A decade of improved fits to satellite observations at the Met Office

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Global observations from space

Satellite observations represent an increasingly important component of the global observing system for weather prediction. As shown in Fig. 1, each assimilation cycle of the Met Office forecast model makes use of a globally comprehensive set of satellite radiances.

Observed minus background ("O-B") statistics are archived daily for observations assimilated in 4D-Var. The background is a short-range forecast transformed into radiance using a radiative transfer model (RTTOV). The standard deviation (std dev) in O-B is a measure of the background fit – we expect this measure to reduce over time as the quality of the forecast improves.

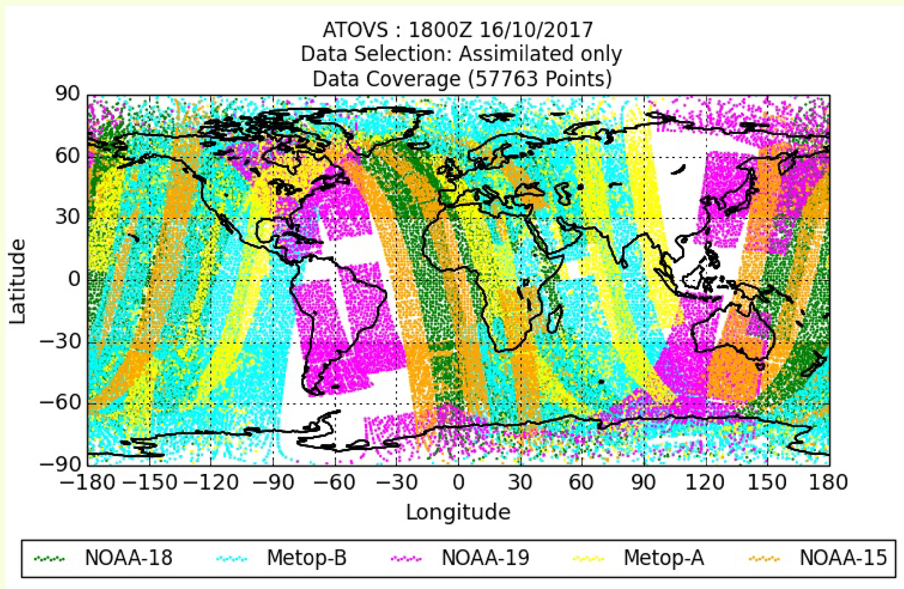

Fig. 1 Example data coverage from ATOVS (AMSU-A and MHS instruments) on five satellite platforms. Satellite footprints are shown for a six-hour data assimilation window of the global model.

AMSU-A and MHS 10-year trends

O-B statistics from the global model are analysed here to assess trends over the past decade (since 2006). Time series of std dev in O-B have been collated from daily 4D-Var output for each observation type. Trends over the past decade can reveal if numerous operational changes to the Met Office Unified Model (UM) have been successful in improving the background fields.

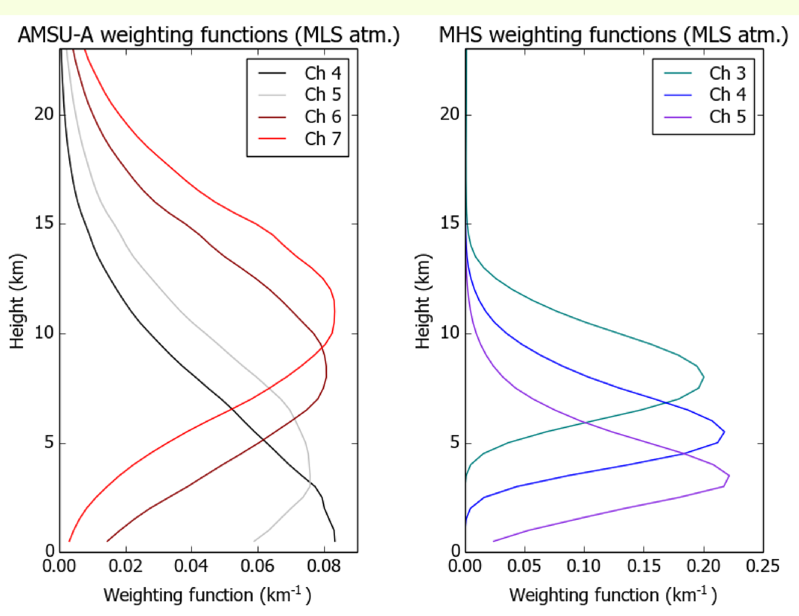

Fig. 2 Weighting functions showing sensitivity of satellite channels with respect to height in the atmosphere. Left: AMSU-A channels 4-7. Right: MHS channels 3-5.

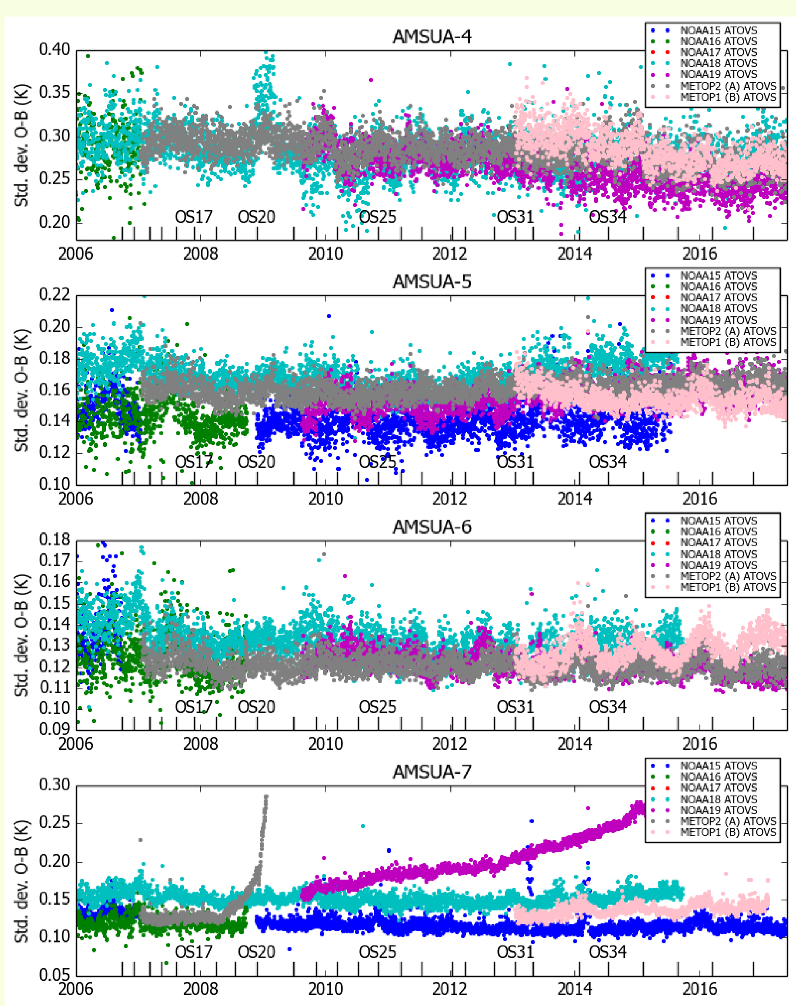

Fig. 3 Daily statistics of std dev in O-B for AMSU-A channels 4-7 (respectively from top panel downwards) plotted over time since 2006. Data from different satellites are denoted by symbols of different colours, as shown in the legend. Upgrades to the global forecast suite are also shown on the horizontal axis, e.g. "OS34" indicates the introduction of Operational Suite 34 in 2014.

First, we consider AMSU-A channels 4-7 with peak sensitivity in the troposphere (see Fig. 2). With some exceptions (e.g. AMSU-A channel 7 radiances suffered from episodes of increased instrument noise on both MetOp-A and NOAA-19) the O-B statistics show a small but sustained long term reduction.

The magnitude of std dev in O-B is determined by contributions due to UM background errors (which we aim to reduce over time) and observation errors (comprising instrument noise, errors in radiative transfer and representativeness errors due to scale mismatch between the model grid and observations). In the case of temperature, the short range forecasts tend to have rather small errors compared to observation errors, and so the trends in Fig. 3 appear modest.

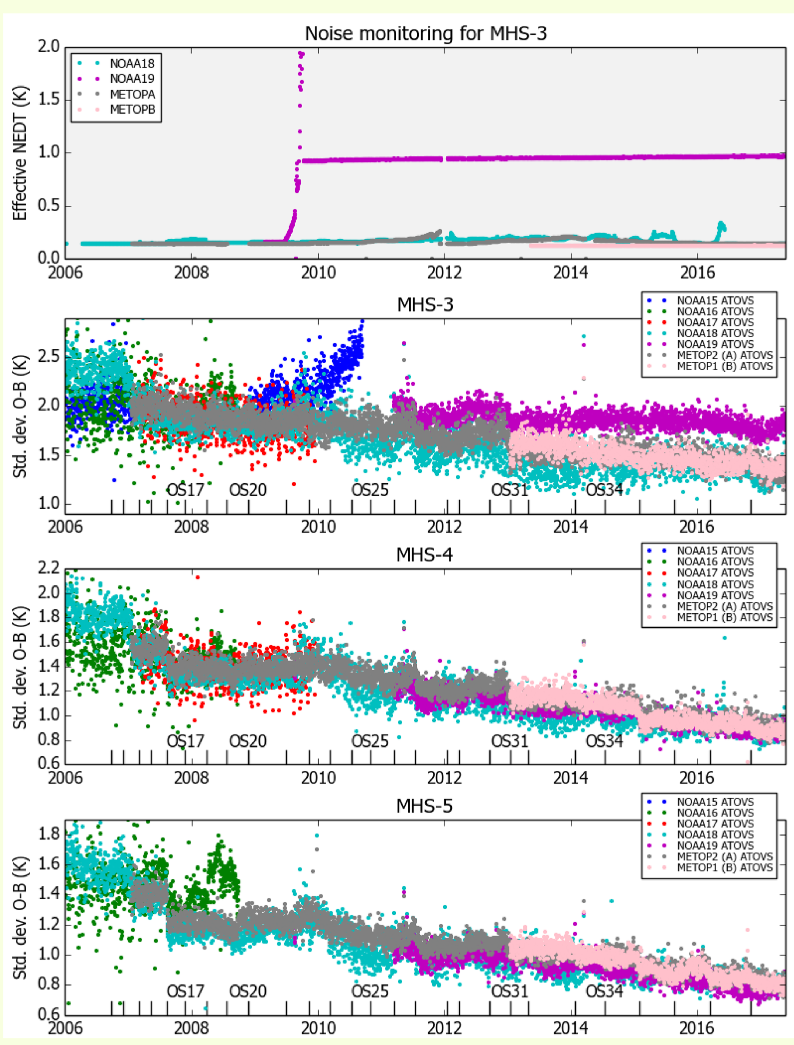

Fig. 4 As Fig. 3, plotted for MHS. The uppermost panel shows monitoring statistics of NEDT for MHS channel 3, multiplied by a factor 0.27 to account for the noise reduction from ATOVS remapping.

For satellite observations sensitive to atmospheric humidity we see larger changes in O-B statistics over time. Fig. 4 shows substantial reductions in O-B std dev for MHS channels 3-5 peaking at different heights in the troposphere (see Fig. 2). Here, background errors are large enough to be visible as a sizeable component of the overall std dev, and downward trends over time are evidence of improvements in UM humidity fields.

Hyperspectral IR data

The Met Office now assimilates four hyperspectral infrared sounders in its global forecast model: AIRS on the Aqua satellite, IASI on MetOp-A and -B, and CrIS on Suomi NPP. We consider first AIRS with a long heritage in NWP data assimilation.

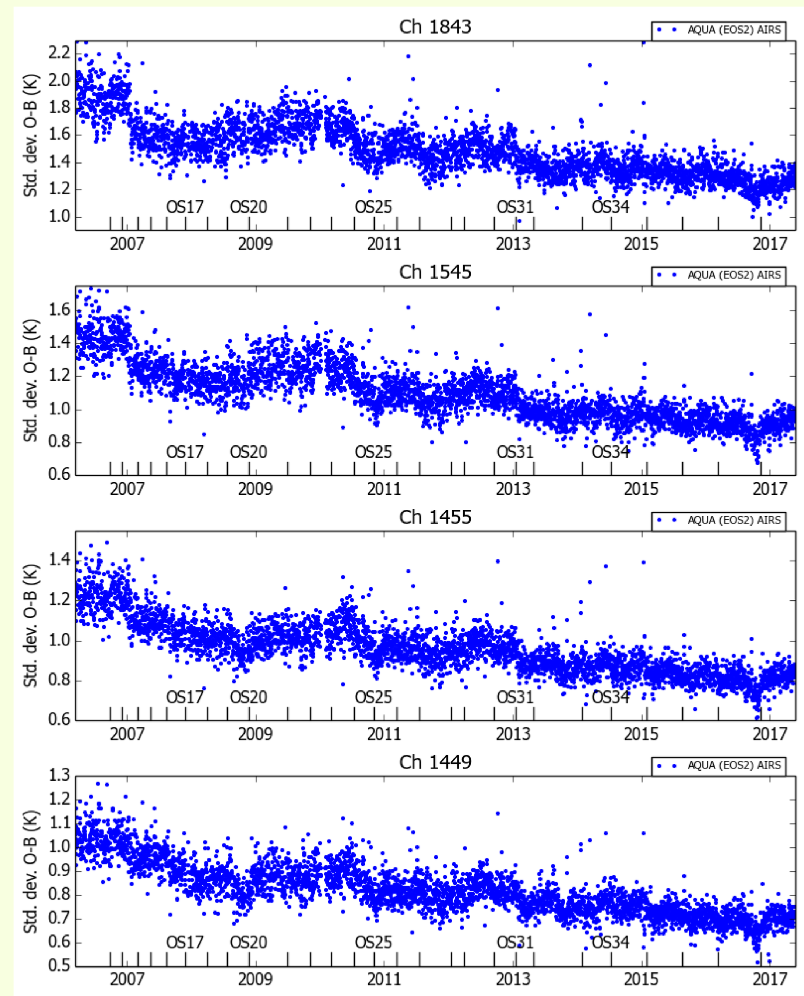

Fig. 5 As for Figs. 3 and 4, time series of std dev in O-B for four AIRS channels, numbered 1843 (1598.5 cm^{-1}) to 1449 (1331.0 cm^{-1}). These are humidity-sensitive channels with peak sensitivity at heights in the atmosphere of approximately (top to bottom, respectively) 6 km, 4 km, 3 km and 2 km.

Statistics for four AIRS channels are presented in Fig. 5, sensitive to humidity in the troposphere at heights peaking between 2 km and 6 km. All show decreasing standard deviations in O-B over the period since 2006. This is consistent with the data from MHS, indicating reduced background errors in humidity.

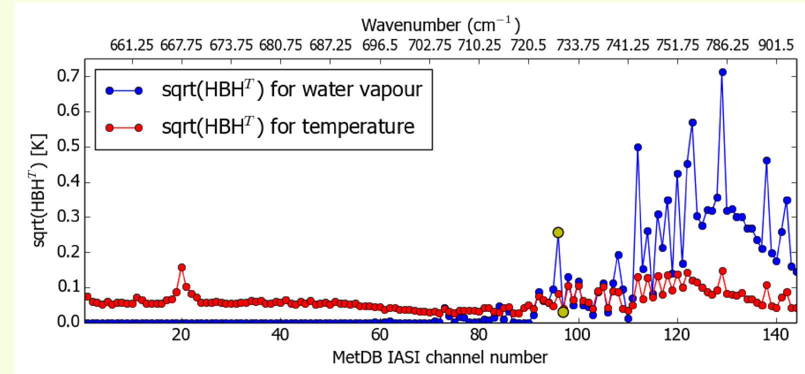

Fig. 6 Background errors for temperature and humidity mapped into brightness temperature for Met Office monitored IASI channels, computed as the square root of $\mathbf{HBH}^T$ diagonal terms. Jacobian (**H**) and background error covariance (**B**) matrix elements related to temperature and water vapour have been considered separately. Channels shown in Fig. 7 (MetDB numbers 96 and 97) are highlighted by the two yellow circles for water vapour.

Fig. 6 shows the impact on IASI channels of typical short range forecast errors in temperature and humidity, as estimated from Met Office 1dVar background error covariances. We typically refer to channels in the 650-780 cm^{-1} spectral range as temperature sounding channels, yet the figure shows the impact due to humidity profile errors can match or exceed that due to atmospheric temperature errors. For some "temperature sounding" channels such as IASI-96 in Fig. 7 we infer there is a reduced O-B std dev over time due to improved representation of model humidity.

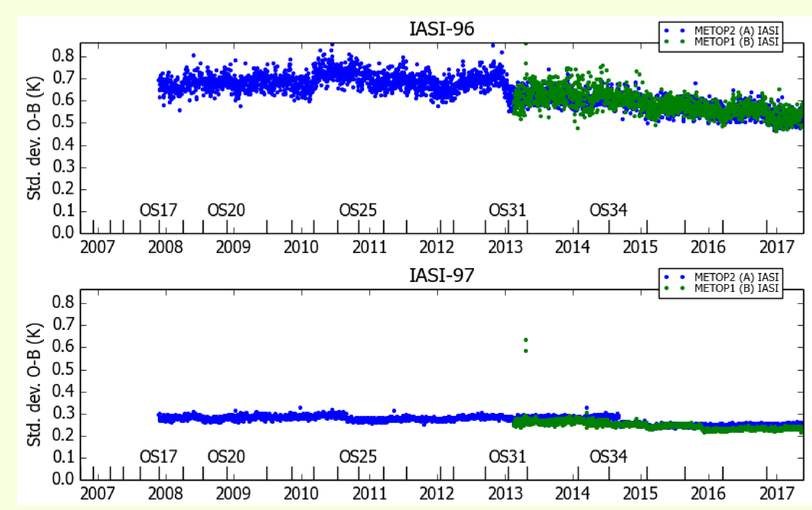

Fig. 7 Trends in O-B std dev for IASI channels number 96 (731 cm^{-1}, top) and 97 (731.5 cm^{-1}, bottom panel). Both have peak sensitivity around 4 km height.

Sonde statistics

It is instructive to compare the satellite O-B statistics with those from conventional observations. Fig. 8 shows time series of std dev in O-B for radiosonde relative humidity at various heights (between 2-10 km). A trend of reduced std dev (improved model fit to the sondes) over time is seen for all heights.

As for the satellite statistics, the std dev in O-B has a floor determined by the magnitude of the observation error. For sonde RH this is estimated to be around 0.1 (10%) in the troposphere. Note that sonde data are geographically concentrated over northern hemisphere land areas.

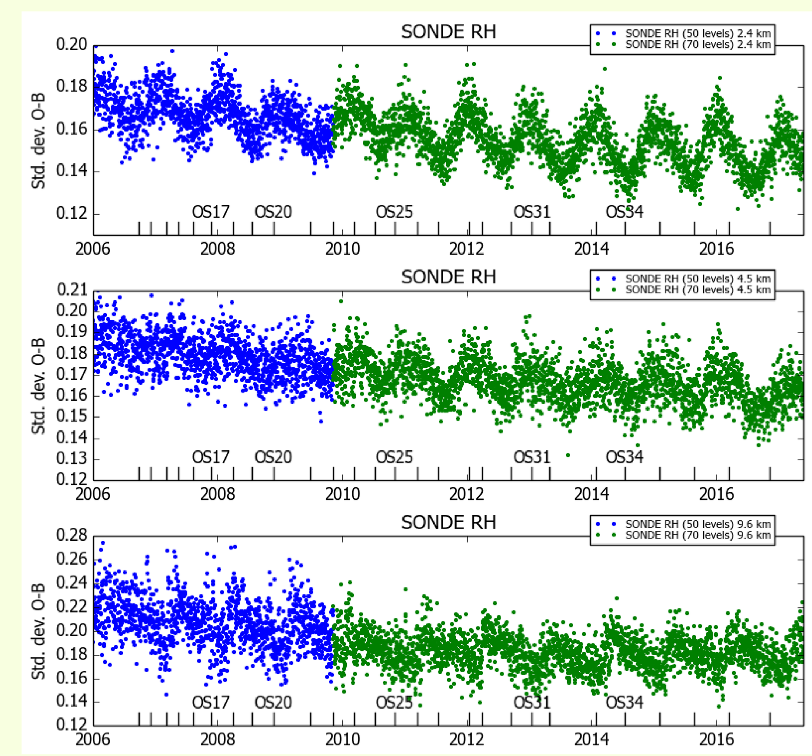

Fig. 8 Daily statistics of std dev in O-B for radiosonde relative humidity (expressed as a fraction).

Summary

Standard deviations in O-B, a measure of the fitting error of short range forecasts to observations, are found to decrease over time due to model enhancements. This is particularly evident for satellite humidity observations from MHS (Fig. 4) where the std dev in O-B has roughly halved since 2006. This improved background fit to observations is driven by numerous model upgrades over the last decade. These include:

- Improvements in the use of satellite observations and changes to data assimilation techniques. (Examples: OS16 in 2007; OS31 in 2013 with improved satellite observation errors; OS35 in 2015; OS37 in 2016 which introduced VarBC for satellite data.)
- OS22 in 2009 implemented the change to higher vertical resolution in the global model, with 70 levels and a revised definition of the tropopause.
- OS27 in 2011 introduced hybrid data assimilation and a new moisture control variable.

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