DEVELOPMENTS IN THE USE OF ATOVS DATA AT ECMWF

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Abstract

Data from the ATOVS suite of instruments continues to contribute substantially to the skill of today's numerical weather forecasts. With NOAA-19 as the latest addition, ATOVS data from up to seven satellites is currently available. Here we report on the introduction of NOAA-19 data, with a summary of the early monitoring experience and results from assimilation trials. Also, estimates are provided for observation errors and their spatial and inter-channel error correlations, forming the first step towards a review of observation error or thinning scale choices.

INTRODUCTION

Maintenance and further development of the use of ATOVS data at ECMWF is an ongoing task. In the first part of the paper, we summarise the experience from monitoring and adding NOAA-19 ATOVS data to the operational assimilation system. In the second part of this contribution we summarise first steps to revise choices for observation error or thinning scales, giving estimates for observation errors and their spatial and inter-channel correlations. Other developments in the use of ATOVS data are an improved use of surface-sensitive microwave radiances (Krzeminski et al. 2009a) and the revision of the cloud detection for HIRS (Krzeminski et al. 2009b). In addition, totally overcast radiances from HIRS are now actively assimilated (McNally 2009; see also in these proceedings).

NOAA-19

NOAA-19 was launched successfully on 6 February 2009 as the latest and last satellite in the NOAA-series of polar orbiting satellites, carrying the ATOVS suite of instruments (AMSU-A, MHS, HIRS-4) and a SBUV instrument. NOAA-19 takes over from NOAA-18 as NOAA's primary afternoon satellite, and it becomes the seventh satellite with some ATOVS instruments currently considered for assimilation at ECMWF. There are now three satellites with fairly similar orbital characteristics: NOAA-19, NOAA-18, and Aqua, and particularly for AMSU-A the early afternoon orbit is well covered.

Monitoring and cross-validation

NOAA-19 ATOVS data have been monitored in operations at ECMWF since 7 April 2009 for clear-sky conditions. In the following, bias corrections are based on the variational bias correction (VarBC, Dee 2004), and the bias coefficients were spun up for two weeks for the statistics presented here.

AMSU-A

The initial quality control applied to NOAA-19 AMSU-A data is as for all other AMSU-A data, that is, channels 5-14 are considered for assimilation, with channels 5 and 6 rejected over land over higher orography. Lower tropospheric channels are rejected over sea when the First Guess (FG) departure for channel 3 exceeds 3 K to avoid regions with a strong cloud or rain signal (a FG-departure threshold of 0.7 K on channel 4 is used over land). Additional checks for scattering signatures are also performed. The outermost three fields of view (FOVs) of each scanline are rejected. The variational bias correction uses a linear bias model with a constant and four layer-thicknesses as air-mass predictors, in addition to a 3rd-order polynomial in the scan position. The window channels 3 and 4 do not have an airmass-dependent component in the bias correction to reduce feedback with the quality control. Channel 14 is used without bias correction to anchor the stratospheric analysis.

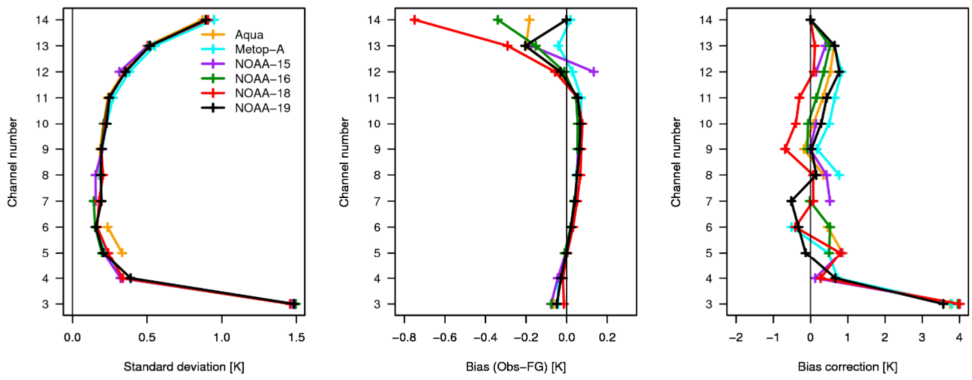

Figure 1: **Global FG-departure statistics for AMSU-A over sea for the satellites considered in the ECMWF system, in terms of the standard deviation of FG departures after bias correction (left), the mean residual observation-minus-FG bias after bias correction (middle), and the mean bias correction (right). For NOAA-19, statistics are based on passively monitored data after quality control, whereas for the other satellites statistics are shown for assimilated data or passive data that is used for quality control. Statistics are based on the 5-day period 21-25 April 2009 and they have been taken from the operational assimilation system.**

Figure 1 shows departure statistics for AMSU-A from NOAA-19 in comparison to similar statistics for other satellites currently assimilated at ECMWF. Overall, statistics for NOAA-19 agree well with those from other satellites, with standard deviations, bias corrections, and residual biases after bias correction within the range of what has so far been acceptable for assimilation. A hint of a poorer performance can be seen for channel 7 for which standard deviations are slightly poorer than those from NOAA-15, -16, and -18. This can be traced back to more rugged scan-bias characteristics which are not fully corrected for by using a 3rd order polynomial in the scan position (not shown).

MHS

The initial quality control applied to NOAA-19 MHS data is as for all other AMSU-B or MHS instruments: Channels 3 and 4 are used over sea and low orography, whereas the use of channel 5 is restricted to data over sea only. No data is used over sea ice. Cloud or rain affected data are rejected when FG departures for channel 2 exceed 5 K. The outermost 9 scan positions on either side are also not considered for assimilation. Channels 3-5 use the variational bias correction with the same bias model as for the sounding channels of AMSU-A, whereas only a constant offset and a 3rd order polynomial in the scan position is used for channel 2.

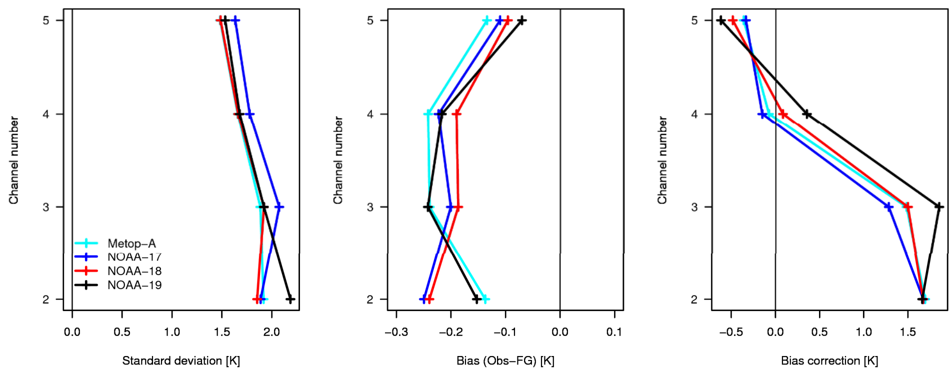

Figure 2: **As Fig. 1, but for AMSU-B or MHS instruments. NOAA-17 carries an AMSU-B instrument, whereas all other satellites have a MHS instrument. NOAA-19 MHS statistics are based on passively monitored data after quality control, whereas for the other instruments statistics are based on used data or passive data used for quality control.**

Figure 2 shows departure statistics for NOAA-19 MHS in comparison to statistics for similar instruments currently assimilated at ECMWF. Standard deviations of FG departures and residual biases after bias correction for channels 3-5 are comparable to other MHS instruments. Note that bias corrections for channel 3 and 4 are slightly larger than for earlier MHSs; this has been traced back at EUMETSAT to a suboptimal antenna pattern correction (esp. for channel 1, not shown here; Jörg Ackermann, pers. communication), and an update was introduced in the dataset used by ECMWF on 23 June 2009. The FG-departure statistics also highlight again the superior performance of the MHS instruments compared to the single remaining AMSU-B instrument onboard NOAA-17.

HIRS

The initial quality control applied to NOAA-19 HIRS data is the same as for all other HIRS instruments currently assimilated. Channels 4-7, 11, 14, and 15 are assimilated over sea, whereas channel 12 is used over sea and land areas with low orography. Cloud screening has recently been revised and is based on checks of the FG departures and their spectral gradients to identify clear channels (Krzeminski et al., 2009b). The three outermost scan positions on either side in each scan are excluded. The models used in the variational bias correction for HIRS are based on the same approach as for AMSU-A, with an added predictor that is zero during night-time and the cosine of the solar zenith angle during daytime for channels 14 and 15 (Bormann et al. 2008).

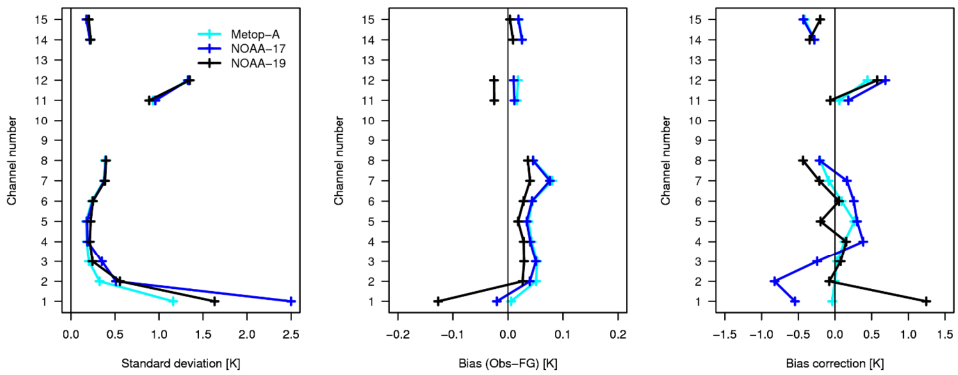

Figure 3: **As Fig. 1, but for the HIRS instruments. For NOAA-19, statistics are based on passively monitored data after quality control, whereas for the other instruments statistics are based on used data or data used in the quality control.**

Global FG-departure statistics for NOAA-19 HIRS indicate a good performance for the channels assimilated in the ECMWF system. Standard deviations, residual biases after bias correction, and bias corrections are within what has been found for other HIRS instruments (Fig. 3). The stratospheric HIRS channels (1-3) show somewhat larger noise than the same channels for the METOP-A HIRS-4 instrument. In ECMWF's operational system, these channels are not assimilated, but they nevertheless enter the cloud detection algorithm. In any case, the global departure statistics are still better than those for the HIRS-3 instrument on NOAA-17, an older version of the HIRS instrument.

Assimilation experiments

The forecast impact of NOAA-19 ATOVS data has been assessed in assimilation experiments. Two experiments were performed: the control experiment uses the current set of observations, whereas in the NOAA-19 experiment AMSU-A, MHS, and HIRS data from NOAA-19 were added as sixth AMSU-A, fourth AMSU-B/MHS, and third HIRS instrument. Both assimilation experiments used 12-hour 4-dimensional variational data assimilation (4DVAR), with a model resolution of T255 (~80 km), an incremental analysis resolution of T159 (~125 km), and 91 levels in the vertical up to 0.01 hPa. The experiments cover the period 28 March - 26 May 2009. Coefficients for the variational bias correction for the new sensors were spun up for four days prior to the experimentation period.

The forecast impact of NOAA-19 ATOVS data is neutral or slightly positive for geopotential, wind, and relative humidity. For the Northern Hemisphere, the reduction in forecast error for the geopotential is statistically significant at the 90 % level for most forecast ranges (Fig. 4). Similarly statistically significant improvements can be reported for wind scores over the Northern Hemisphere whereas humidity gives overall more neutral results (not shown).

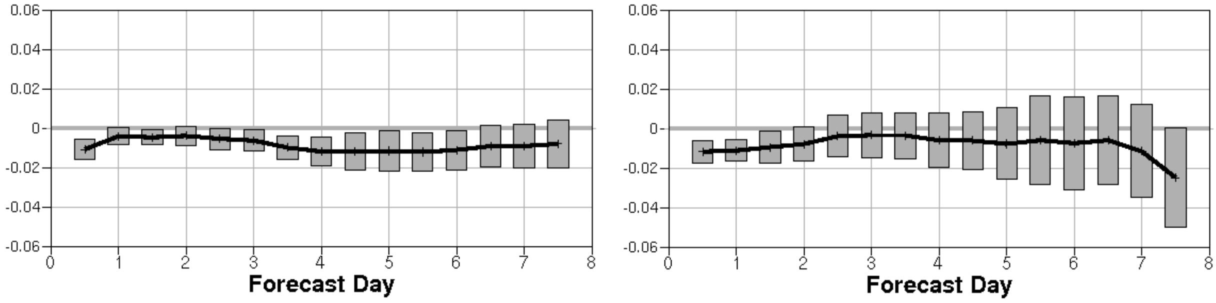

Figure 4: **Normalised differences in the root mean squared forecast error between the NOAA-19 experiment and the control for the 0 Z forecast of the 500 hPa geopotential for the Northern Hemisphere (left) and the Southern Hemisphere (right). Verification is against the own analysis, and the period is 28 March - 18 May 2009 (52 cases). Error bars indicate 90 % significance intervals from a t-test. Negative numbers show a reduction in forecast error and therefore a positive forecast impact as a result of the introduction of NOAA-19 data.**

Conclusions

NOAA-19 ATOVS data have been evaluated in terms of FG-departure statistics in comparison to other ATOVS instruments from other platforms, and in terms of forecast impact in assimilation experiments. Overall, NOAA-19 ATOVS data show characteristics that are broadly in line with expectations. In our assimilation trials, NOAA-19 ATOVS data give a small positive forecast impact over the Northern Hemisphere when added as sixth AMSU-A, fourth AMSU-B/MHS, and third HIRS instrument. It is remarkable that a small positive forecast impact is found despite the presence of so many similar instruments in the assimilation. NOAA-19 ATOVS data is assimilated operationally at ECMWF since 2 June 2009.

Since the introduction of NOAA-19 data into operations at ECMWF, channels 3 and 4 of the NOAA-19 MHS showed a deteriorating noise performance, prompting the removal of the instrument from the operational assimilation on 4 August 2009. Also, the NOAA-18 and NOAA-19 orbits have drifted so close together that at the time of writing the two largely overlap, and only NOAA-19 data is currently used in the ECMWF system. The current proximity of the two orbits is a somewhat suboptimal use of the resources of the two satellites.

ESTIMATION OF OBSERVATION ERRORS

We will now summarise results of a study aimed at estimating observation errors and their correlations for clear-sky radiances used in the ECMWF system. The assumed observation error covariances, together with assumed background error covariances, play an important role in determining the weight of a given observation in data assimilation systems. For technical or computational reasons, observation error covariance matrices used in data assimilation systems are mostly assumed to be diagonal. Estimation of observation errors is seen as a first step towards refining the observation error and thinning scale choices, or, alternatively, to provide input to take such error correlations explicitly into account in the assimilation. We have only space for a brief summary here; for more details the reader is referred to Bormann et al. (2009).

Data and methods

The statistics presented here are based on FG and analysis departures for pairs of observations for the respective instruments. The observations in each pair are required to be less than 1 h apart (i.e., within one orbit) and originate from the same instrument on the same satellite. The pairs of observations were binned by separation distance to calculate isotropic spatial covariance statistics as a function of separation distance. The results are based on data for the 21-day period 22 August - 11 September 2008. The assimilation experiment employed 4DVAR with a 12-hour observation window, a model resolution of T799 (~25 km), an incremental analysis resolution of T255 (~80 km), and 91 levels in the vertical up to 0.01 hPa. The experiment used a thinning scale of 60 km, approximately half the operational thinning scale.

The methods used to estimate the observation errors are the Hollingsworth/Lönnberg method (Hollingsworth and Lönnberg 1986), the consistency diagnostic provided by Desroziers et al. (2005), and a method based on subtracting a scaled version of the assumed background error, mapped into radiance space. The Hollingsworth/Lönnberg method assumes that true background errors are spatially correlated, whereas observation errors are not. It may therefore give misleading results for channels with significant spatial error correlations. The Desroziers diagnostic assumes that assimilation systems can be approximated by linear estimation theory; if the observation weights are consistent with true weights, a consistency diagnostic for the observation error covariance $\mathbf{R}$ and the background error covariance $\mathbf{B}$ in observation space is given by:

$$\tilde{\mathbf{R}} = E\left[\mathbf{d}_a\ \mathbf{d}_b^T\right]$$
$$\mathbf{H}\tilde{\mathbf{B}}\mathbf{H}^T = E\left[\mathbf{d}_b\ \mathbf{d}_b^T\right] - E\left[\mathbf{d}_a\ \mathbf{d}_b^T\right]$$

Here, $\mathbf{d}_b$ and $\mathbf{d}_a$ are FG- and analysis departures respectively, $\mathbf{H}$ the tangent linear of the observation operator and E[] is the expectation operator. The last method uses a spatial representation of the FG error covariances in radiance space, calculated by randomisation from the assumed background errors. If these mapped background errors are too large compared to the FG-departure covariances, a scaling factor is introduced, using the assumption that background errors dominate FG departure covariances for longer separation distances. The method will be referred to as "background error method". All three methods assume no correlations between FG errors and observation errors.

The methods are based on spatial FG or analysis departure covariances, calculated from the database of pairs of observations introduced above. The departures are taken after the variational bias correction (e.g., Dee 2004). We only consider FOVs for which all channels currently considered for assimilation are used in the assimilation system. The quality control and bias correction procedures are as described in the NOAA-19 section. Further details on the methods employed here and the assumptions inherent in these methods are given in Bormann et al. (2009).

Results

The observation error analysis has been performed for AMSU-A, HIRS, and MHS, as well as for AIRS and IASI. Here, we summarise only the results for AMSU-A and MHS over sea; for further details and results, the reader is referred to Bormann et al. (2009).

AMSU-A

Figure 5 shows estimates of the spatial error correlations for AMSU-A observations. The two estimates are fairly consistent and give relatively small spatial error correlations for AMSU-A for separations larger than the thinning scales currently used at ECMWF. For the current operational thinning scale of 125 km, the correlations are at or below 0.2 for all channels. Channels 5 and 6 have slightly higher correlations at shorter separation distances, but they are still relatively small (less than 0.3). Channels 5 and 6 have some sensitivity to the surface and to thick clouds and rain, and these aspects may lead to higher spatial error correlations, for instance, through the surface emission, undetected cloud or rain, or the quality control applied.

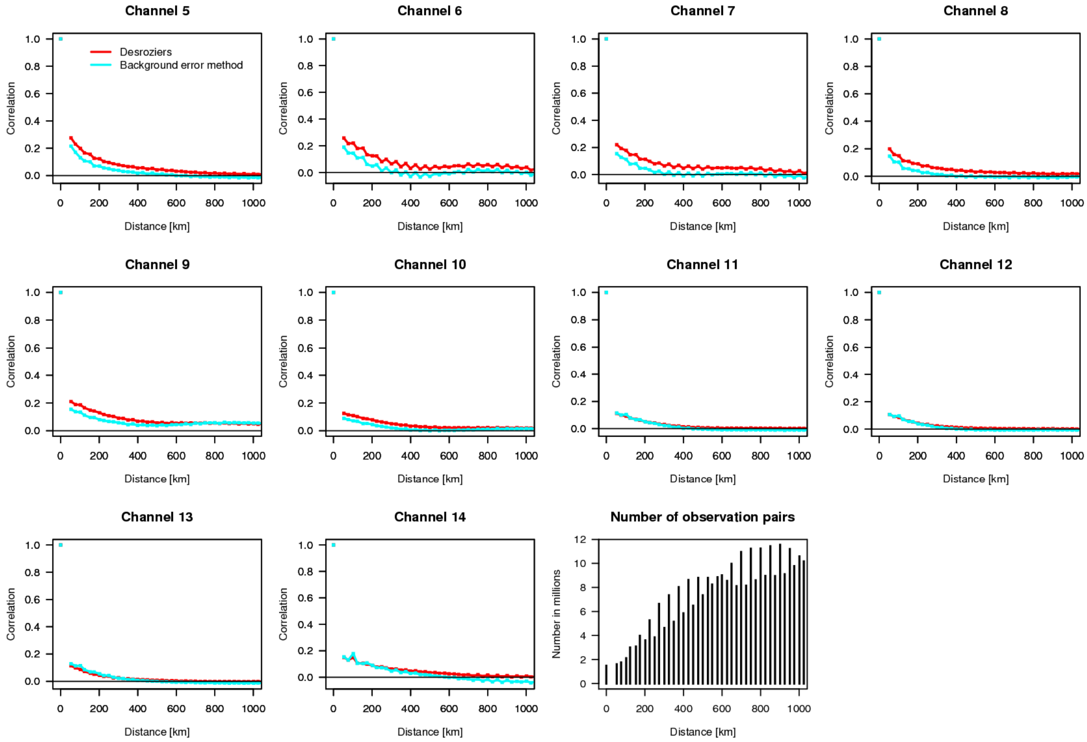

Figure 5: **Estimates of spatial error correlations as a function of separation distance for NOAA-18 AMSU-A for the channels used at ECMWF. The estimates are based on Desroziers' diagnostic (red) and the background error method (cyan). The number of collocations as a function of separation distance is shown in the last panel.**

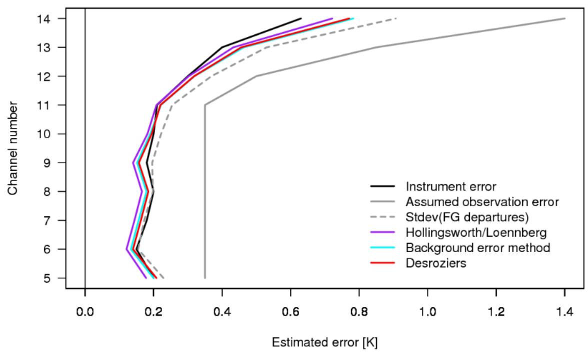

Figure 6: **Estimates of observation errors for NOAA-18 AMSU-A channels used in the ECMWF system. The estimates are based on the measured in-flight instrument error (black), the observation error assumed in ECMWF's assimilation system (grey), the Hollingsworth/Lönnberg method (purple, calculated from the difference in FG-departure covariances at 0 km and 50 km separation), the background error method (cyan), and Desroziers' diagnostic (red). Also shown are the standard deviations of FG departures (dashed grey).**

Estimates of observation errors from the three methods are in good agreement (Fig. 6), with values of less than 0.2 K for channels 5-10. For these channels, the estimates of the observation error are at or below the mean measured instrument noise. This is most likely due to sampling and quality control. The finding suggests that the radiative transfer error for these channels is relatively small, at least after applying the bias correction used in the ECMWF system. The three estimates of observation error are much smaller than what is currently assumed as observation error in the ECMWF assimilation system, typically by about 40 %.

There is little evidence of inter-channel error correlations for AMSU-A (not shown). The three methods consistently give correlations of less than 0.2 between any channels. The largest error correlations are found for Desroziers' diagnostic, up to 0.13 between channels 5 and 6 and channels 6 and 7.

MHS

For MHS, estimation of observation errors is more difficult, partly because FG-departure variances are dominated by background errors for these humidity-sounding channels, and their spatial correlation scales are also sharper.

For short separations (<200 km), the estimates of spatial observation error correlations for MHS are significantly larger than those obtained for AMSU-A (Fig. 7). Even though there are considerable differences between the two estimates shown, both indicate correlations close to or above 0.2 for some channels for separations of less than 140 km, the thinning scale currently used for MHS in the operational ECMWF system. The estimates of spatial observation error correlations partly reflect aspects of representativeness. The analysis increments in the incremental assimilation system used here and the mapped background error estimates are calculated at a resolution of T255 (~80 km), much coarser than the MHS FOV of 16 km (at nadir) and coarser than the model resolution of T799 (~25 km).

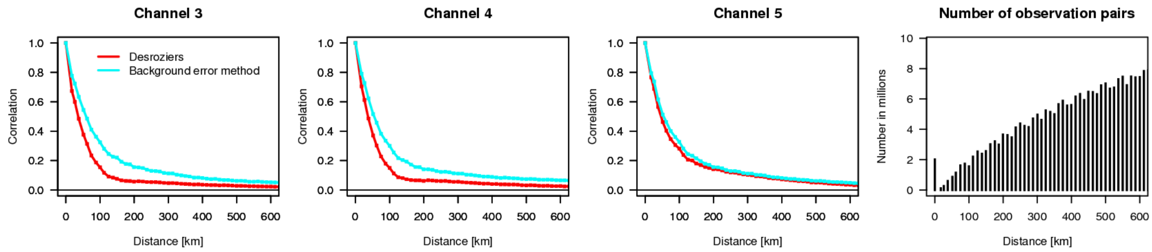

Figure 7: **As Fig. 5, but for MHS on METOP-A with a binning interval of 12.5 km. Estimates for the observation error correlations from subtracting values for the mapped background error covariances from the FG-departure covariances are based on unscaled values. Note also the smaller range of separation distances shown compared to AMSU-A.**

Figure 8 gives estimates for the observation error for MHS. There is considerable variation between them, reflecting the difficulties mentioned earlier. The estimates from the Hollingsworth/Lönnberg method give the lowest values, as they explicitly neglect any spatial correlations in the observation error. The other two methods provide estimates that are considerably larger than the instrument noise.

Estimates for inter-channel error correlations are shown in Fig. 9. There is some spread in the estimates for the error correlations, but all three methods employed here show significant inter-channel error correlations, in the range of 0.4-0.8 for neighbouring channels.

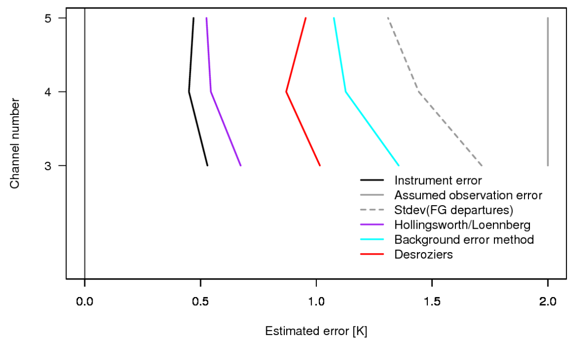

Figure 8: **As Fig. 6, but for MHS on METOP-A. Estimates for the Hollingsworth/Lönnberg method are based on subtracting the FG-departure covariances from the 12.5 km bin (covering 6.25-18.75 km separations) from the FG-departure variances at zero separation. Estimates for the observation errors from subtracting values for the mapped assumed background error covariances from the FG-departure covariances are based on unscaled values.**

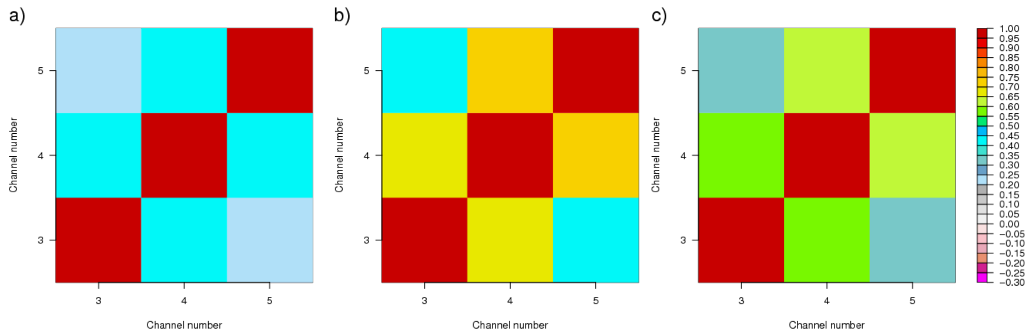

Figure 9: **Estimates of inter-channel error correlations for METOP-A MHS. a) Based on the Hollingsworth/Lönnberg method (calculated from the difference in FG-departure covariances at 0 km and 12.5 km separation). b) Based on subtracting the unscaled mapped background error covariance from the FG-departure covariance. c) Based on Desroziers' diagnostic.**

CONCLUSIONS

The present paper summarised some recent developments in the use of ATOVS data at ECMWF. The addition of NOAA-19 data showed a small positive forecast impact over the Northern Hemisphere over the chosen trial period. In addition, we summarised estimates of observation error characteristics from three methods. For AMSU-A, the statistics indicate relatively small inter-channel or spatial error correlations and observation errors that are smaller than the currently assumed diagonal observation errors. This suggests that the current use of AMSU-A data is fairly conservative, and may explain why adding further ATOVS data to the system (as in the case of NOAA-19) still results in a positive forecast impact. For MHS, some observation error correlations could be found, and some error inflation seems justified if the data is assimilated with the assumption of diagonal observation errors.

The observation error estimates will be used to revise observation error and thinning scale settings in the ECMWF assimilation system. It is not expected that the estimates are directly applicable, as the presence of residual biases, local effects, aspects of quality control or the background error specification may also need to be taken into account in practice.

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