.24	1.55	5.03	-0.44	3.44	91.96
183.31±4.5	ATMS (19)	14244	-0.18	1.36	4.79	-0.33	2.50	93.35
183.31±7.0	ATMS (18)	14281	-0.12	1.18	4.74	-0.25	1.78	92.80
190.31	MHS (5)	14267	-0.12	1.20	4.80	-0.26	1.84	93.23

Table 2: Microwave, mid-latitudes, ECMWF

Frequency (GHz)	Instrument (chan)	Matchups	Mean (K)	StDv (K)	Kurtosis	Skew	Uncertainty (K)	Success rate (%)
54.94	AMSU-A (7)	13443	-0.13	0.12	4.68	-0.47	0.07	77.78
55.50	AMSU-A (8)	14908	-0.18	0.14	2.53	-0.32	0.07	76.32
57.29	AMSU-A (9)	15644	-0.33	0.19	1.63	-0.11	0.09	38.69
57.29±0.21	AMSU-A (10)	14785	-0.38	0.22	1.86	0.05	0.10	29.56
183.31±1.0	ATMS (22)	13501	-0.34	2.00	7.80	0.81	2.80	89.39
183.31±1.8	ATMS (21)	13919	-0.09	1.79	7.26	-0.49	2.34	91.27
183.31±3.0	ATMS (20)	14181	0.11	1.55	6.60	-0.16	1.80	86.97
183.31±4.5	ATMS (19)	14241	0.19	1.37	6.08	0.05	1.42	90.42
183.31±7.0	ATMS (18)	14286	0.21	1.20	5.41	0.09	1.21	89.14
190.31	MHS (5)	14272	0.21	1.22	5.52	0.10	1.21	87.25

Table 3: Infrared, mid-latitudes, Met Office

Wavenumber (cm^{-1})	Instrument (chan)	Matchups	Mean (K)	StDv (K)	Kurtosis	Skew	Uncertainty (K)	Success rate (%)
657.50	IASI (51)	15513	0.17	0.22	2.04	-0.18	0.09	49.47
696.00	IASI (205)	14983	0.11	0.16	1.32	-0.04	0.08	53.40
697.75	IASI (212)	14888	0.09	0.15	1.44	-0.06	0.08	56.71
706.25	IASI (246)	15001	0.02	0.14	2.00	-0.02	0.08	54.33
731.00	IASI (345)	14363	-0.11	0.67	5.42	-0.29	1.27	85.50
731.50	IASI (347)	14925	-0.01	0.19	4.27	-0.08	0.20	97.47
1361.9	HIRS (11)	14334	-0.20	1.08	4.97	-0.48	2.27	96.35
1367.00	IASI (2889)	14403	-0.15	1.24	4.67	-0.27	1.91	81.48
1402.00	IASI (3029)	14403	-0.20	1.46	4.63	-0.40	2.97	64.53
1408.00	IASI (3053)	14419	-0.17	1.37	4.44	-0.33	2.49	64.67
1540.25	IASI (3582)	9901	-0.51	0.91	3.03	-0.95	3.21	73.23
1556.25	CrIS (991)	11973	-0.66	1.66	8.00	-1.22	7.21	66.46

Table 4: Infrared, mid-latitudes, ECMWF

Wavenumber (cm^{-1})	Instrument (chan)	Matchups	Mean (K)	StDv (K)	Kurtosis	Skew	Uncertainty (K)	Success rate (%)
657.50	IASI (51)	15546	-0.33	0.19	1.84	-0.03	0.08	65.75
696.00	IASI (205)	14981	-0.15	0.13	2.18	-0.30	0.07	65.35
697.75	IASI (212)	14884	-0.14	0.13	2.27	-0.32	0.08	77.39
706.25	IASI (246)	15004	-0.11	0.11	3.02	-0.31	0.08	54.22
731.00	IASI (345)	14361	0.05	0.67	6.72	0.06	0.70	88.32
731.50	IASI (347)	14922	-0.08	0.18	4.73	-0.02	0.14	98.18
1361.9	HIRS (11)	14339	0.07	1.08	6.33	-0.19	1.23	90.75
1367.00	IASI (2889)	14406	0.21	1.23	5.63	0.01	1.20	83.07
1402.00	IASI (3029)	14403	0.14	1.45	6.13	-0.16	1.70	74.45
1408.00	IASI (3053)	14423	0.19	1.36	5.69	-0.02	1.47	66.63
1540.25	IASI (3582)	9983	-0.81	0.95	3.69	-1.02	1.05	81.95
1556.25	CrIS (991)	11974	-0.78	1.69	10.13	-1.18	2.84	65.93

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[1] Carminati et al., 2019, https://doi.org/10.5194/amt-12-83-2019
[2] Immler et al., 2010, https://doi.org/10.5194/amt-3-1217-2010