Evaluation and exploratory assimilation trials with data from the TROPICS* constellation in the ECMWF system

Niels Bormann and David Duncan

Research Department, ECMWF, Reading, United Kingdom; niels.bormann@ecmwf.int

*Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats

1) Introduction

NASA's TROPICS mission is a constellation of cube-sats carrying passive MW sounders, with one pathfinder satellite in polar orbit, and three functioning satellites in 30º inclination orbits. Three further satellites were planned, but two were lost during launch and one experienced communication problems once in orbit.

TROPICS provides a test-bed for the data quality that can currently be achieved from a cubesat, with relevance for the future evolution of the Global Observing System. Here we evaluate the data in the ECMWF system.

2) TROPICS data and its use

Data: real-time data from 3 low-inclination satellites, TR-3, -5, -6

Period: 26 June – 3 October 2024 (up to 7 Aug 2024 for TR-6)

Calibration: based on a noise diode, combined with vicarious calibration tied to NASA's GEOS-5 data assimilation system

Treatment of TROPICS in the IFS follows that of MHS for the 183 GHz channels:

- Superobbing to N200 Gaussian grid (~50 km), followed by "diamond" thinning to ~70 km
- All-sky approach using RTTOV 13.2; 91/204 GHz scatter index used as cloud indicator in standard all-sky observation error model
- Standard bias correction in VarBC: 4 atmospheric thickness predictors, polynomial in scan-angle, global constant
- Geographical screening as for MHS

TROPICS channels:

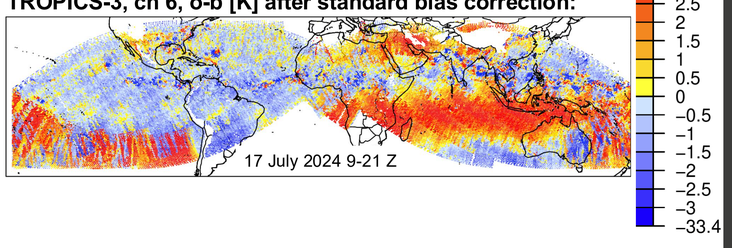
Channel number	Frequency [GHz]	Bandwidth [MHz]
1	91.655 ± 1.4	1000
2	114.50	1000
3	115.95	800
4	116.65	600
5	117.25	600
6	117.80	500
7	118.24	380
8	118.58	300
9	184.41	2000
10	186.51	2000
11	190.31	2000
12	204.8	2000

3) Orbital biases

Background departures after standard bias correction show considerable orbital biases, not present in equivalent channels from MHS or MWHS-2. The characteristics differ from channel to channel and satellite to satellite. The origin of these orbital biases is unclear, but they are likely linked to thermal conditions on the TROPICS satellites.

For the 118 GHz channels, the orbital biases are currently considered too large for a successful assimilation. This is because random errors in the background are of the order of 0.1 – 0.2 K for the tropospheric 118 GHz channels.

TROPICS-3, ch 6, o-b [K] after standard bias correction:



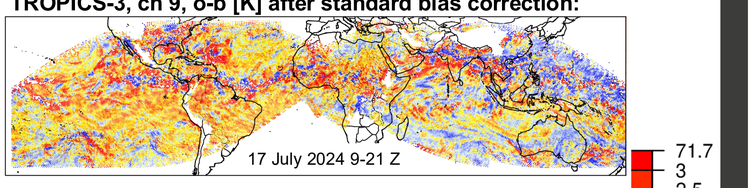
For the 183 GHz channels, we adapt an orbital bias correction by adding selected terms of a Fourier-series to the bias model used in VarBC, following Bormann et al (2023):

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

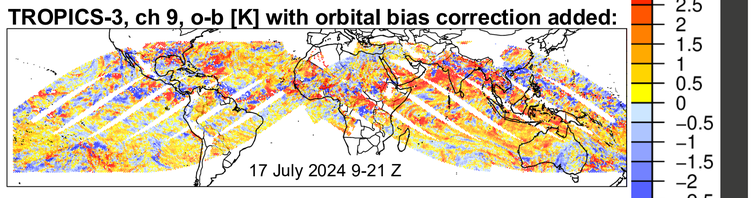
β is the orbital angle of the satellite, relative to the intersection with the equatorial plane on the ascending part of the orbit.

The correction is moderately successful in reducing the orbital biases for the 183 GHz channels, though it does not capture the full characteristics.

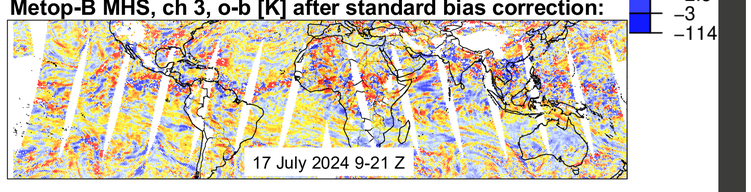
TROPICS-3, ch 9, o-b [K] after standard bias correction:



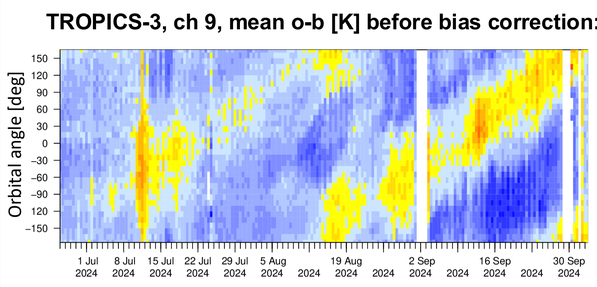
TROPICS-3, ch 9, o-b [K] with orbital bias correction added:



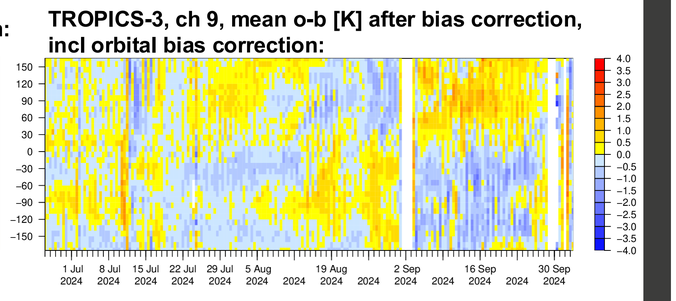
Metop-B MHS, ch 3, o-b [K] after standard bias correction:



TROPICS-3, ch 9, mean o-b [K] before bias correction:



TROPICS-3, ch 9, mean o-b [K] after bias correction, incl orbital bias correction:



4) Scene-temperature dependent biases

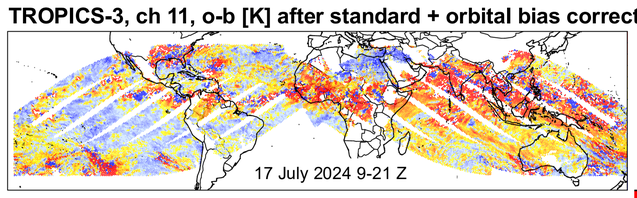
For some 183 GHz channels, significant geographical biases remain after applying the orbital bias correction, such as negative biases in subsidence regions:

These appear to be due to scene-temperature dependent biases. The origin is not clear, but such biases can be due to unaccounted non-linearity characteristics in the calibration.

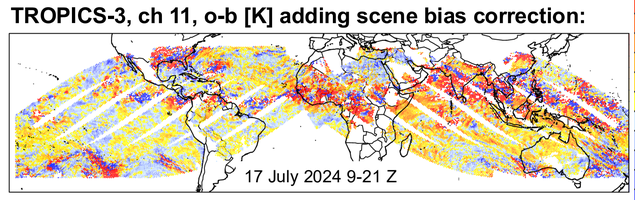
An ad-hoc correction of the scene-temperature dependent biases is applied based on a linear fit against the channels' brightness temperature. The fits are derived from clear-sky scenes over ocean and subsequently applied everywhere. For technical reasons, the correction is applied prior to assimilation and not included in VarBC.

With this correction applied, maps of O-B are more similar to their MHS counterparts.

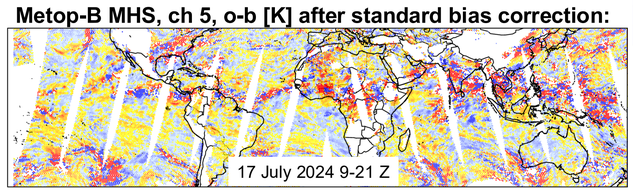
TROPICS-3, ch 11, o-b [K] after standard + orbital bias correction:



TROPICS-3, ch 11, o-b [K] adding scene bias correction:



Metop-B MHS, ch 5, o-b [K] after standard bias correction:

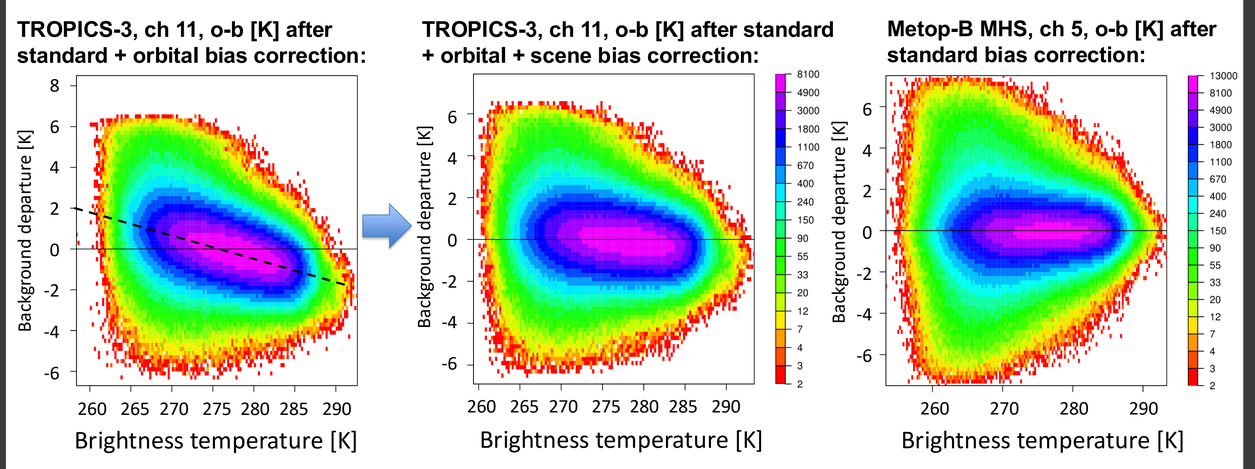


Two-dimensional histograms for lowest 183 GHz channel (26 June – 3 Oct 2024):

TROPICS-3, ch 11, o-b [K] after standard + orbital bias correction:

TROPICS-3, ch 11, o-b [K] after standard + orbital + scene bias correction:

Metop-B MHS, ch 5, o-b [K] after standard bias correction:



5) Assimilation experiments

Control: Full observing system without TROPICS

TROPICS 183 GHz OrbitVarBC: 183 GHz channels activated, with orbital bias correction added

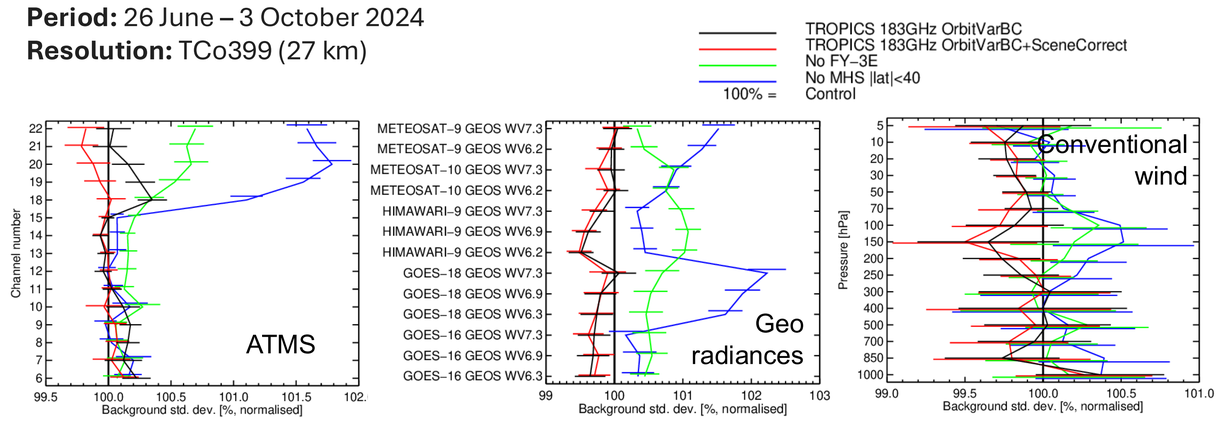
TROPICS 183 GHz OrbitVarBC+SceneCorrect: same, but with additional scene-bias correction

No FY-3E: Denial of MWHS-2 on FY-3E

No MHS |lat| < 40° : Denial of MHS data from Metop-B, -C, NOAA-19 for |lat| < 40°; the assimilated number of MHS data are roughly comparable to that of 3 TROPICS instruments.

Period: 26 June – 3 October 2024

Resolution: TCo399 (27 km)



Standard deviations of background departures for other humidity-sensitive or wind observations are slightly reduced when TROPICS 183 GHz channels are assimilated with the orbit+scene bias correction (red). This indicates a slightly improved short-range forecast impact. Both corrections are necessary to achieve this impact. The impact from adding TROPICS is considerably smaller than the opposite negative impact from denying the tropical MHS data (blue). The medium-range forecast impact is neutral (not shown).

6) Conclusions

The main findings of the present work are:

- TROPICS data show complex biases for the sounding channels in the 118 and 183 GHz bands, not present in comparable heritage instruments. For the 118 GHz channels, the biases are considered too large and complex for successful assimilation.
- For the 183 GHz channels, the biases can be adequately addressed through a Fourier-based orbital bias correction combined with a scene-dependent bias correction (on top of standard bias-correction approaches).
- With these bias corrections, a small positive impact is obtained for the short-range forecast of humidity and wind from assimilating the 183 GHz channels from three satellites of the TROPICS constellation. The impact is, however, smaller than might be expected from a denial of a similar amount of MHS data in the tropics. This is likely due to remaining residual biases in the TROPICS data.

The results suggest that further work is required to either improve the calibration of such sensors or to develop better bias corrections, in order to achieve a better impact. The maturity of MW-sounding data from cubesats for operational NWP applications has yet to be demonstrated.

Reference

Bormann at al (2023): Characterisation and correction of orbital biases in AMSU-A and ATMS observations in the ECMWF system, ECMWF TM 912, https://doi.org/10.21957/d281dc221a.