Assessment of residual biases in microwave instruments:
impact of improved radiative transfer modelling for lower tropospheric AMSU-A channels and development of a variational bias correction scheme for SSMIS

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The AMSU-A and SSMIS microwave instruments have provided valuable observations that have been assimilated in the Met Office's NWP system for many years. Presently, the bias correction scheme prior to assimilation is being reappraised: although the current method is effective in removing significant components of the bias, it is clear that residual biases still remain. In order to extract further positive impact from AMSU-A and SSMIS, treatment of the bias correction is improved through two different approaches.

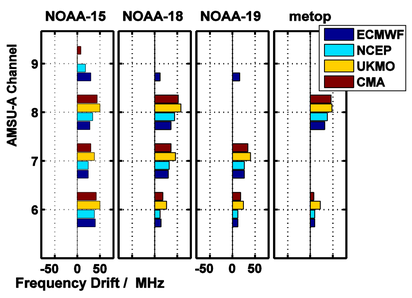
Firstly, better understanding of the underlying physical causes of the bias in lower tropospheric channels of AMSU-A has led to improvements in the radiative transfer modelling, that consequently prove effective in mitigating air mass and scan dependent biases.

Secondly, for SSMIS, an improved bias correction scheme is developed, aiming to account for the complex residual orbital biases arising from calibration anomalies.

Reducing bias through improved AMSU-A radiative transfer modelling

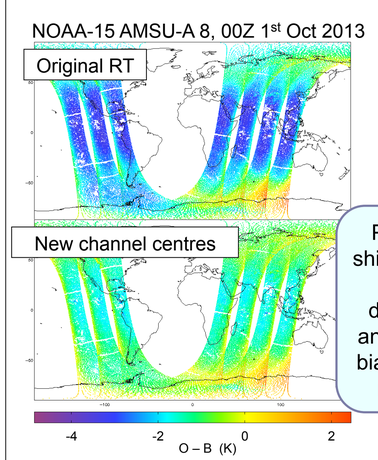
Improvements in the radiative transfer (RT) modelling for the lower tropospheric channels of AMSU-A 6-8 have been achieved through generating more accurate estimates of the central frequencies for the channel passbands.

Shifts and drifts in the centre frequencies caused by instability in the local oscillators used for AMSU-A 6-8 have been diagnosed for different satellites[1].



Comparison with model data from different NWP centres confirms that this is an instrument rather than model based bias

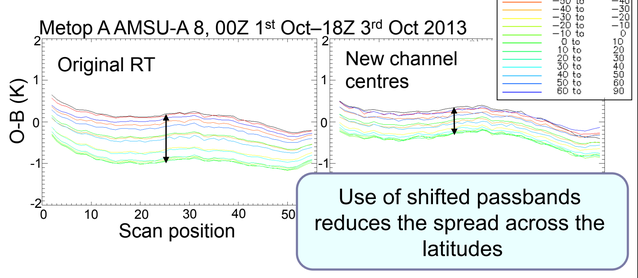
Utilizing new RT coefficients: Impact on first guess departures



New RT model (RTTOV) coefficients were generated using the revised centre frequencies and updated model background (B) brightness temperatures were then obtained.

Passband shifts manifest as scan dependent and air mass biases – now mitigated

Assessment of the new observed – background (O-B) departures for AMSU-A 6-8 showed reductions in air mass and scan dependent biases in nearly all cases.

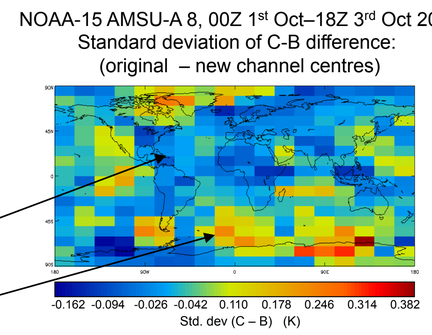


Use of shifted passbands reduces the spread across the latitudes

However, residual biases still remain so a bias correction must be applied prior to use in the assimilation system.

Recalculating the bias correction: Impact on corrected departures

The bias correction[2] was recalculated (generating new bias corrected observations (C)) to accompany the updated model background containing the RT model improvements.



More varied impact demonstrates the original correction scheme was effective at accommodating the passband induced biases

Impact of biases in the assimilation system

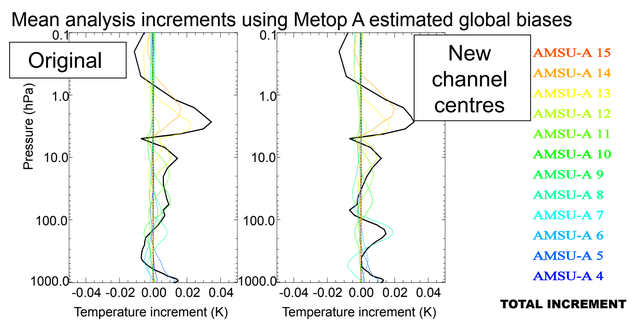
Typical global residual biases were estimated for each channel after bias correction. The mean analysis increment caused by observation bias (assuming no background bias) was investigated using the following equation:

$$\underbrace{\langle x_A - x_B \rangle}_{\text{Mean analysis increment}} = \mathbf{G}(\beta_y) \quad \text{where} \quad \mathbf{G} = \mathbf{B}\mathbf{H}^{\mathrm{T}}(\mathbf{H}\mathbf{B}\mathbf{H}^{\mathrm{T}} + \mathbf{R})^{-1}$$

Observation bias

Kalman gain matrix

Small differences arise in the upper troposphere but generally global biases are similar between new and old RT modelling and still relatively small (<0.05K). A larger total increment still remains in the upper atmosphere.



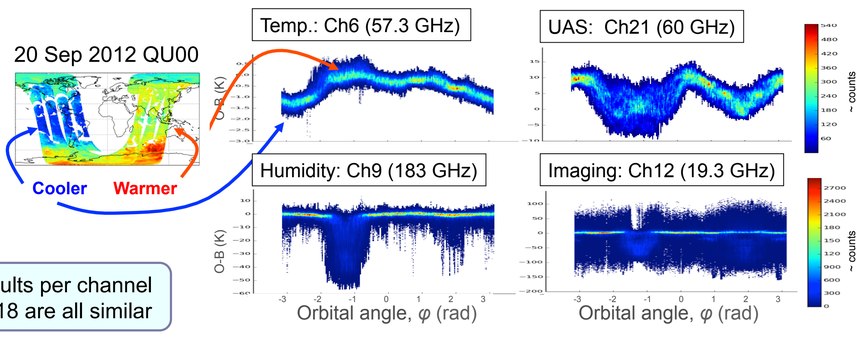
An improved bias correction scheme for SSMIS

The SSMIS data is pre-processed using the Unified Pre-Processor (UPP) at the Naval Research Laboratory, applying corrections for physical sources of bias, such as solar intrusions. However, these corrections are only partially successful…

Characteristics of the orbital biases

Analysis of the O-B departures clearly reveals significant structure underpinning the orbital biases and it is particularly apparent when assessed w.r.t. the satellite's along-track position, expressed here as an orbital angle, ϕ.

The temperature sounding, humidity, imaging and upper atmosphere (UAS) channels exhibit differing *orbital* characteristics



Examples show typical results per channel type, and F16, F17 and F18 are all similar

2D histogram (O-B) BT departures: F-16, 20-23 Sep 2012

However, applying a correction that can fit the structure should mitigate the bias…

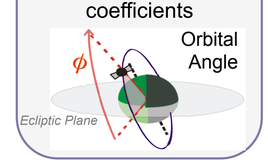
An orbital/along-track predictor: a Fourier approach

An orbital predictor should utilize a periodic function to represent the cyclic nature of the correction, so a Fourier series expansion is ideal. The brightness temperature correction is thus given by:

$$\Delta T_B = \sum_{i=0}^{N} a_i \cos(i\varphi) + b_i \sin(i\varphi)$$

Subtracting it from the observed brightness temperatures (O) is effective in mitigating the bias.

N – number of (cos & sin) predictor sets
a, b – correction coefficients



Maintaining a stable correction: VarBC "Toymodel"

The residual biases are known to vary seasonally, so the predictor scheme was implemented (offline) in a variational bias correction system "Toymodel" in which the correction could be updated at each cycle. The observations (O-B) were thus input, then corrected (C-B), using coefficients updated by minimising *J*:

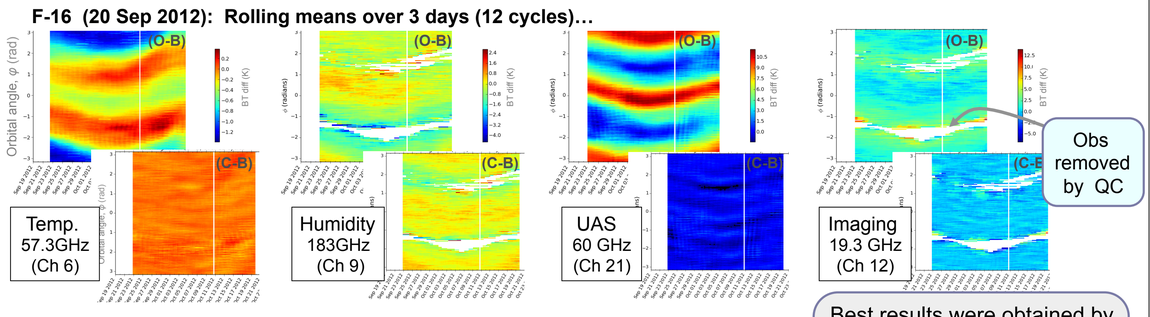
$$J = \frac{\left(\sum^{M}\left((O-B) - \sum_{i=0}^{N} a_i' \cos(i\varphi) + b_i' \sin(i\varphi)\right)\right)^2}{\sigma_o^{\,2}} + \frac{\left(\sum_{i=0}^{N}\left(a_i - a_i'\right) + \left(b_i - b_i'\right)\right)^2}{\sigma_B^{\,2}}$$

fit of predictor to observations

fit of predictor to previous correction

M – number of observations
a', b' – previous coefficients
σ_o σ_B - weightings

The brightness temperatures were assessed w.r.t φ for a month period. During this time the structure of the bias has evolved. But the Fourier series correction also evolved, successfully mitigating the residual biases, as indicated by reduced (C-B) departures.



Obs removed by QC

The standard deviations are reduced over majority of the orbits…

	pre-correction (K)	post correction (K)
Temperature (e.g. Ch 6)	~1.2	~ 0.2
Humidity (e.g. Ch 9)	~ 1.6	~ 0.8
Imaging (e.g. Ch 12)	~ 3	~ 3
Upper Atmos. (e.g. Ch 21)	~ 9	~ 3

Best results were obtained by varying the number of predictors, (*N* = 5 temperature / UAS, *N* = 1 imaging / humidity)

Results were consistent for F16, F17 and F18.

The correction scheme is being implemented within the Met Office's VarBC system.

In order to avoid degrading the NWP forecast accuracy it is important to mitigate residual biases, and the improved process of correcting for biases in AMSU-A and SSMIS have been shown to achieve this. The biases identified are not necessarily restricted to these instruments and the techniques described could be applied to other microwave instruments if found to experience similar radiometric calibration issues.

(1) Lu, Q. and W. Bell, 2013: Characterising channel center frequencies in AMSU-A and MSU microwave sounding instruments. *ECMWF tech. memo.* http://www.ecmwf.int/publications/library/do/references/show?id=90728
(2) Harris and Kelly, 2001, QJRMS 127, p.1453

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