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Improving the assimilation of IASI and ATOVS data in polar region and limited area models

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Improving the assimilation of the IASI and ATOVS data in polar region and limited area models

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Objective

Statistical comparison of IASI and ATOVS data usage for NWP in polar regions and intercomparison of satellite data biases with respect to NWP between limited area models (LAM) and global models.

Introduction

For data assimilation in limited area models, in particular for polar regions, understanding of how the surface type affects the assimilation scheme is very important because of the increased number of data points over land and sea ice. Cloud detection techniques are generally designed in the context of global assimilation where the primary focus has been in using observations over the sea surface.

In most numerical weather prediction (NWP) centres, satellite data are assimilated in the form of raw radiances. For the efficient use of raw radiances, biases between the observed radiances and those simulated from the model states (first-guess) must be removed.

Many investigations were carried out on the removal of these biases. *Eyre* (1992) introduced the radiance bias as the combination of the scan-angle dependent (originating form the measurement quality) and air mass dependent errors. *Harris* and *Kelly* (2001) showed that scan angle biases vary with the geographical latitude bands. *Dee* (2004) proposed an adaptive bias correction scheme that can automatically sense the change in the bias of a given channel and responses correspondingly. The bias parameters are then updated jointly and simultaneously with the model state during the variational analysis, and are fully consistent with all observational information available to the analysis. *Watts* and *McNally* (2004) introduced a bias correction scheme, which is based on a modification of the transmittance coefficients in the radiative transfer model (RTTOV), involving two global parameters for each channel that can be adjusted to reduce the systematic errors in the RTTOV calculations.

Although bias correction schemes are believed to be reasonably effective for global models, there is little guidance on their performance in limited area models, particularly at centres where no global model is run. It is important to understand whether there are any deficiencies in particular bias correction schemes in limited area models relative to global models. Randriamampianina in his earlier studies (*Randriamampianina*, 2005), applying the *Harris and Kelly* (2001) method to correct the radiance bias for the Hungarian version of the ALADIN model (ALADIN/HU), showed the importance of the computation of the air-mass bias in the LAM environment instead of using the one estimated with the global model. It was also shown that the number of active radiance pixels and a “stable” positive impact depended on the way the coefficients for the bias correction were computed.

To study the effectiveness of two bias correction algorithms (the Harris and Kelly's scheme – HKS, and the adaptive variational bias correction – VarBC), we will use different LAM models (ALADIN-HARMONIE/Norway and the NAE-UM models) and the UK Met Office (UKMO) global model. The HKS is applied in the UKMO models, while VarBC is used in ALADIN-HARMONIE observation processing to correct the radiance biases.

It is clear that three working days stay at Met Office is not enough to work out a final

conclusions from our assimilation system monitoring.
During the stay the results of the preliminary test done with the HARMONIE/Norway large domain and the short-time statistics estimated within the NAE domain were analysed first. Further, we drew a plan for a comprehensive comparison of the observations processing in both the NAE (North Atlantic and European) and the HARMONIE assimilation systems and the way of updating the bias correction coefficients.

In the UKMO assimilation systems the *Harris and Kelly* (2001) bias correction scheme is used, while In the IFS/ARPEGE/ALADIN/HARMONIE the adaptive variational (*Auligné* et al. 2007) bias correction scheme is applied.

Different ways for estimating the coefficients for the VarBC in the ALADIN-HARMONIE/Norway model

At the Norwegian Meteorological Institute (Met.no), the High Resolution Limited Are Model (HIRLAM) is used in operational for data assimilation. Figure 1 shows the two domains of the operational systems. Recently, the ALADIN-HARMONIE data assimilation and forecast system is being implemented at Met.no. For the HARMONIE implementation, we tried to keep the size of the operational domains. For simplicity (less computing resources for example, etc ...) the smaller domain have been investigated the most. Hence, the radiance assimilation was not set up for the bigger domain, which means it is a good candidate for our exercises.

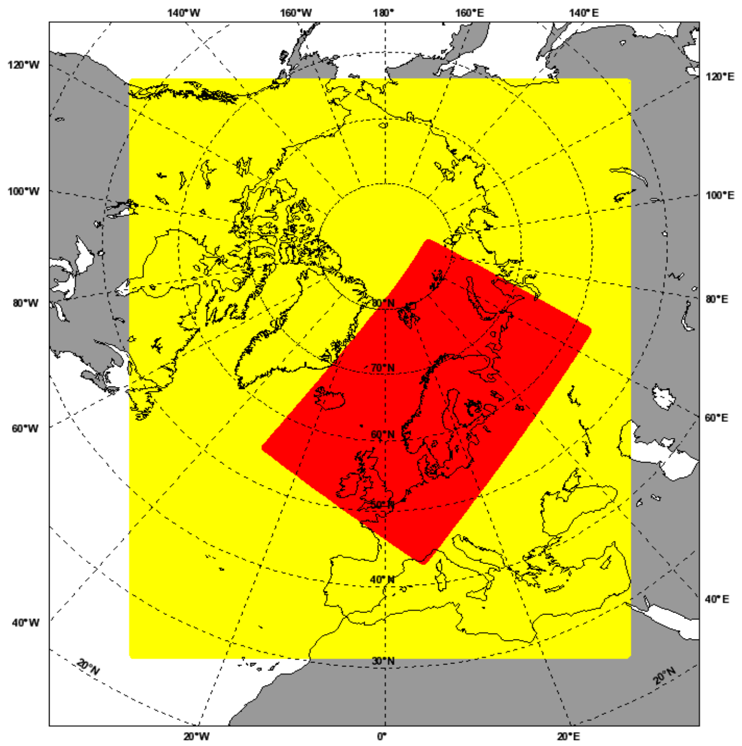


Figure 1. Domains chosen for the ALADIN-HARMONIE/Norway LAM implementation. The smaller domain is in rotated Lambert projection with 11 km resolution in both x- and y-directions, and 60 eta levels up to 0.2 hPa, while the larger domain uses the polar stereographic projection with 16 km resolution and have the same vertical discretization than the smaller one.

As reported in Randriamampianina and Storto (2008), changing the way of updating the bias correction coefficients for radiances data assimilation, we succeed to improve the impact of radiance data in the above presented smaller HARMONIE/Norway domain. In

this exercise, we set up the assimilation of the ATOVS AMSU-A and AMSU-B/MHS with the IASI data in the large HARMONIE domain. Using the adaptive variational bias correction scheme, the bias correction coefficients are updated in the following ways:
- A background field suitable for the assimilation was prepared (projected in time using the LAM forecast core model) using downscaled fields from the operational ECMWF global model. So, 6-hour forecasts were used as first-guess for the separate analyses.
- Different sets of bias correction coefficients were computed:
a- the coefficients were updated separately for the four assimilation times (tough we use 6-hour cycling) at 00, 06, 12, and 18 UTC.
b- the coefficients were update using the ones estimated during the previous assimilation time. So, in a cyclic way. Note that this is the way it is done for the global models.
- The best way to estimate the bias correction coefficients is to start with a zero bias, but we decided to use the bias files for the smaller domain evaluated for the summer period. Note that our trials were performed during a winter period (February 2008). This allowed us to test the use of bias correction coefficients estimated for one LAM with an other one.

The preliminary trials

In fact, with the HARMONIE model, we have got three sets of bias correction files: 1- the daily updated ones (separate file for each assimilation times), 2- the one estimated at the end of the 20-day period, and taking into account the coefficients from the previous assimilation, and 3- the one estimated for the smaller domain. Applying the above mentioned bias correction files, we performed a three-week assimilation trials with 48-hour forecasts for verifications purposes at 00 and 12 UTC. The first 4 days served as a spin up period, and were not used in the verifications. Figure 2 and 3 show the impact of each utilised bias correction (bcor) coefficients on the analysis and forecasts for the surface pressure, where one observes differences in the forecast scores on the verification against the observations.

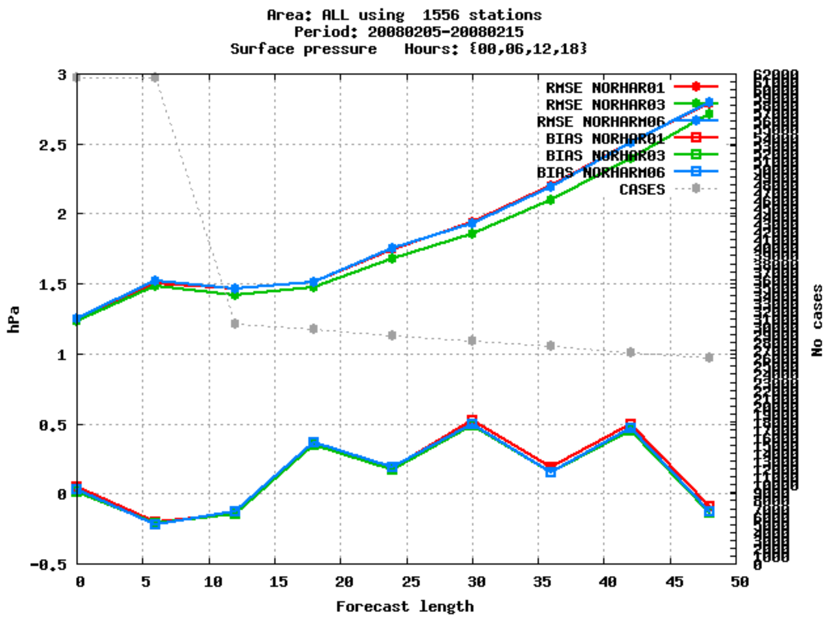


Figure 2: Mean root-mean-square errors (RMSE) and bias for the surface pressure from the four analysis times (00, 06, 12, and 18 UTC). The number of cases drops after 6-hour forecast range, because at 06 and 18 we do only 6-hour forecast to have the guess, while at 00 and 12 UTC, we do 48-hour forecasts. In green we have the run with daily updated bcor files, in blue the run with bcor updated in cyclic way, and in red the run started with the bcor estimated for the smaller domain.

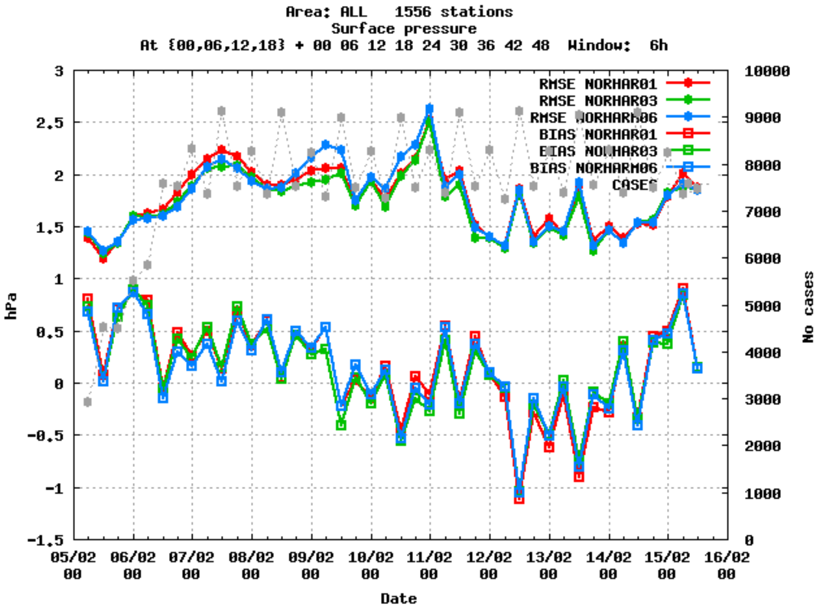


Figure 3: Mean time series for RMSE and bias for the surface pressure from the statistics computed for the available forecast ranges. In green we have the run with daily updated bcor files, in blue the run with bcor updated in cyclic way, and in red the run started with the bcor estimated for the smaller domain.

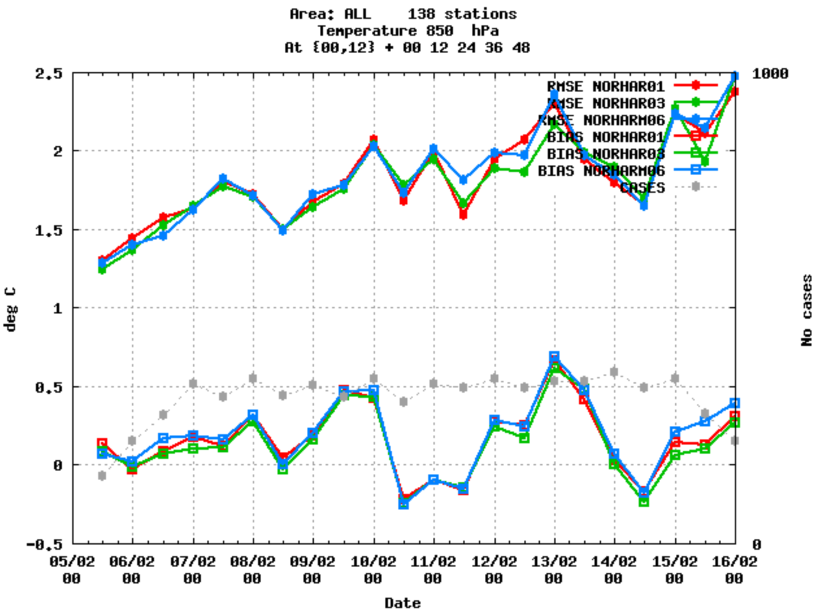


Figure 4: Mean time series for RMSE and bias for the temperature at 850 hPa from the statistics computed for the available forecast ranges. In green we have the run with daily updated bcor files, in blue the run with bcor updated in cyclic way, and in red the run started with the bcor estimated for the smaller domain.

Although updating the bias correction daily shows better results, we observe an overall growing error in the troposphere (Fig. 4) meaning that some radiance data are not well used in these trials. A careful monitoring of all the used channels from different instruments is needed to find the problematic observation, and the deficiency in the assimilation scheme. For example, during the implementation of the radiances for the smaller domain, a blacklist of a set of channels or instruments at specific assimilation times was needed to account a very small path (only the extreme edge of the path is available inside the domain) or erroneous radiance measurement. Also, we had to change the way of updating the bias coefficients to have a “reliable” impact in the analysis, as well as in the forecasts performance.

Brief monitoring of the functionality of the assimilation systems with the bias correction schemes

As it was mentioned above, we intend to extensively monitor the functionality of our assimilation systems (HARMONIE/Norway and NAE at the UKMO) and the use of radiance observations. In this short report we investigate the impact of the bias correction schemes in the HARMONIE/Norway and in the NAE limited area models.

The NAE Model

The NAE model domain is shown below in Figure 5. The blue line delimits the NAE area and the black line gives the edges of the lateral boundary conditions passed to the NAE from the global model.

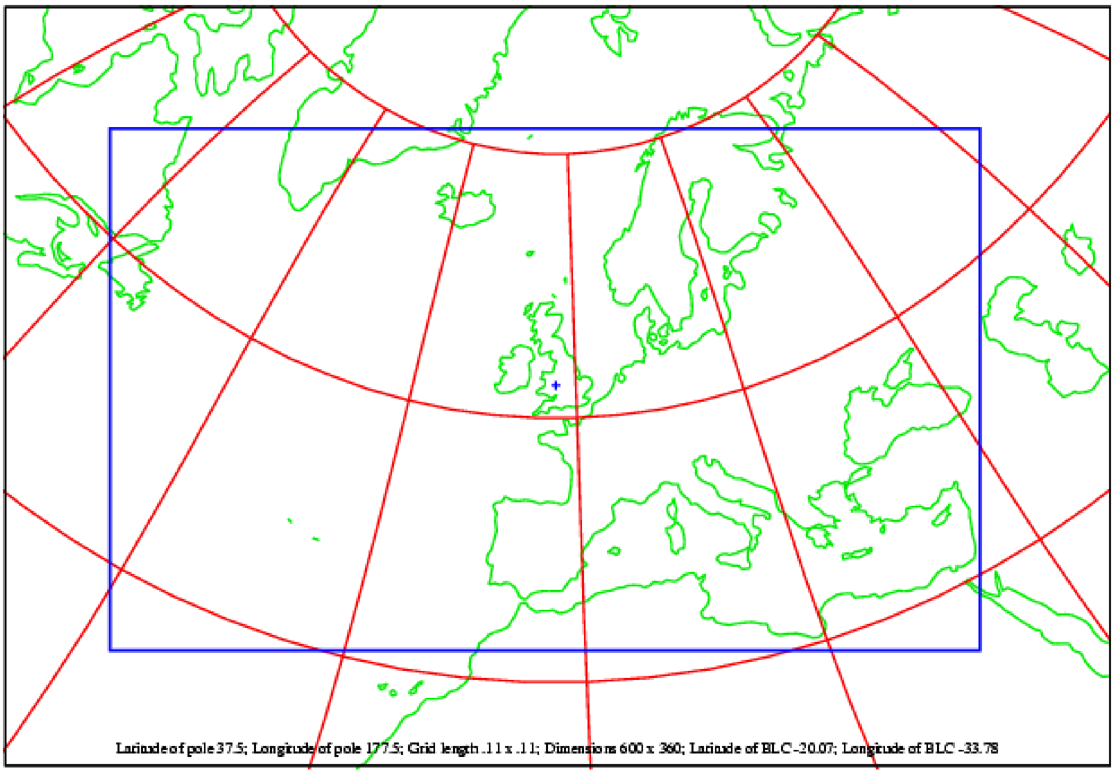


Figure 5: The North Atlantic and European model domain

The NAE model is run every six hours at 00Z, 06Z, 12Z and 18Z. The “update” runs used to produce the 6-hour forecast for the next assimilation cycle are named respectively QZ00, QZ06, QZ12 and QZ18. The data assimilation mimics the global assimilation for IASI in many respects. However, the NAE model top is at 36km as opposed to 63km for the Global mode, so the upper levels of the background temperature profile needed for radiative transfer are estimated by regression to collocated AMSU-A observations. The stratospheric temperatures are then retrieved in 1D-Var and held fixed in 4D-Var.

Despite this difference in the background atmospheric profile, the bias correction used in the NAE is the same as that used in the global model. Historically, the Met Office limited area models were on the same atmospheric levels as the global model (although this has not been the case for several years) so there was good justification for using the same bias corrections. Global bias statistics allow for full sampling of all scan positions and a full quotient of observations to be used in the calculation of airmass bias predictors. It is hoped that in the near future the NAE and Global models will again be run on the same vertical levels, bringing the biases in line, but it is still worth understanding whether a reasonable set of bias coefficients can be calculated from statistics gathered from the NAE model.

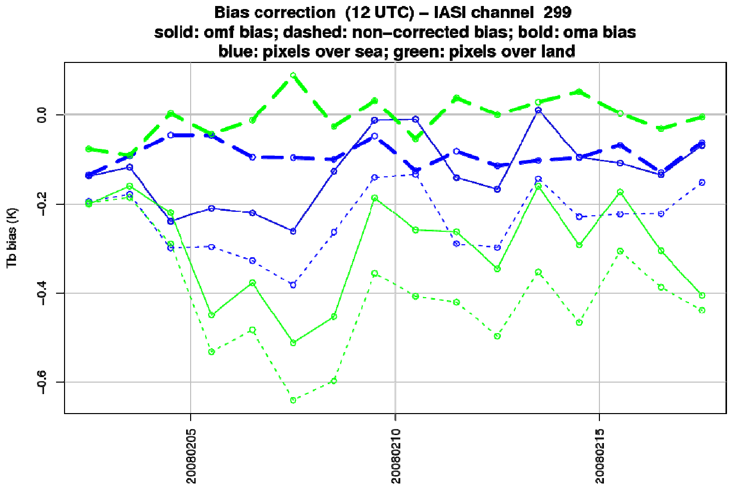
1) Monitoring the use of IASI data in the HARMONIE assimilation system

Figures 6 show the a common picture of the impact of the two bias correction coefficients updating techniques for the high peaking channels. Although the number of assimilated pixels (*Fig 7*) are almost the same, the analysis biases are slightly different. But, we observed also a slight differences in number of active pixels for the tropospheric peaking channels (see for example *Figs. 8 and 9*). We mentioned a slight increase in time of the forecasts error in the troposphere during the above trials. Analysing the time series of bias for each chosen channel, we found that the more sensitive the channel to the surface or lower troposphere, the larger the impact on the bias and so on the number of the active pixels (see Fig. 8, where we can see clear analysis bias). It is more than probable that this problem comes from unsatisfactory quality of some important surface fields used in radiative transfer computation. This needs to extend the observation departure (Observation minus forward-modelled Background - O-B) monitoring to different surface types (high/low land, open sea or sea ice, etc ...).

2) Monitoring the use of ATOVS data in the NAE assimilation system

Regarding the NAE assimilation system monitoring and bias study, the bias correction coefficients were computed using the LAM model and its background. Figure 11-14 show the statistics of corrected observation departures, so far for a few days test, for different channels from different satellites. We observed a reduction of the bias for the low tropospheric peaking AMSU-B/MHS channels, especially the channels 5 (Fig. 12). We observed also similar impact of the utilisation of the bias correction files specific for the LAM on the tropospheric sounding AMSU-A channels (channel 5 to 8).

Plotting the bias of one-week accumulated observation departures for the AMSU-A channels from the NOAA-19 satellite, we observed a quite good agreement between the scanning biases. Figure 15 shows the scan biases for the AMSU-A channel 6.



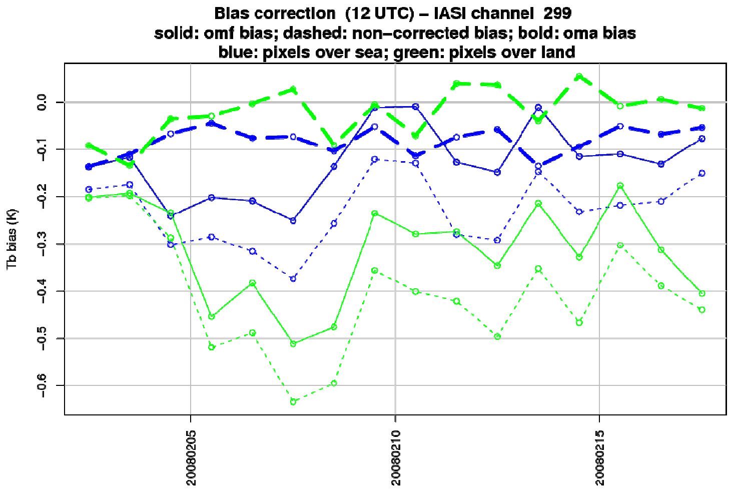


Figure 6: Time series of the bias for the channel 299 (719,50 cm^{-1}), peaking in lower stratosphere. Green lines belong to pixels over land and blue line for the pixels over sea. Dashed lines represent the observation departures before the bias correction, solid thin lines show the bias of corrected observation departures, and bold solid lines show the analysis bias. Top plot shows the monitoring of biases using the daily updated coefficients, while on the bottom plot we see the monitoring of the cycling update of the bias coefficients. One can observe a slight differences in the analysis biases.

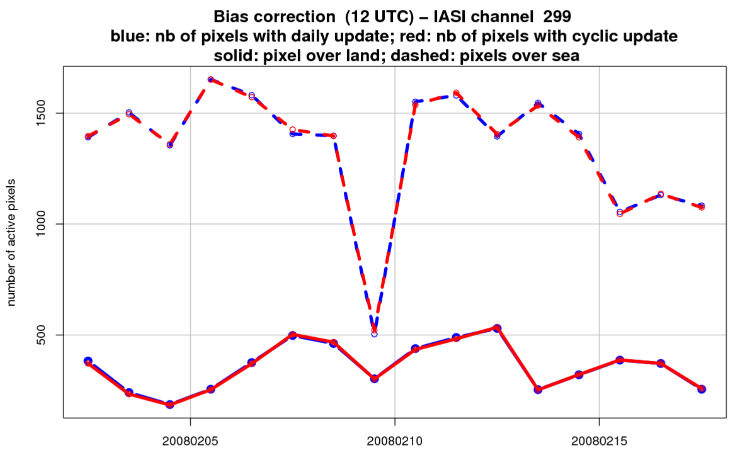


Figure 7: Number of the active for the channel 299; the assimilated pixels in the run with daily updated (blue), and the cyclic updated (red) bias correction files. Dashed lines show the number of active pixels over sea, and solid lines stand for the number pixels over land.

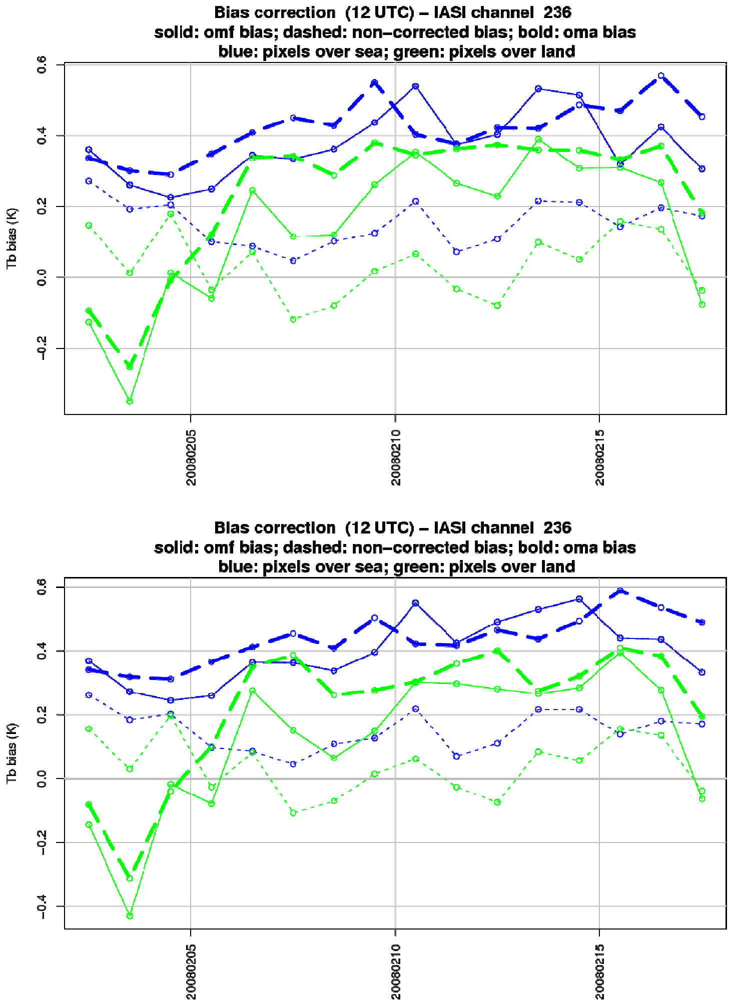


Figure 8: The same as *Fig. 6*, but for the IASI channel 236 (703,75 cm^{-1}), peaking in the upper troposphere.

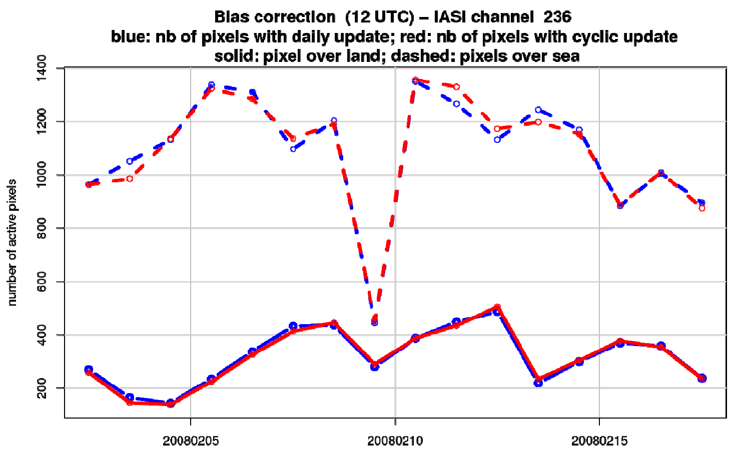
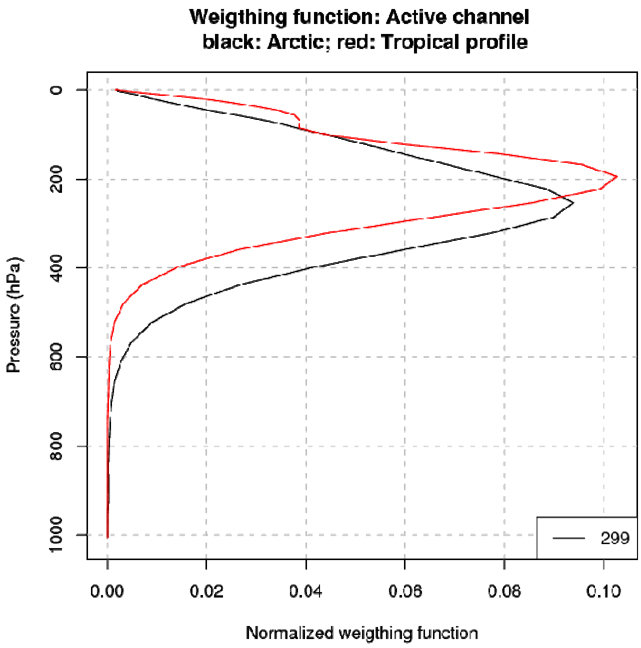


Figure 9: Number of the active for the channel 236; the assimilated pixels in the run with daily updated (blue), and the cyclic updated (red) bias correction files. Dashed lines show the number of active pixels over sea, and solid lines stand for the number pixels over land.



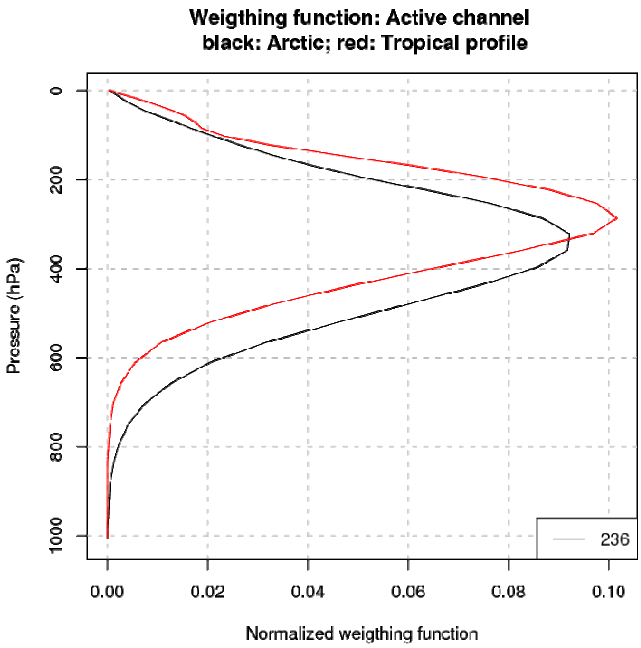


Figure 10: Example of weighting function for the above discussed IASI channels (236 and 299), estimated with some tropical and Arctic atmospheric conditions and surface properties. Tthe 299 have a very long-tailed shape, but does not sense the lower part of the troposphere, while the channel 236 does in certain Arctic or high-latitude conditions.

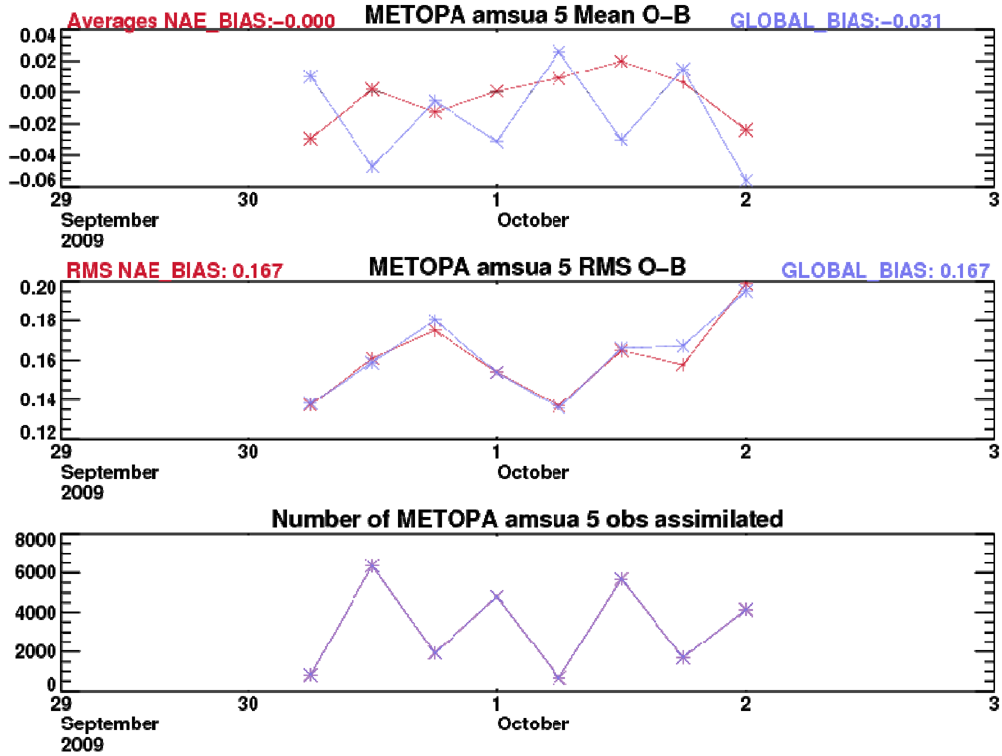


Figure 11: Statistics of the corrected observation departures for the AMSU-A channel 5 on-board the MeTOp satellite. Red lines show the statistics related to the use of the NAE-derived bias correction coefficients, and in blue the statistics obtained when using the global model-derived coefficients.

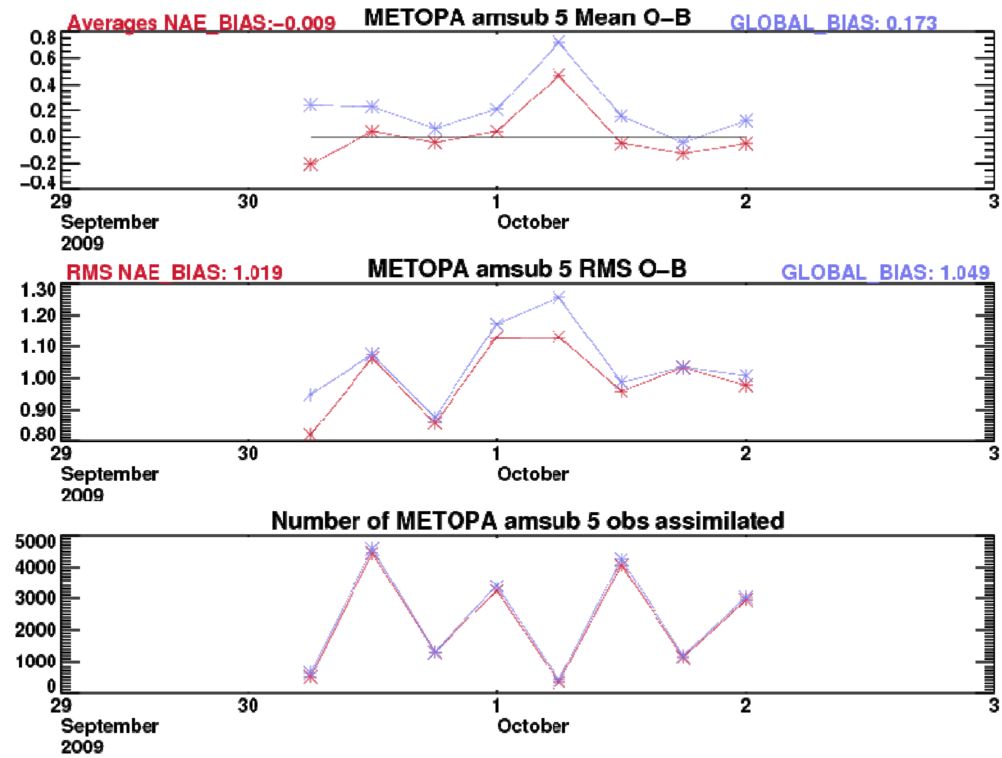


Figure 12: Statistics of the corrected observation departures for the AMSU-B channel 5 on-board the MeTOp satellite. Red lines show the statistics related to the use of the NAE-derived bias correction coefficients, and in blue the statistics obtained when using the global model-derived coefficients.

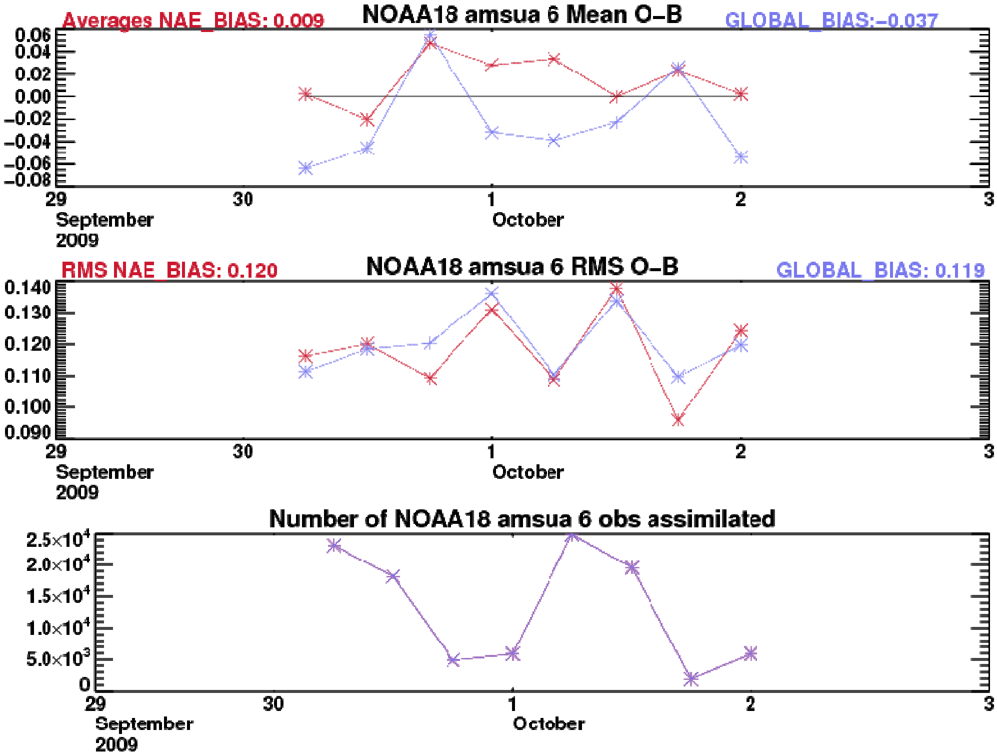


Figure 13: Statistics of the corrected observation departures for the AMSU-A channel 6 on-board the NOAA-18 satellite. Red lines show the statistics related to the use of the NAE-derived bias correction coefficients, and in blue the statistics obtained when using the global model-derived coefficients.

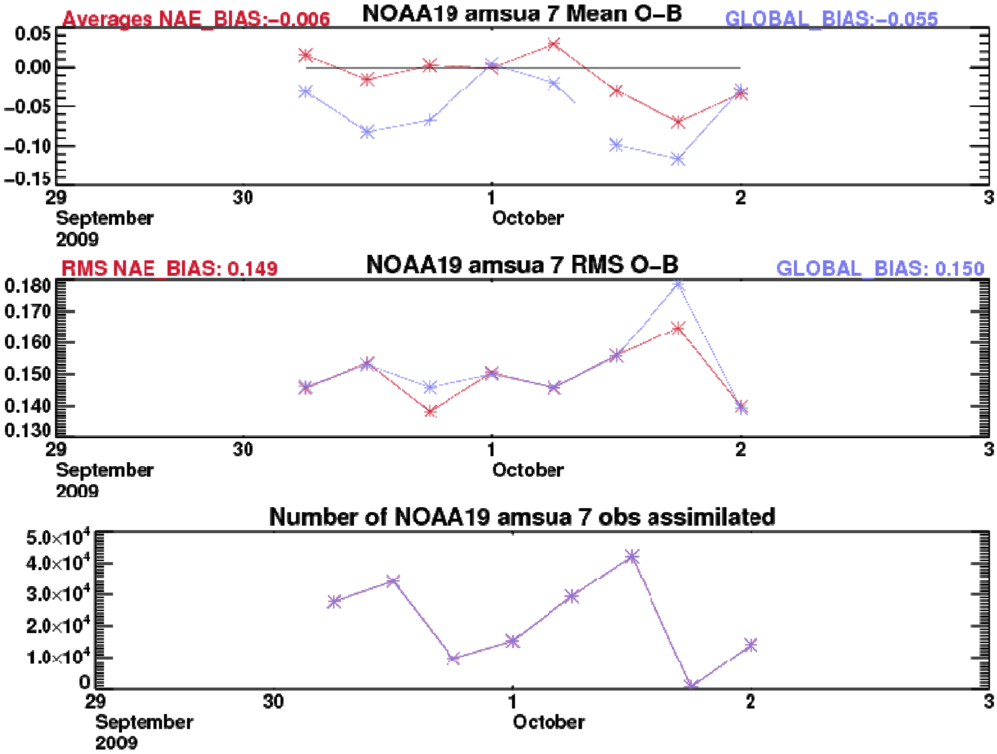


Figure 14: Statistics of the corrected observation departures for the AMSU-A channel 7 on-board the NOAA-19 satellite. Red lines show the statistics related to the use of the NAE-derived bias correction coefficients, and in blue the statistics obtained when using the global model-derived coefficients.

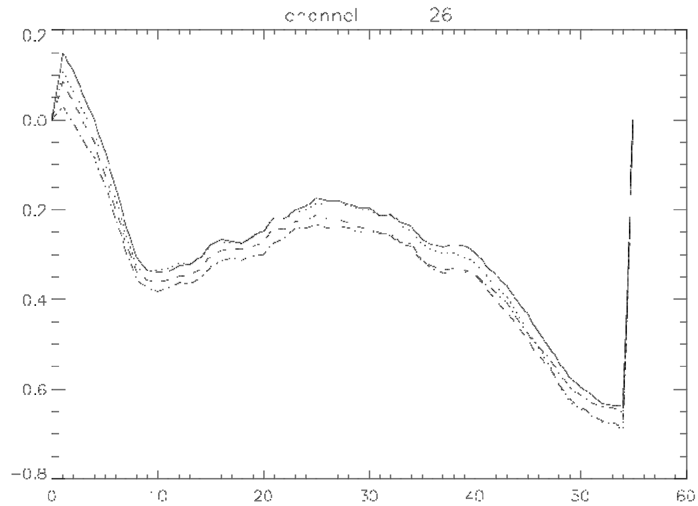


Figure 15: Cross-scan bias, observed at different assimilation times (00, 06, 12 and 18 UTC), of the observation departures for the AMSU-A channel 6 from NOAA-19. One can see a clear similarity in the shape of the biases.

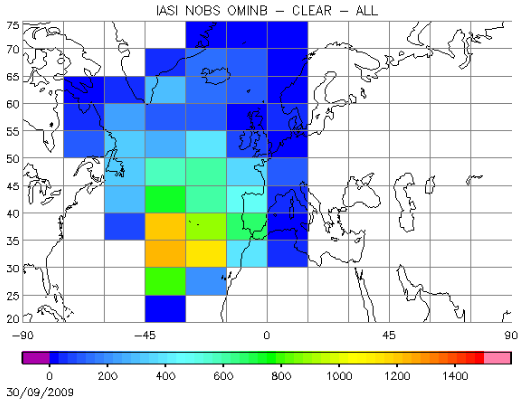
3) IASI biases in the Met Office North Atlantic and European model

In this study , we investigate the impact of calculating bias corrections for the Met Office North Atlantic and European (NAE) model configuration from its own statistics rather than statistics from the global model.
We also investigate whether there is any justification for calculating bias corrections for each cycle of the model independently rather than aggregating data from all cycles into one set of statistics before calculation of bias correction coefficients.

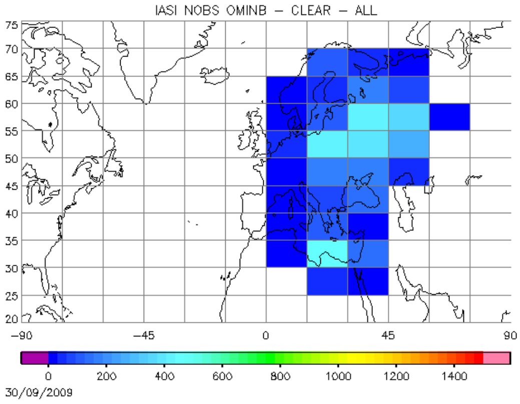
3.1) Variations in IASI-model biases between cycles

As well as testing whether reasonable bias corrections can be derived from the NAE model itself, we are also interested in whether there are significant bias variations between 6-hour cycles, and whether these biases are better dealt with by having different bias corrections for each cycle separately. The Observation minus forward-modelled Background (O-B) statistics have been analysed for each cycle separately for the 30 channels monitored operationally at the Met Office. These channels have been chosen to have a reasonable spread in terms of atmospheric sensitivity and spectral location. The mean O-B over 5° latitude x 15° longitude boxes have been plotted for the NAE domain.

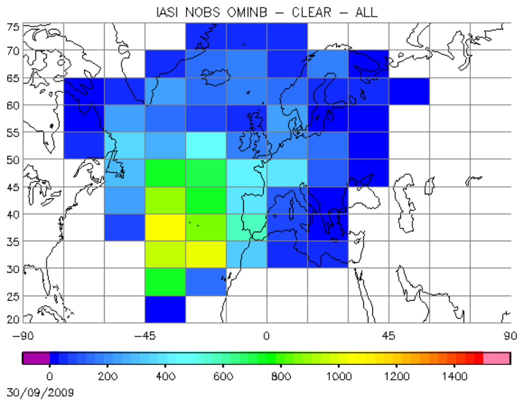
To create these plots, statistics were summed over 13 days from September 16 to September 29 2009. The NAE model typically accepts through 1D-Var quality control procedures between 200 and 1500 observations per cycle in total. Some of the grid boxes therefore contain little data and the statistics are rather noisy for such a short aggregation period. The number of observations included in each grid box is indicated in Figure 16.



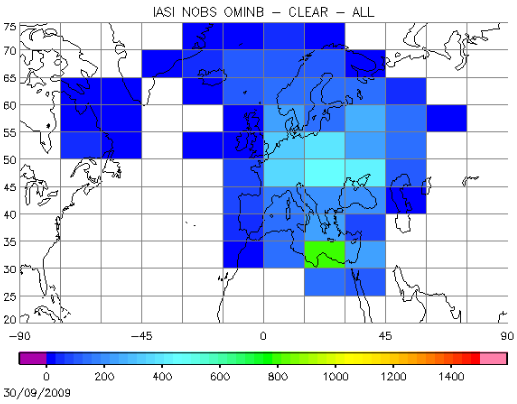
a) QZ00



b) QZ06



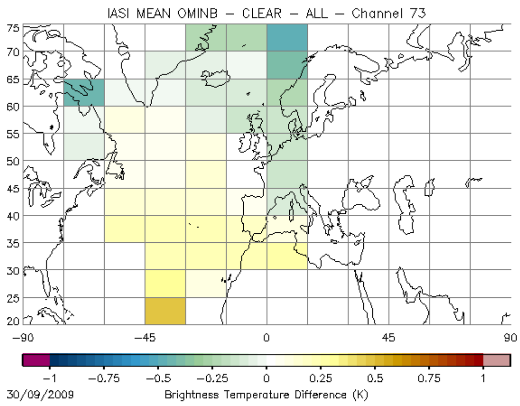
a) QZ12



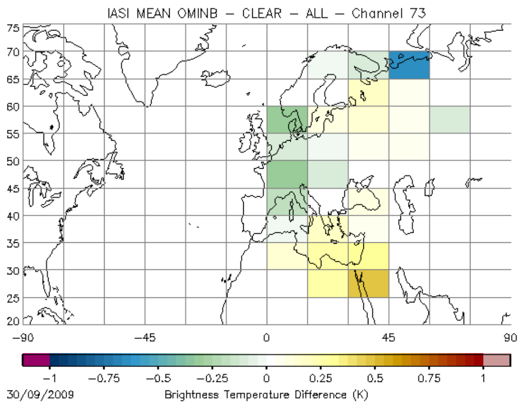
b) QZ18

Figure 16: Number of Observations in each grid box for the statistics plots shown in figures 17 to 18.

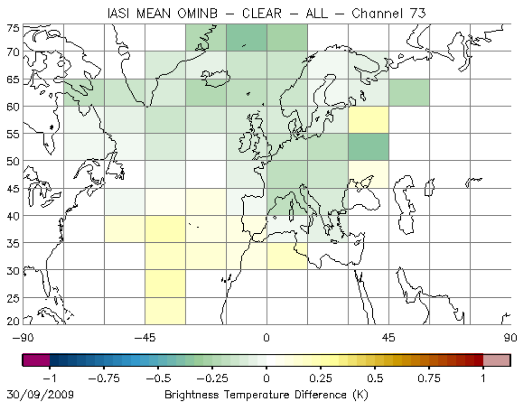
When examining the mean O-B before bias correction, there was found to be little difference in value across the domain for the majority of monitoring channels. An example for a temperature sounding channel is shown in Figure 17. The two exceptions to this are a slight diurnal change in bias in some of the window channels (Figure 18), and a strong shift in bias in high-peaking short-wave channels (Figure 19). The former is likely to be a model surface temperature bias change, and the latter is caused by the lack of modelling of the non-local thermodynamic equilibrium effect in the radiative transfer process. The channels affected by non-LTE are not assimilated or used in 1D-Var, so the diurnal variation in bias is not important for IASI assimilation at the present time.



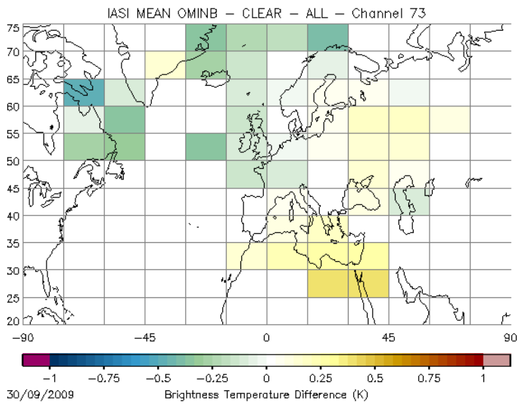
a) QZ00



b) QZ06



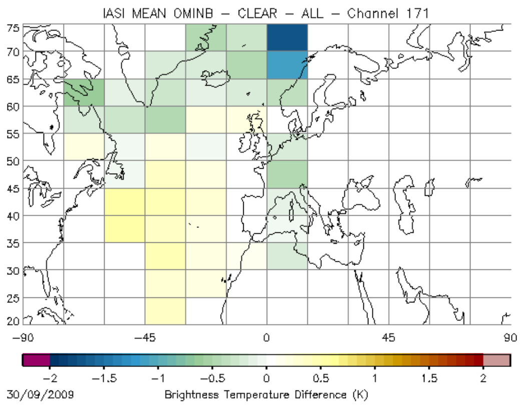
a) QZ12



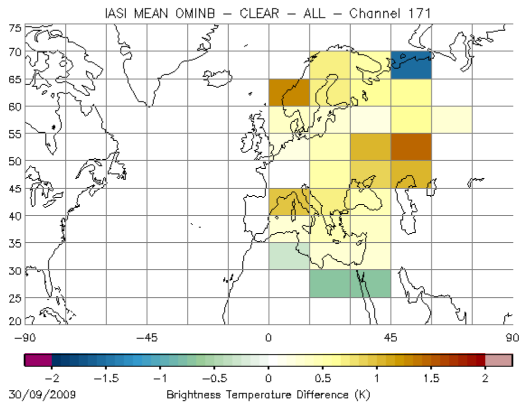
b) QZ18

Figure 17: Temperature sounding channel 73 in the 314 Channel Set (Channel 242 at 705.25cm^{-1}) which peaks at about 300hPa

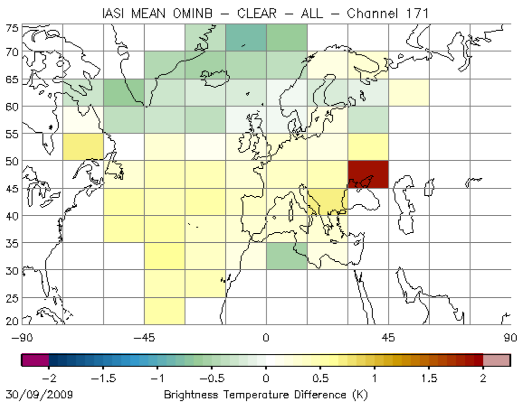
The observation minus background statistics have also been examined after bias correction with coefficients derived from the global model. This quantity is referred to as “Corrected minus Background” or C-B. This is expected to show up smaller variations across cycles which are not effectively removed by the application of a single bias correction for all cycles. Plots of C-B do show some evidence of differences in bias between cycles in some tropospheric temperature sounding channels (Figure 20). The effect, however, is small, and it is not known at this time whether attempting to correct out this effect will just lead to the 4D-Var analysis agreeing to a greater extent with the possibly biased forecast state for some cycles. Nevertheless, the calculation of biases for each cycle separately is tested below.



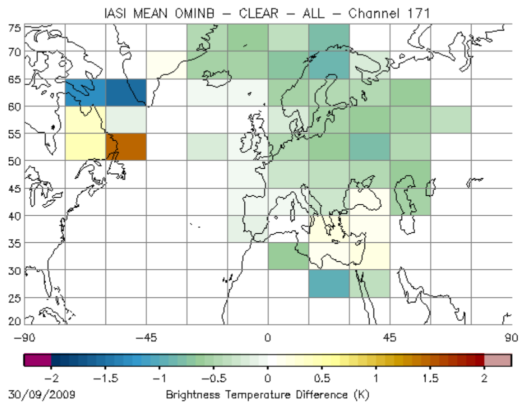
a) QZ00



b) QZ06

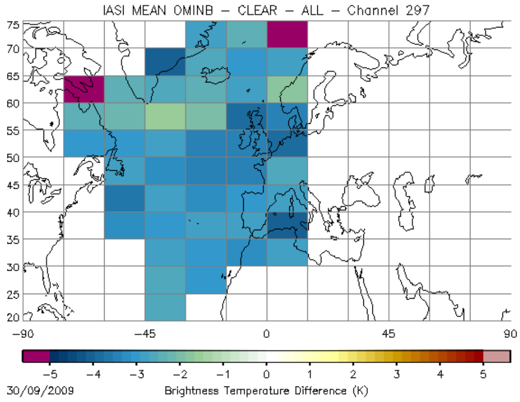


a) QZ12

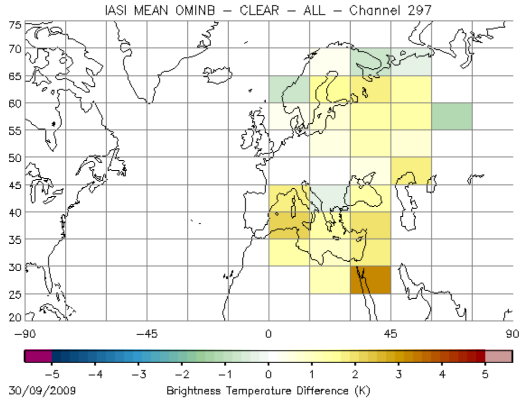


b) QZ18

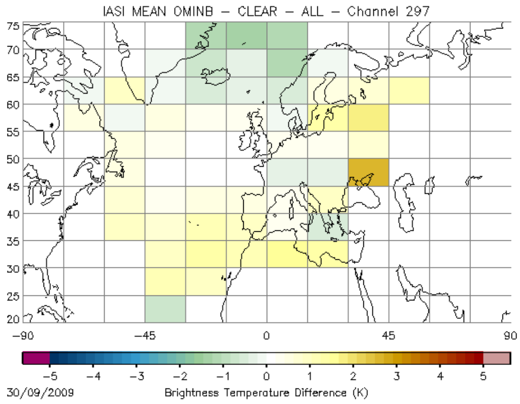
Figure 18: Mean O-B for Window Channel 171 in the 314 Channel Set (Channel 2245 at 1206.0cm^{-1})



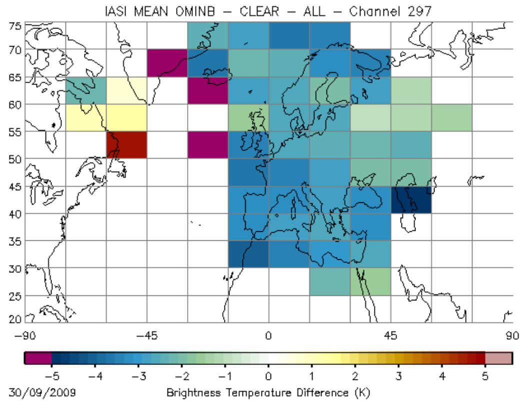
a) QZ00



b) QZ06

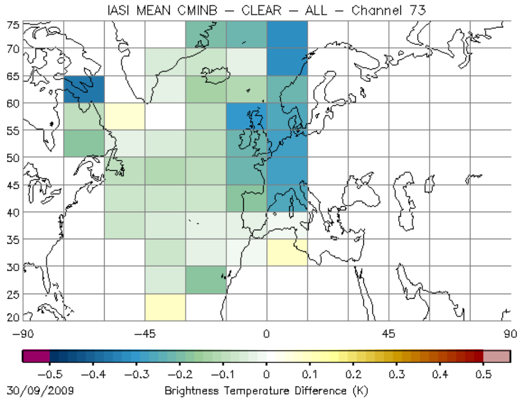


a) QZ12

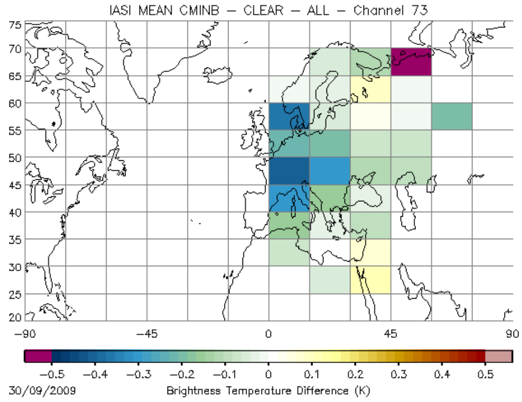


b) QZ18

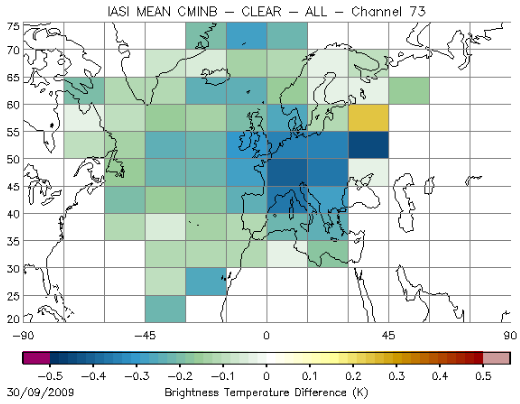
Figure 19: Mean O-B for non-LTE Channel 297 in the 314 Channel Set (Channel 6601 at 2295.00cm^{-1}) which peaks at 0.87hPa



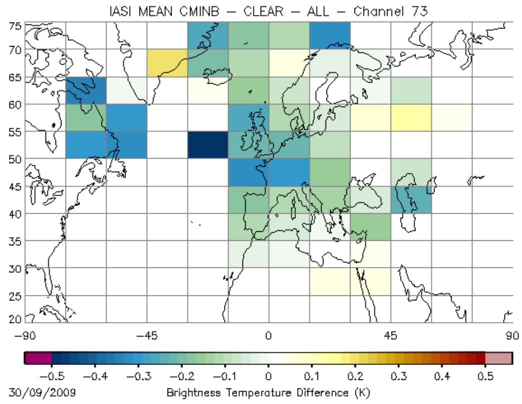
a) QZ00



b) QZ06



a) QZ12



b) QZ18

Figure 20: Temperature sounding channel 73 in the 314 Channel Set (Channel 242 at 705.25cm^{-1}) which peaks at about 300hPa

3.2) Testing different bias corrections for independent cycles

Three experiments were run for the four cycles QZ06, QZ12 and QZ18 on September 14 2009 and QZ00 on September 15. The first experiment ("Operational Biases") used the operational bias corrections derived from the global model. The second experiment ("NAE Biases") calculated new biases from all four cycles combined over 13 days of NAE runs between September 16 and September 29 2009. This experiment was deigned to demonstrate whether reasonable bias corrections can be calculated for a limited area model over a relatively short period of time. We would normally aggregate one month's worth of data to generate bias corrections from the global model but in certain circumstances (e.g. during a parallel suite before operational implementation of new science changes) only 10 days to 2 weeks of statistics are available. The final experiment ("QZ?? Biases") used biases calculated separately for each cycle, using the statistics gathered over the same period as the second experiment.

Figures 21-24 show the differences in mean C-B for the whole NAE area for the four cycles on September 14-15. Note that the number of observations plotted are variable by cycle, and can be very small (e.g. 200 or so for QZ06). Additionally, window and water vapour channels have even lower observation counts because they are not used over land or where a microwave cloud test on collocated AMSU-A data is failed.

Although this is a very small sample and more comprehensive tests should be run before any firm conclusions drawn, it seems that it is possible to calculate reasonable bias correction coefficients from the NAE model. The operational global biases show large fluctuations in the higher-peaking channels, presumably related to differences in the specification of stratospheric temperatures between the models. The biases calculated from the NAE itself do not show this behaviour. The residual water vapour channel biases seem to be more consistent when the NAE bias corrections are applied. In general, the residual bias from the NAE bias corrections is quite small. The exception is for the QZ06 cycle, where the operational biases appear to leave a smaller residual. It should be noted that very few observations are available for the QZ06 run, so the statistics may not be valid.

Figures 25 and 26 show the cycle-by-cycle variation in residual bias for the two experiments using the NAE statistics to calculate bias corrections. Whilst the results are rather inconclusive, the residual biases for the temperature sounding channels appear to be more consistent cycle-by-cycle when calculated for each cycle separately. However, the residual biases for QZ18 and QZ00 are smaller when all the statistics are aggregated. The statistics for QZ06 are rather different from the other cycles, possibly because of the small sample size.

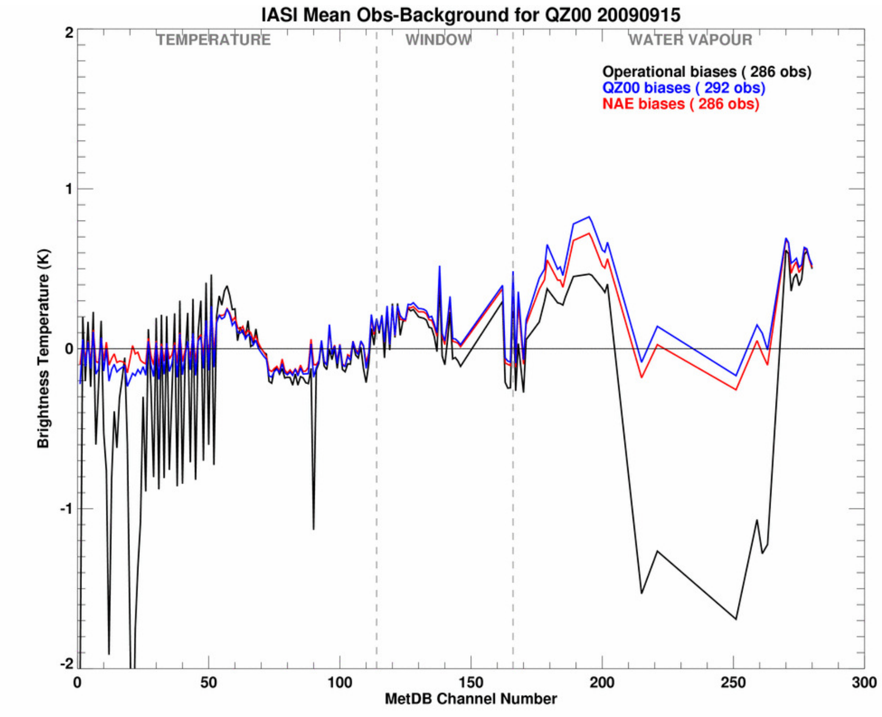


Figure 21: Mean C-B for QZ00. The number of observations in each run is indicated. “MetDB Channel Numbers” are channel numbers within the 314 channel set. Only those channels used in 1D-Var are plotted.

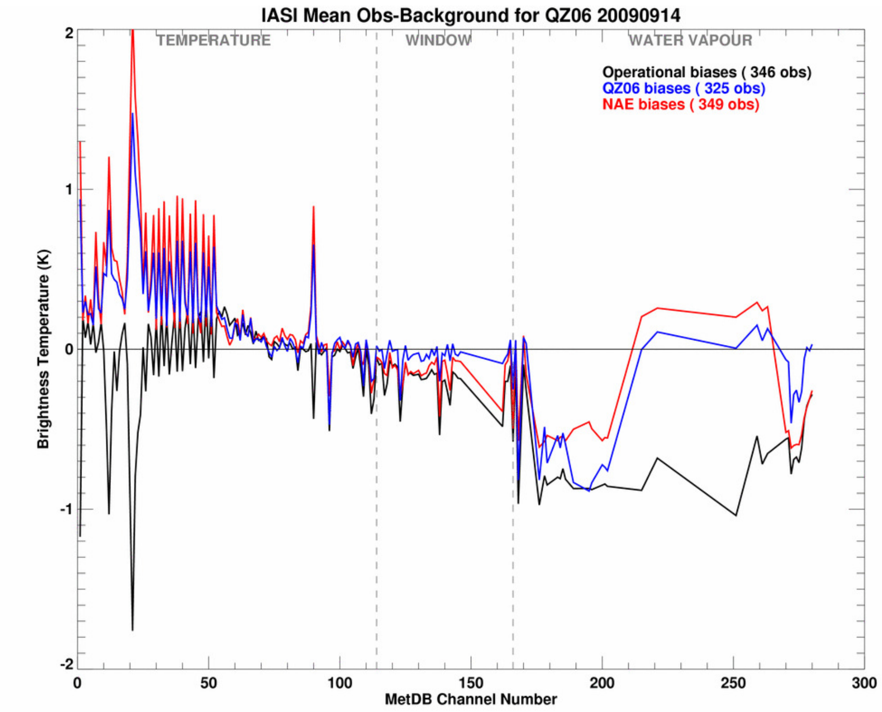


Figure 22: Mean C-B for QZ06. The number of observations in each run is indicated. “MetDB Channel Numbers” are channel numbers within the 314 channel set. Only those channels used in 1D-Var are plotted.

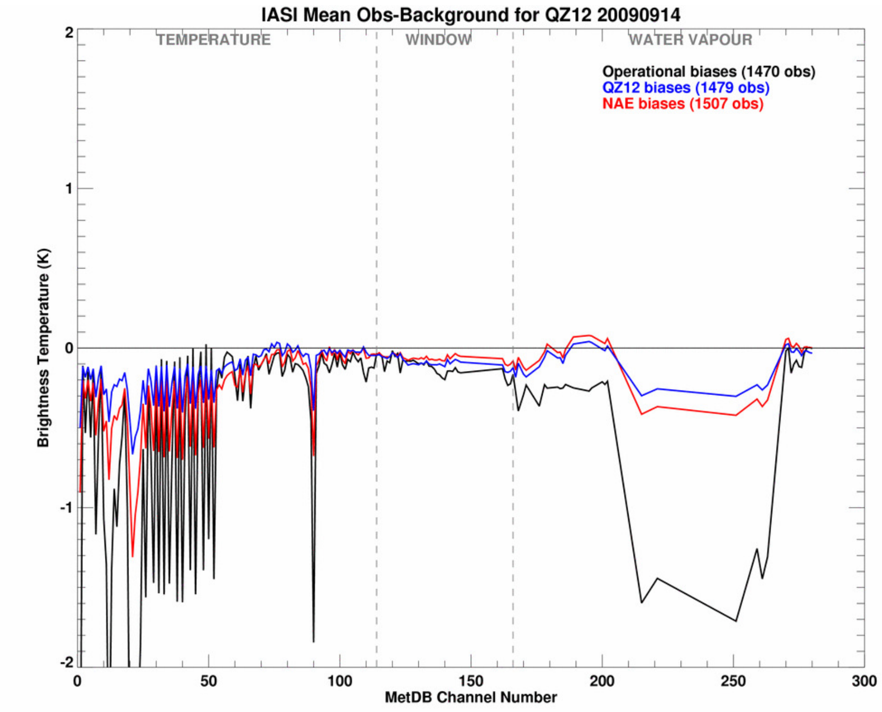


Figure 23: Mean C-B for QZ12. The number of observations in each run is indicated. “MetDB Channel Numbers” are channel numbers within the 314 channel set. Only those channels used in 1D-Var are plotted.

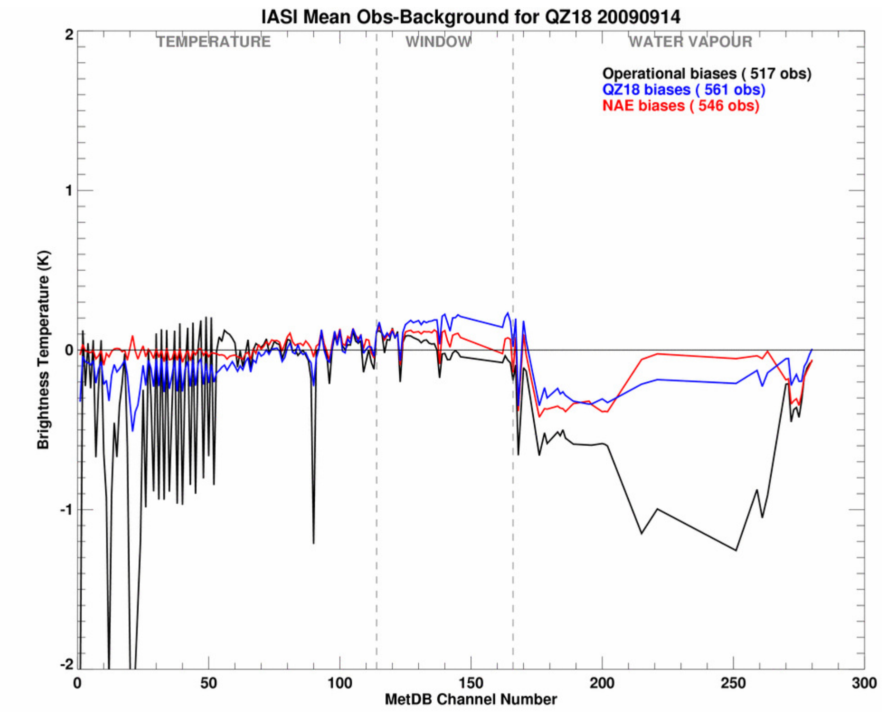


Figure 24: Mean C-B for QZ18. The number of observations in each run is indicated. “MetDB Channel Numbers” are channel numbers within the 314 channel set. Only those channels used in 1D-Var are plotted.

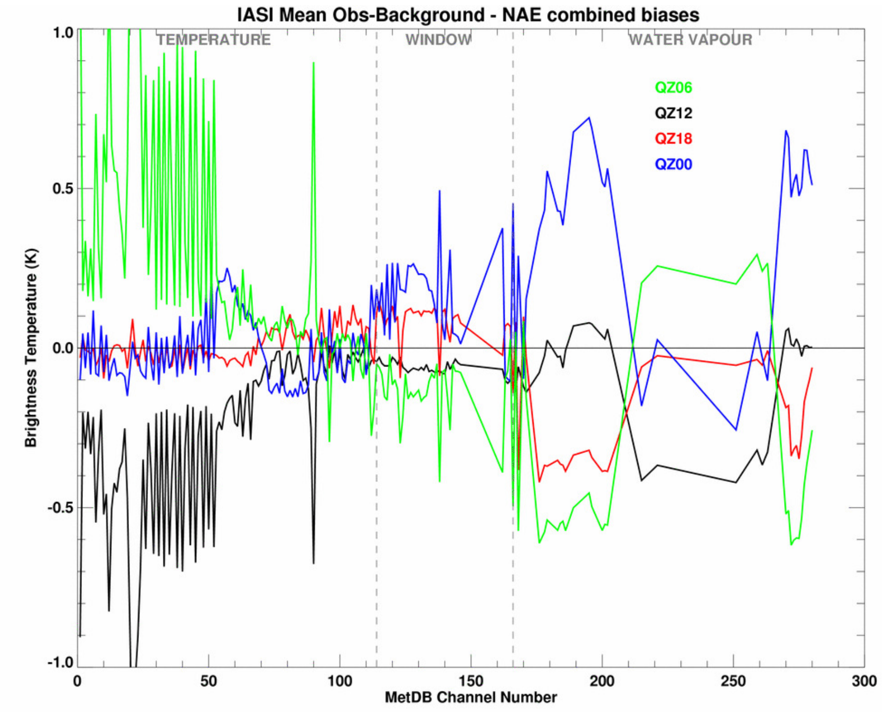


Figure 25: Residual bias by cycle. All bias corrections calculated by aggregating statistics for all cycles from NAE runs.

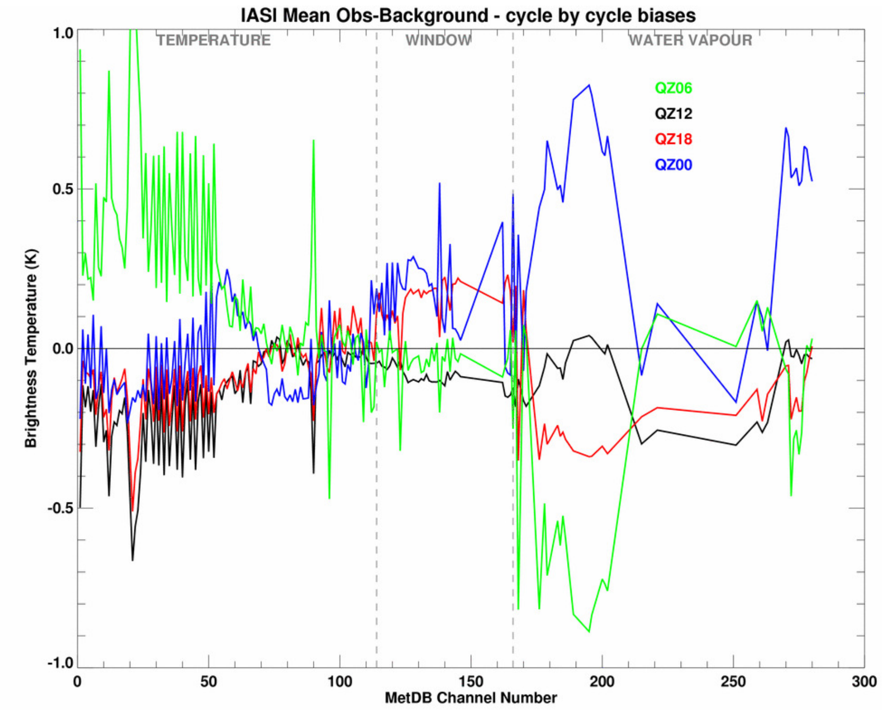


Figure 26: Residual bias by cycle. Bias corrections calculated using statistics for each NAE cycle separately.

Concluding remarks

Regarding the study on NAE domain

Whilst it is generally recommended to aggregate together much more data to generate stable bias corrections, the study is quite promising in terms of being able to use a relatively small amount of NAE data to generate some fairly sensible bias corrections. Further experiments are required to determine whether biases are best calculated separately for each cycle, or whether the statistics from all cycles should be aggregated. Due to the limited extent of the testing performed in this study, further tests would be required to show whether there was any general improvement in cycle-by-cycle biases when calculating statistics separately for each run, and indeed whether such an improvement led to improved forecast performance.

Regarding the study on the HARMONIE/Norway domain

It has been shown in (Randriamampianina and Storto, 2008) that doing daily update of the bias correction coefficients at each assimilation time lead to the improvement of the impact of radiances assimilated in the HARMONIE system. Doing so, we exclude the effect of diurnal temperature variation, especially for channels with peaks in the lower troposphere. Despite of observing some error growth in the troposphere during the set up of the radiance assimilation over the larger HARMONIE domain, our short trial seems to approve that updating the bias correction coefficients separately for each assimilation network (cycle-by-cycle) is the most appropriate way for LAMs. Nevertheless, it is recommended to extend the monitoring of the usage of radiance observations over different surface types (high/low land, open sea and sea ice), as well as under different cloud conditions, for a better data selection and usage.

It has been decided to perform two seasonal trials (winter and summer) with both the NAE and the HARMONIE LAMs to estimate the impact of different ways of updating the bias correction coefficients on the analyses and forecasts performance.

Acknowledgements

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