Adaptive bias correction of radiance data

Dick Dee

ECMWF
Shinfield Park, Reading, Berks RG2 9AX, UK

1. Introduction

In a data assimilation system, radiance biases depend not only on systematic errors in the measured data, but are also strongly affected by the quality of the radiative transfer models used to relate those data to the atmospheric state variables. Radiative transfer calculations involve estimates of the local atmospheric state and the biases therefore depend on the overall configuration of the assimilation system, which is continually changing. This makes radiance bias correction a challenge (Harris and Kelly 2001) and leads to the need for occasional adjustments to the bias estimates. ERA-40 production was often interrupted for bias retuning after sudden events, such as an instrument failure or the introduction of a new sensor, or when system monitoring indicated the developments of drifts or other problems with precomputed bias corrections.

Automating the procedures for detection, estimation, and correction of biases in satellite radiances is therefore primarily a practical necessity, which has become more urgent as the complexity of the observing system increased. It is also desirable to put the bias correction on a more objective footing by incorporating it in the variational statistical analysis procedure used for state estimation. The bias correction scheme for satellite data to be used in the ERA-Interim reanalysis is based on the inclusion of additional degrees of freedom in the 4D-Var minimisation to represent the biases in each of the radiance channels (Derber and Wu 1998; Dee 2004). These bias parameters are then adjusted, simultaneously with the atmospheric state, by optimising the fit to all available observations. This greatly simplifies the handling of satellite data, because the radiance bias corrections are continuously updated and automatically applied as part of the data assimilation process. The system smoothly corrects bias drifts, handles data gaps, and can quickly develop bias corrections for new instruments.

2. Performance of the adaptive scheme

We have conducted many experiments to test the behaviour of the adaptive scheme under many different circumstances. For example, Figure 1 illustrates the response to a series of sudden changes in the bias for NOAA-9 MSU channel 3 radiances starting on 2 November 1986, which were apparently caused by solar flares. The curves in the upper panel show Northern Hemisphere mean bias corrections (black) and mean departures of the bias-corrected observations from the background (red dashed) and analysis (blue dashed). As can be seen from the data counts in the lower panel, the sudden jumps in the mean departures initially cause most of the data to be rejected by quality control, but the data counts return to normal within a few days as the bias estimates are gradually adjusted. The sensitivity of MSU channel 3 peaks near 200hPa, but the change in bias corrections has no visible impact on time series of observed radiosonde temperature departures at that level (not shown).

In our experiments we have seen strong indications that a variational bias correction of radiance data tends to improve the fit to conventional data as well. This is probably due to the fact that the variational analysis continuously adjusts the bias corrections to maintain consistency with the corrections that are applied to the atmospheric state variables. The additional degrees of freedom in the analysis improves the coherence among different components of the observing system, and also results in smaller corrections to the state. Both of these factors prevent the introduction of spurious spatial and multivariate structures in the assimilation, which are known deleterious side effects of the large corrections implied by the presence of systematic errors (Dee 2006).

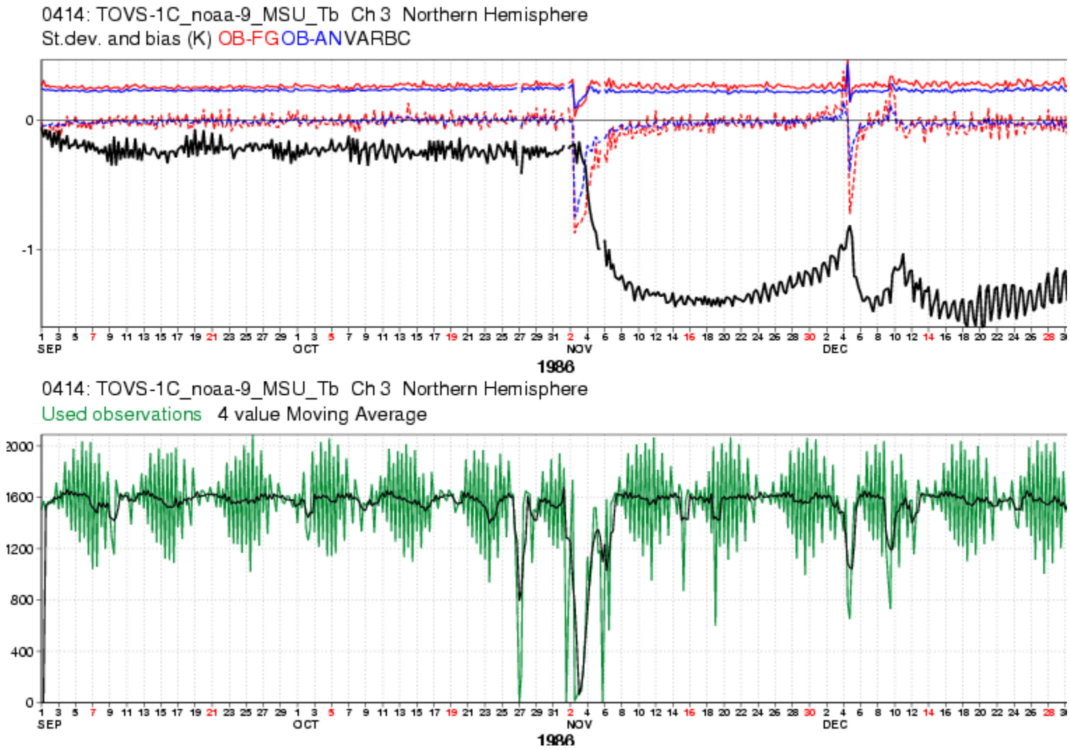

Figure 1: NOAA-9 MSU Ch3 radiance departures and bias corrections (top) and data counts (bottom). After a sudden change in bias on 2 November1986 the quality control rejects most data, but the data counts return to normal within a few days as the bias estimates are gradually adjusted.

On the other hand, a variational bias correction scheme may wrongly correct observations where the model is biased and no other unbiased observations exist. This is evident in Figure 2, which shows adaptive bias corrections applied to NOAA-11 SSU channel 2 in the Southern Hemisphere. At the time, SSU provided the only available observational information about upper stratospheric temperatures. The implication is that the real climate signal represented in the radiance data can be damped, in this case because the model has a strong seasonally-dependent stratospheric temperature bias. False attribution of bias to either the model or the observations is a fundamental in data assimilation that cannot be solved without the use of additional information.

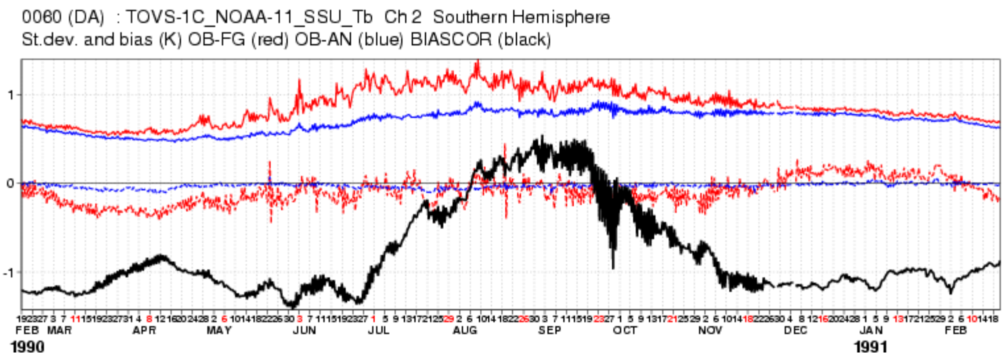

Figure 2: NOAA-11 SSU Ch2 radiance departures and bias corrections averaged over the Southern Hemisphere. Stratospheric model bias is wrongly attributed to the observations in this case.

3. Asymptotic stability of the adaptive system

The stability of the adaptive scheme depends on the amount of information about the radiance biases that can be extracted from other (unbiased) observations. To test and illustrate this, a simple experiment was performed in which all observations were withheld from one of two otherwise identical assimilations during a period of two weeks, causing the two systems to drift apart considerably. Figure 3 shows the divergence of the global mean analysed temperatures in the two systems followed by a re-convergence after the reintroduction of observations. Re-convergence in the stratosphere is relatively slow, consistent with the lack of unbiased observations there.

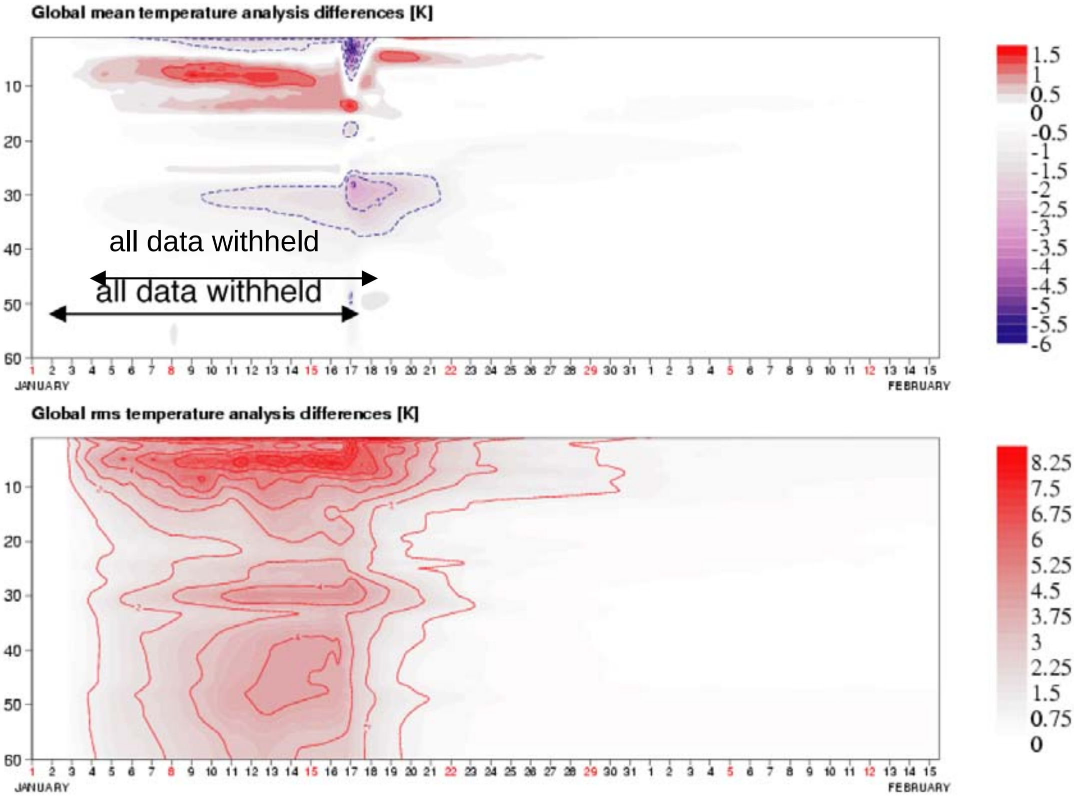

Figure 3: Evolution of the global mean (top) and global rms (bottom) temperature differences between a control assimilation (using all available observations and variational bias correction on all radiance data) and an experimental assimilation in which all observations were withheld from 3-17 January. Vertical scale is model level. Divergence in the mean (top) is due to model bias.

4. References

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