Orbital biases in microwave temperature-sounding observations (AMSU-A, ATMS)

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1) Introduction

Temperature-sounding channels from AMSU-A and ATMS remain some of the most impactful observations in global NWP. Optimal assimilation requires (among other things) that biases are adequately addressed prior to assimilation. Recently, it was noted that MW sounders introduce systematic diurnal increments in the ECMWF system (Fig. 1). These have been linked to residual orbital biases for the temperature-sounding channels of AMSU-A and ATMS (ie, biases present after performing Variational Bias Correction (VarBC), using the currently operational bias correction model) – and these are the topic of this poster.

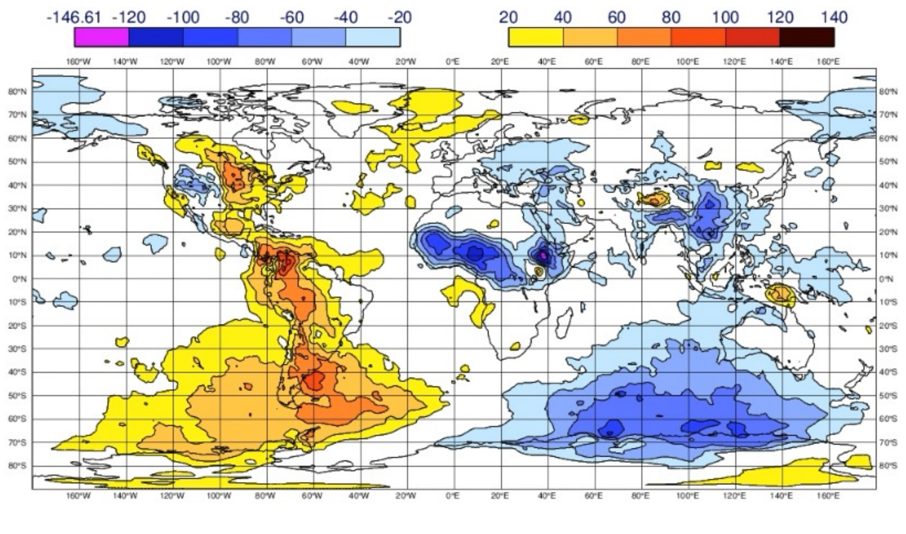


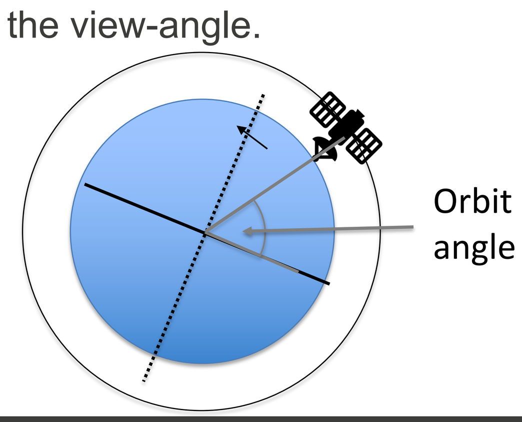
Fig. 1: Difference in the mean increments in the 925-200 hPa thickness [m²/s²] between the 12Z and 00Z assimilation cycles for June – August 2020. The differences over the S. Hem. are caused by the assimilation of MW sounders, as established through OSEs. The differences in the Tropics are likely due to model biases related to tropical convection.

Current operational bias-correction model used in VarBC:

For the channels considered, the operational bias correction is modelled using a global constant, 4 layer-thicknesses as linear bias predictors, and a 3rd-order polynomial in the view-angle.

Orbit angle definition:

Residual biases are shown here as a function of the orbit angle. The orbit angle used is 0° for the ascending node at the equator, increasing with satellite movement. This definition is not dependent on the position of the sun.



2) Characteristics of the orbital biases

- Considering the period Jan 2015 to June 2022, orbital biases have been found for the temperature-sounding channels of all AMSU-A and ATMS instruments, with values approaching the size of NeDT.
- The biases have a seasonal pattern, with strongest signals in June-September (over the Southern Hemisphere) and December-January (over the Northern Hemisphere), see Fig. 2.
- The seasonal pattern stays fairly constant over time, incl for satellites which have experienced significant orbital drift (e.g., NOAA-18: LTAN 16:30 in 2015; 22:00 in 2022) and hence changes in thermal conditions at the satellite (Fig. 2).

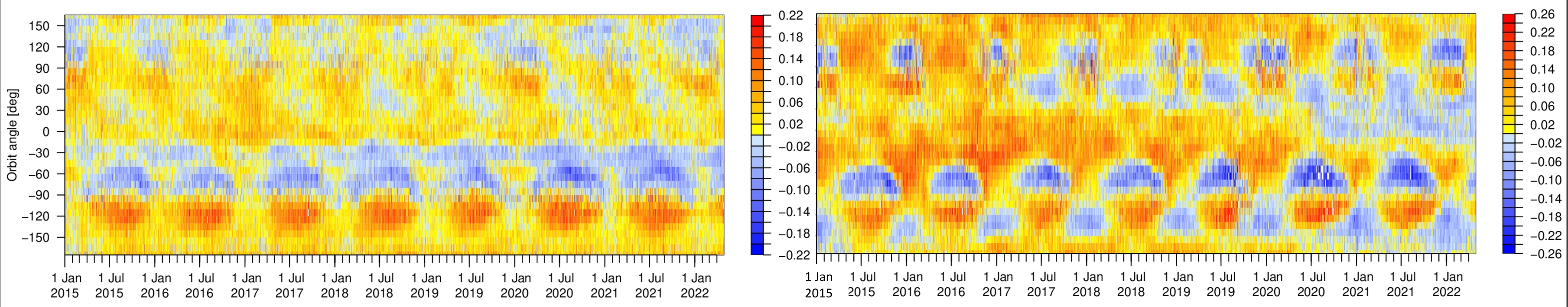


Fig. 2: Mean residual bias (o-b) [K] after bias correction for NOAA-18 AMSU-A channel 6 (left) and channel 10 (right). Data are shown for every 5-th day only, split into 12-hour chunks, taken from ECMWF's operational system.

- The orbital bias pattern are similar for several channels of AMSU-A, though with different magnitudes (Fig. 3). They are overall consistent between different AMSU-A instruments, but again magnitudes vary, with NOAA-18 exhibiting the strongest orbital biases (Fig. 3).
- ATMS also exhibits orbital biases, but pattern are different from the AMSU-A ones (Fig. 3, lower right).

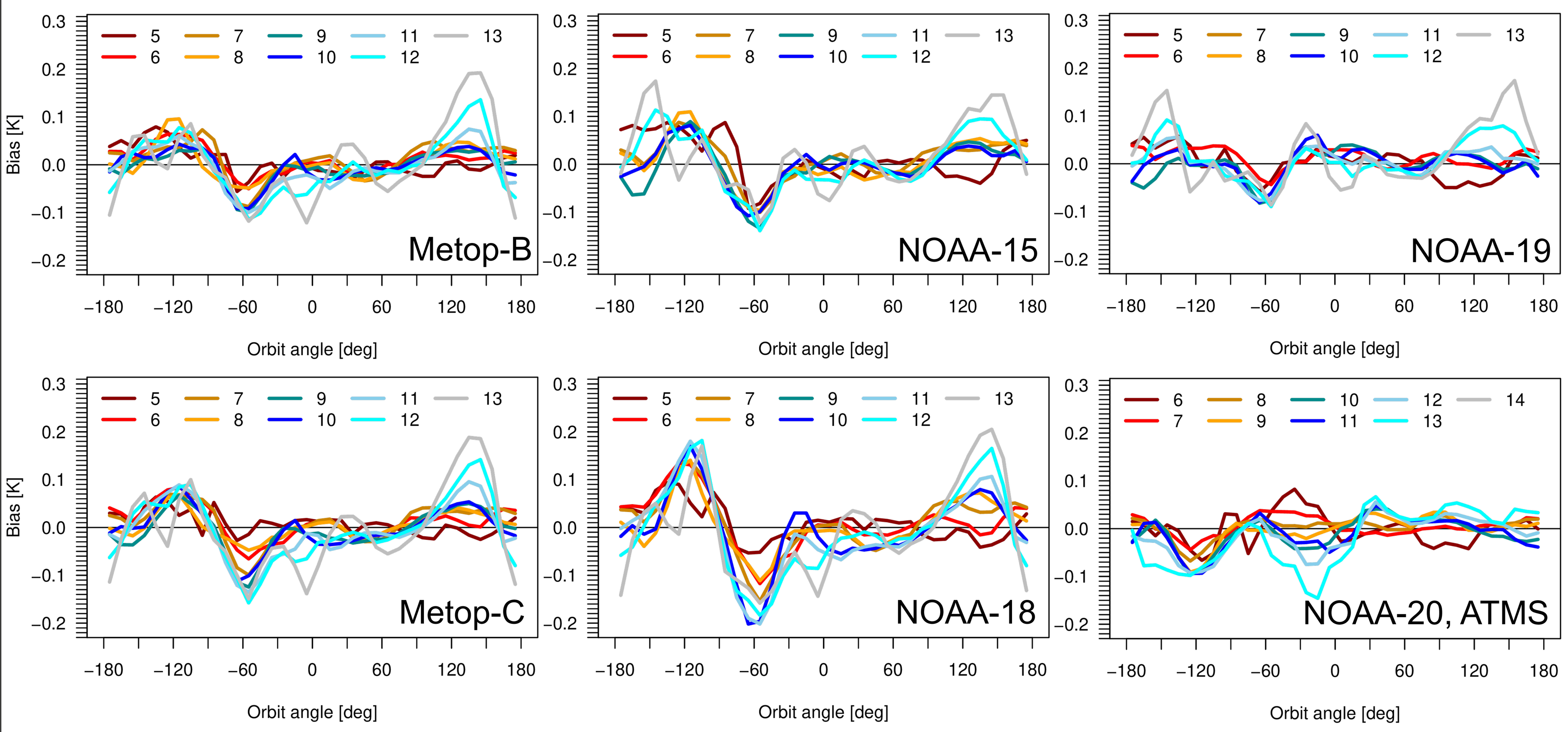


Fig.3: Mean bias after bias correction for August 2021 as seen in ECMWF's operational system for the temperature-sounding channels of different AMSU-A instruments and the NOAA-21 ATMS. See the legend for channel numbers.

3) Comparison to different instruments

- Similar orbital biases are not found in other instruments with temperature-sounding channels, such as IASI and CrIS (e.g., Fig. 4). While these other instruments do show seasonally-varying biases as a function of orbital angle, the pattern are locally symmetric around ±90° and are hence likely to be zonal/air-mass dependent residual biases.
- This suggests the orbital biases in AMSU-A and ATMS are an observation bias, rather than a bias in the model background.

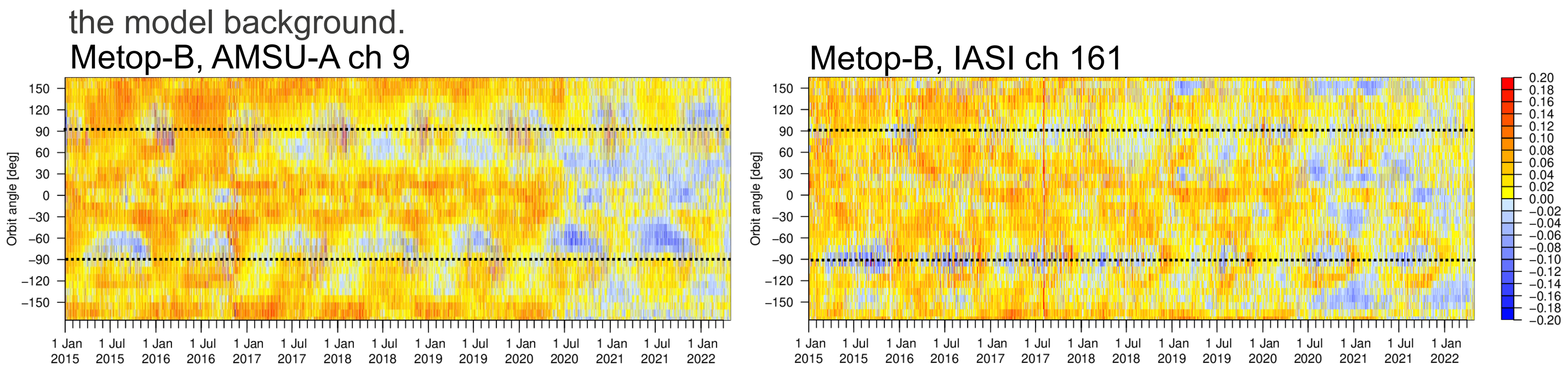


Fig. 4: Mean residual bias (o-b) [K] after bias correction for Metop-B AMSU-A channel 9 (left) and Metop-B IASI channel 161 (right), peaking at approximately the same height. Data are shown for every 5-th day only, split into 12-hour chunks, taken from ECMWF's operational system.

4) Search for the origin of the biases

The origin of the observation bias remains unclear (*Please let me know if you have any ideas!*). In some cases, the bias in the strongest-affected areas shows some dependence on the scene-temperature (Fig. 5). This may point to unaccounted variations in the cold-space correction around the orbit, or possibly variations in the non-linearity, but the relationship is not very clear.

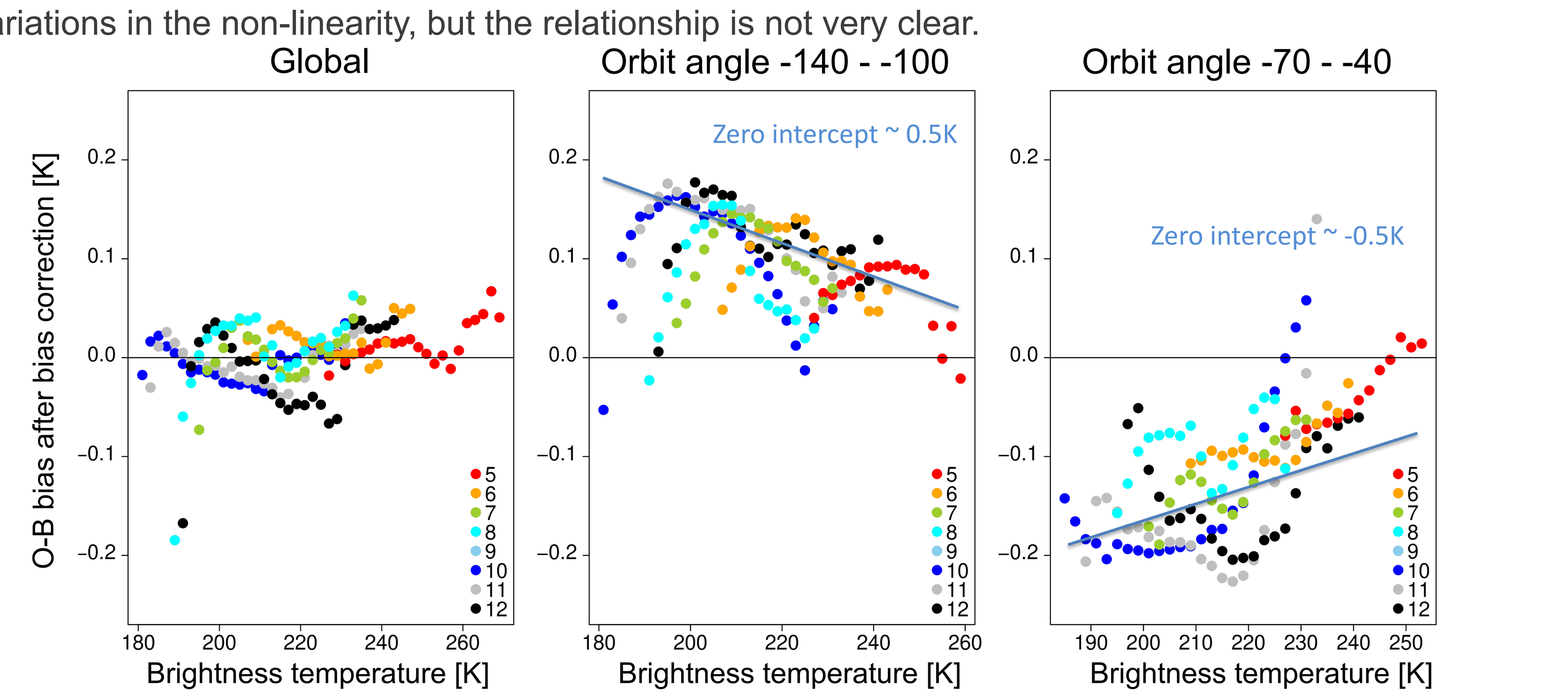


Fig. 5: Mean residual bias as a function of observed brightness temperature for August 2021 for NOAA-18 AMSU-A. Different colours indicate values from different channels (see colour legend). The three panels show global statistics (left) and orbit-angle ranges with considerable biases, -140 to -100° (middle) and -70 to -40° (right).

5) Correcting the biases with VarBC

The residual orbital biases can be mostly modelled using a suitably chosen Fourier series or variation thereof (Fig. 6), following work by Booton et al (2015, ITSC-20). Two approaches are considered which add the following terms to the operational VarBC predictor model used:

5th order Fourier series:
β – orbital angle; a_n and b_n are bias coefficients

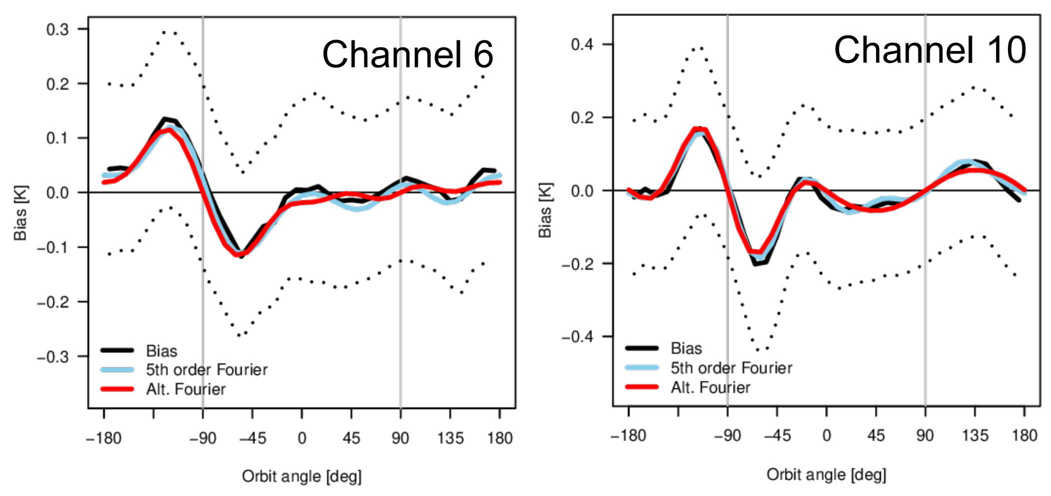
$$f(\beta) = \sum_{n=1}^{5} \left(a_n \cos(n\beta) + b_n \sin(n\beta)\right)$$

"Alternating" 6th order Fourier series:

$$f(\beta) = a_1 \cos(\beta) + a_2 \sin(2\beta) + a_3 \cos(3\beta) + a_4 \sin(4\beta) + a_5 \cos(5\beta) + a_6 \sin(6\beta)$$

The latter uses fewer parameters by avoiding terms that lead to zonal structure, which is already mostly addressed through air-mass predictors.

Fig. 6: Mean residual bias [K] (o-b, black solid line) after applying the operational bias correction for NOAA-18 AMSU-A channel 6 (left) and channel 10 (right) as a function of orbit angle for August 2021. Offline fits to this residual orbital bias using the 5th order Fourier series (blue) and the alternating 6th order Fourier series (red) are also shown. Dotted lines indicate the stdev(o-b) around the residual bias.



Two assimilation experiments are considered here, in which these modification to VarBC are investigated:
Fourier5Ch6-13: 5th order Fourier series for channels 6-13 of AMSU-A (7-14 for ATMS)
AltFourierCh6-11: "Alternating" 6th order Fourier series for channels 6-11 of AMSU-A (7-12 for ATMS)

Period: June-Aug 2020 & Dec 2020 – Feb 2021
Resolution: $T_{CO}399$ (~25 km)

- The modifications to the bias correction successfully reduce the systematic diurnal increments seen previously (cf Fig. 1 and 7).
- Reduced increments are also seen in a range of other variables (Fig. 8, top).
- Medium-range forecast impact for the troposphere is overall neutral (Fig. 8, bottom). The Fourier5Ch6-13 experiment shows some degradation in the stratosphere, apparently linked to a drift in the mean analysis, as model bias is aliased into the observation bias correction. This is ameliorated in the AltFourierCh6-11 experiment (Fig. 8, bottom right), for which the added bias correction is more constrained.
- Standard deviations of background departures for other assimilated observations show reductions for some observations, but also some increases (not shown).

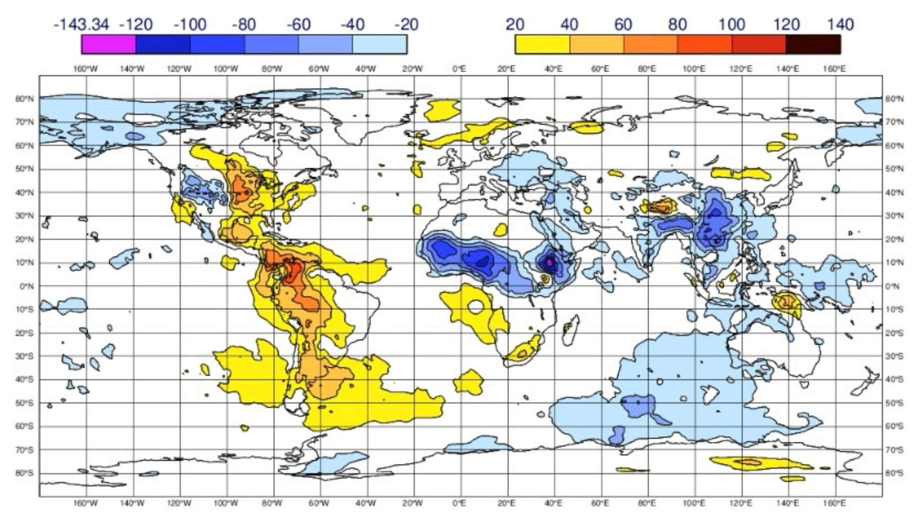


Fig. 7: As Fig. 1, but for the Fourier5Ch6-13 experiment.

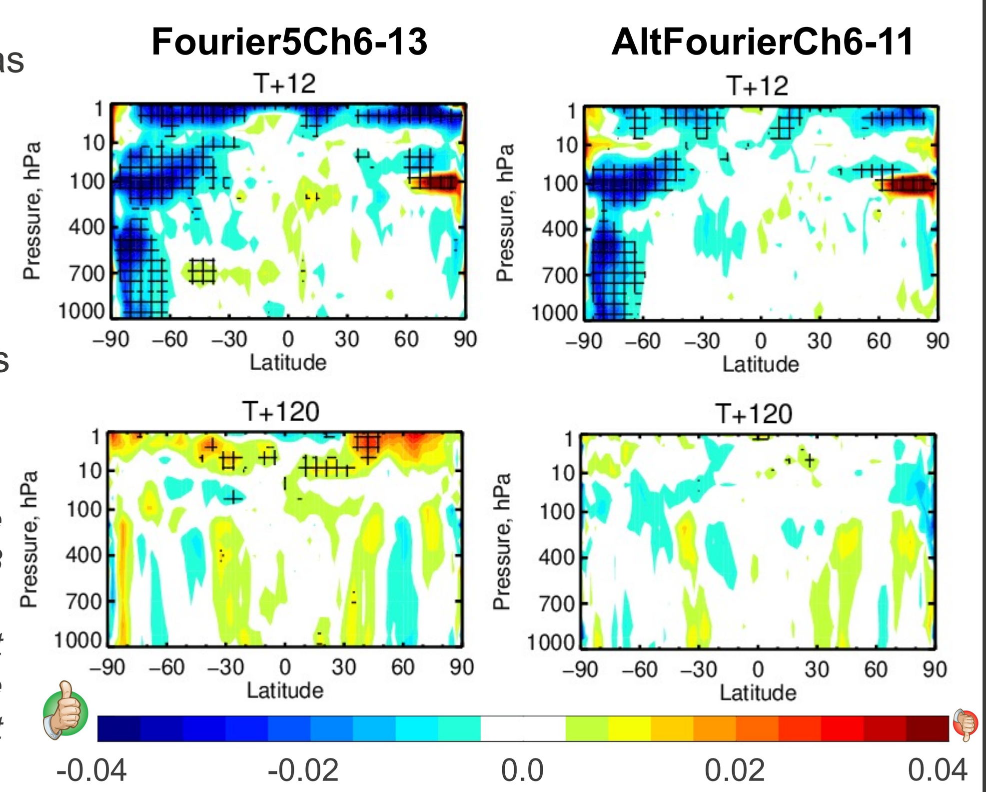


Fig. 8, top row: Normalised difference of the RMS of the vector wind increments between the Fourier5Ch6-13 experiment and the Control (left) and the AltFourierCh6-11 experiment and the Control (right) for the full experiment period. Bottom row: As in the top row, but for the normalised difference of the RMS of the day 5 forecast error for wind.

6) Conclusions

- Temperature-sounding channels from AMSU-A and ATMS exhibit seasonally varying orbital biases against the ECMWF background. They cause systematic diurnal thickness increments in the ECMWF assimilation system.
- The biases are likely instrument-related, rather than a bias in the background fields, but the origin is unclear.
- The biases can be addressed in VarBC by adding a Fourier series in the orbit angle (or a variant of this) to the bias model. This removes the diurnal increments, but the medium-range forecast impact is neutral. Limiting the number of channels treated in this way and using a predictor model with fewer degrees of freedom ("alternating Fourier series") limits the possibility of model bias aliasing into the bias correction.