

Towards a better use of AMSU over land at ECMWF

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Introduction

Assimilation of observed clear-sky brightness temperatures (BT) with variational methods requires calculation of their equivalent First Guess BTs. At ECMWF, they are calculated from 4DVar First Guess (FG) atmospheric profiles using the RTTOV radiative transfer (RT) code. In the case of surface sensitive channels, a good estimation of surface emission is needed for these RT calculations. Accurate microwave land emissivity models typically require input parameters describing surface characteristics, rarely available globally. As a compromise, simplified emissivity models are usually employed, resulting in the significant errors in the simulated BTs. Retrieving emissivities directly from the microwave window channel observations is currently being investigated at ECMWF as an alternative approach. Experiments have shown that using retrieved emissivities significantly reduces FG-departures over land for AMSU-A surface sensitive channels 1-5 and AMSU-B channel 2. This has a direct impact on the quality control of the other AMSU channels. Assimilating surface sensitive channels with the new emissivity scheme also seems to have positive impact on forecast skill. Other topics discussed here include changes to the bias correction and quality control procedures over land.

Current use of AMSU-A and -B over land at ECMWF

Clear-sky AMSU-A/B and MHS radiances are assimilated operationally in the IFS 4DVar system. Over land AMSU-A channels 5-14 have influence on the analysed atmospheric state. Channel 4 is not assimilated due to its strong sensitivity to the surface emission. For the same reason, channel 5 is used only over orography not exceeding 500m and the limit for channel 6 is 1500m. For AMSU-B (and MHS), only channels 3 and 4 are assimilated, both over low orography only.

AMSU observations are bias corrected prior to their assimilation. In the IFS system, an adaptive variational bias correction scheme (VarBC) is implemented (Auligné et al., 2007).

Bias corrected AMSU-A observations are subject to quality control, partly to eliminate cloud and rain contaminated observations in the tropospheric channels 5-7. These quality checks are based on the differences between observations and their clear-sky equivalents simulated from the IFS first guess atmospheric profiles (FG-departures). Channels 5-7 are rejected if the channel 4 FG-departure exceeds +/- 0.7 K. Rain contaminated observations are detected explicitly using the difference between 23.8 GHz and 89 GHz observations (scattering index). Differences larger than 3 K indicates the presence of rain.

The quality control for the AMSU-B channels 3 and 4 over land is done by applying a +/- 5K threshold test to the channel 2 FG-departures.

AMSU-A land surface emissivities are estimated using an algorithm described in detail in Kelly (2000). The method uses window channels 1, 2 and 3 to identify the surface type. Different emissivity models are then applied for different surfaces. In practice, for non-polar regions, more than 99% of locations are identified as "dry/wet land including vegetation" (statistics for November 2006) and the emissivity is computed with the regression formula:

$$\varepsilon = -4.119 \cdot 10^{-2} - 9.0916 \cdot 10^{-3} \cdot BT_{23GHz} + 1.2172 \cdot 10^{-2} \cdot BT_{31GHz} + 4.8851 \cdot 10^{-4} \cdot BT_{50GHz} \quad (1)$$

The land surface emissivity model for AMSU-B is a simple lookup table, representing four possible surface types (table 1). The surface type at a given location is classified using the IFS information about the surface temperature, soil moisture and snow cover.

Table 1: AMSU-B emissivity lookup table

surface type	emissivity
moist land	0.95
light snow	0.95
dry land	0.92
deep snow	0.80

The accuracy of the surface emissivity estimation is important for the assimilation of the tropospheric channels as well as for the performance of the QC tests that utilize window channel FG-departures. The currently used algorithms do not take into account variations of the emissivity with the scan angle and frequency. Additionally the emissivities from the regression formula display unrealistic diurnal tendencies. An alternative approach in which the land emissivities are retrieved directly from the window channel observations is currently under evaluation at ECMWF.

Dynamic emissivity retrievals

Brightness Temperature BT observed by the spaceborne instrument can be expressed as

$$BT_{obs} = \varepsilon T_s \Gamma + BT_{up} + \Gamma(1 - \varepsilon)BT_{down}$$

where T_s is the radiation emitted by the surface, ε is the surface emissivity, BT_{up} and BT_{down} are the atmospheric upwelling and down-welling radiances respectively and Γ is the atmospheric surface-to-space transmissivity. By rearranging the above equation, surface emissivity can be calculated:

$$\varepsilon = \frac{BT_{obs} - BT_{up} - BT_{down} \Gamma}{(T_s - BT_{down}) \Gamma}$$

This is under the assumption of the specular reflection from the surface (Karbou, 2005) and non-scattering plane parallel atmosphere.

The method was implemented at Météo France within the ARPEGE 4DVar system and later ported to the IFS 4DVar (Prigent et al., 2005). BT_{up} , BT_{down} and Γ are estimated with the RTTOV radiative transfer code from the IFS First Guess forecast profiles. A selected window channel provides the observed BT.

The retrieved emissivity is then used to estimate surface emission for the assimilation of the other AMSU surface sensitive channels over land. In our experiments we tried AMSU-A channel 2 (31.4 GHz) which has the smallest atmospheric contribution from all AMSU-A channels, and channel

3 (50.3 GHz) which should provide emissivity retrievals more representative of the other sounding channels around 50 GHz. For AMSU-B, channel 1 (89 GHz) retrievals were investigated. Figure 1 shows an emissivity map obtained by averaging the emissivities retrieved from 50.3 GHz observations.

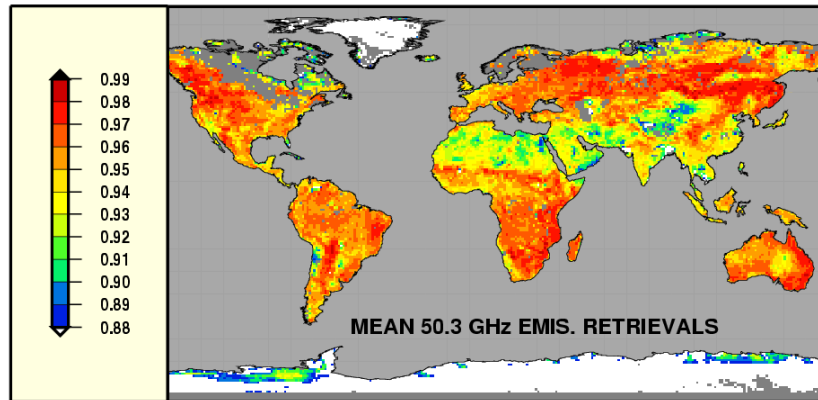


Fig.1: Emissivity retrievals averaged over 1 month (26 Sep 2006 - 26 Oct 2006). NOAA-16 AMSU-A channel 3 observations close to nadir were used for the retrievals.

Comparison with FASTEM emissivities

Retrieved emissivities were compared against FASTEM2 (Deblonde, 2000) over sea for clear-sky conditions. AMSU-A emissivities generally show a good correlation. The retrieval scheme occasionally gives higher emissivities than FASTEM - possibly due to the residual cloud or rain warm signal in the observations over the radiatively cold ocean background. AMSU-B emissivities are less consistent - they are sensitive to the errors in the water vapour profiles of the first guess forecast.

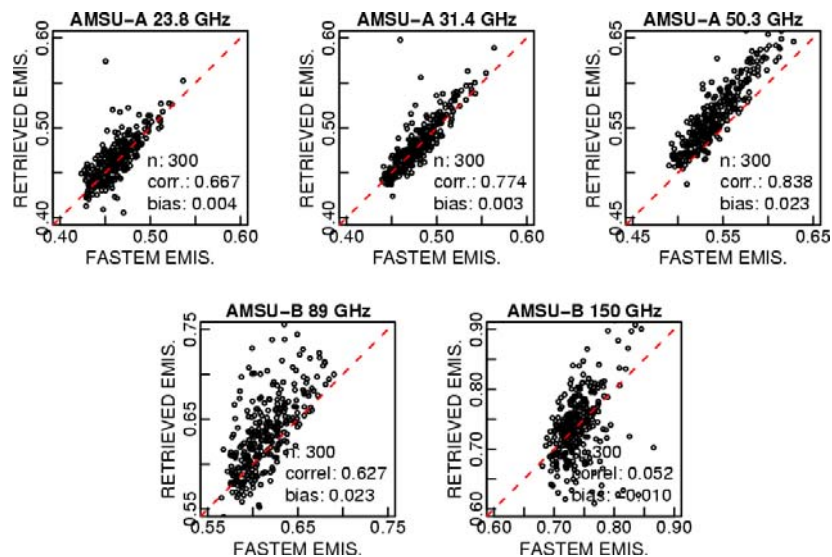


Fig.2: Comparison of FASTEM and retrieved ocean emissivities; A sample of NOAA-16 observations over sea after cloud/rain screening and collocated IFS first guess atmospheric profiles was used for the retrievals; emissivities retrieved from AMSU-A channels 1,2,3 and AMSU-B channels 1,2 are shown. A random sample of cases spans 2 days.

Changes in the bias correction

In the operational setup, biases in the FG-departures are corrected using the VarBC scheme. In the case of the AMSU instrument, this includes correction of the global mean bias followed by the removal of the scan angle dependent bias component. These corrections are applied globally, with no distinction between land and ocean areas. However, biases in the FG-departures of surface sensitive channels over land and water can have different characteristics as a result of using different emissivity models. As there is much more data available over ocean, it is expected to dominate the bias estimations. Indeed, operational bias correction removes bias over water (not shown) but significant residual biases can be observed over land for AMSU-A channel 4 (fig.3) and channel 5. It was therefore desirable to separate the bias correction over different areas.

It should be noted that using the retrieved emissivities already reduces the residual biases in the FG-departures over land (fig.3b,3c). Nevertheless a separate bias correction over land was tested and resulted in further reduction of the bias (fig.3d).

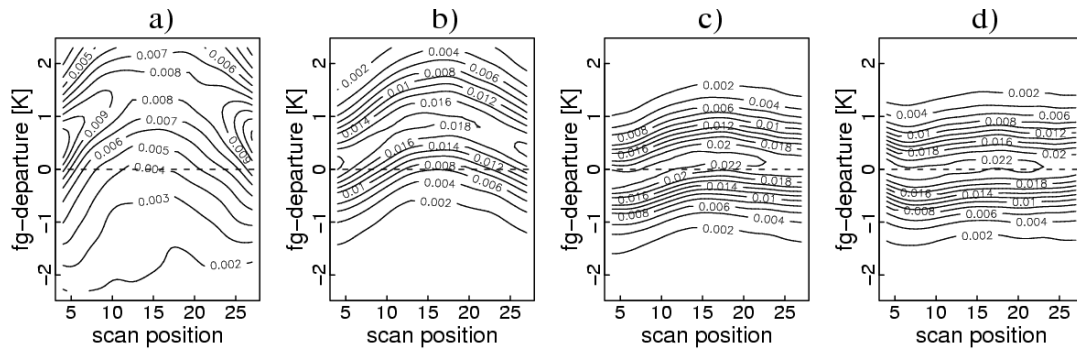


Fig. 3: Density distribution of the NOAA-16 AMSU-A channel 4 FG-departures for different scan positions. Data after the bias correction are shown. a) FG-departures over land with the operational emissivity scheme, b) FG-departures over land with 31.4 GHz retrieved emissivities, c) FG-departures over land calculated with 50.3 GHz retrieved emissivities, d) FG-departures over land calculated with 50.3 GHz emissivities and with separate bias correction applied.

Changes in the quality control

Cloud and rain contaminated AMSU observations should be excluded from the assimilation if the emission and scattering from the cloud water and ice particles is not modeled in the radiative transfer calculations. As described earlier, observations are screened by comparing them with the equivalent clear-sky First Guess BTs (FG-departure threshold test). Such tests work reasonably well to identify cloudy observations over water - they will be significantly “warmer” over the radiatively cold ocean background than the clear-sky First Guess BTs. However, over land, the clear-sky surface emission is typically very similar to the cloud emission making this type of cloud detection problematic (Huang, 1992).

In an attempt to improve the quality of the used data, an additional simple QC test was applied experimentally over land. AMSU-A channel 5-7 and AMSU-B channel 3-5 were excluded from the assimilation if the vertically integrated First Guess cloud liquid water exceeded 0.03 kg/m^2 within the FOV. AMSU-A channel 4 FG-departure threshold test was retained as a safety net but relaxed from ± 0.7 to $\pm 1.2 \text{ K}$ over land. AMSU-B FG-departure test remained unchanged.

Comparison of the QC performance with the METEOSAT images suggests improved cloud detection skill of the revised test (fig.4). The number of good quality data presented to the assimilation is significantly higher with the new emissivity and revised QC in use (fig.5)

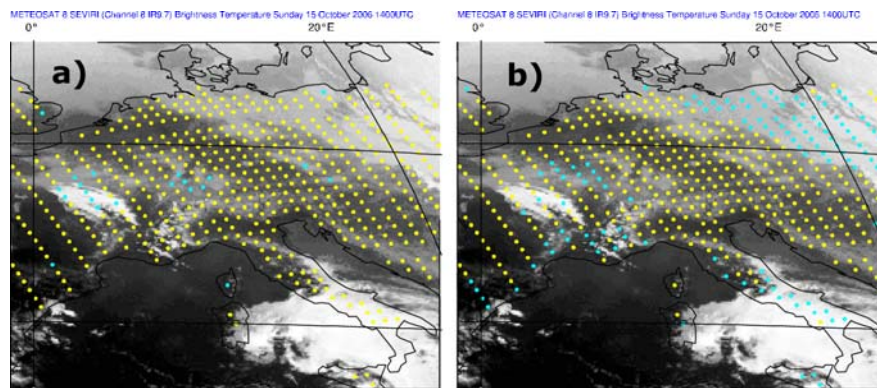


Fig.4: AMSU-A QC results validated against the METEOSAT-8 9.7 μ m images. Panel (a) shows the results of the old QC - some cloudy scenes are not detected by the +/- 0.7K channel 4 FG-departure test. The same scenes are correctly marked as cloudy (blue dots on the panel b) by the new First Guess liquid water content QC test. Emissivities retrieved from AMSU-A channel 3 observations were used in both cases.

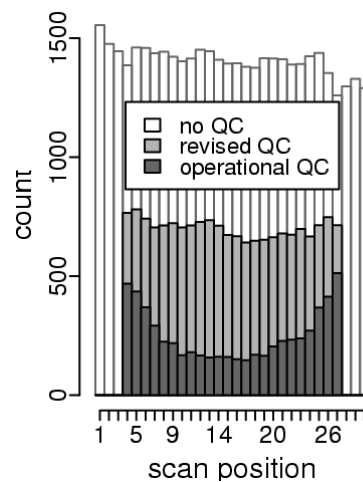


Fig.5: Number NOAA-16 AMSU-A of observations passing QC. The new emissivity scheme together with the revised quality control results in more observations passing the QC compared to the operational configuration. The strong residual scan bias in channel 4 FG-departures is responsible for large variations in the operational QC performance with the scan position. This effect is reduced with the revised QC and new emissivity scheme (emissivities were retrieved from 50.3 GHz observations).

Impact on the RT calculations

The dynamic emissivity retrievals result in the First Guess estimations of the observed BTs that are more consistent with the observations for the surface sensitive channels. FG-departures for AMSU-A channels 1-5 and AMSU-B channel 2 are reduced compared to the operations (fig.6).

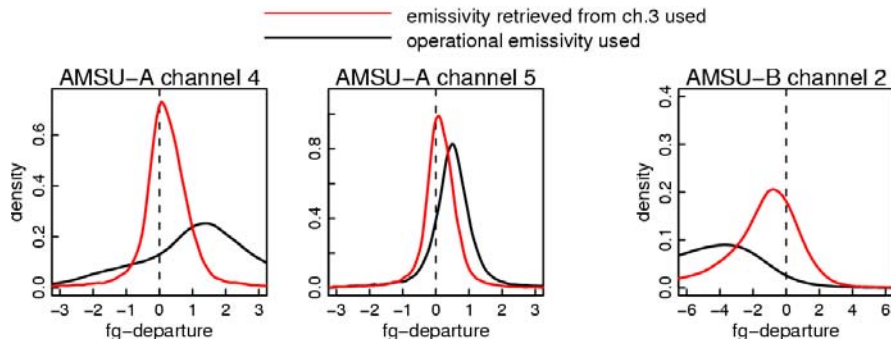


Fig.6: Normalized histograms of the FG-departures for NOAA-16 AMSU-A and -B surface sensitive channels for the operational and experimental emissivity scheme. AMSU-A channel 3 and AMSU-B channel 1 were used to retrieve emissivities.

One reason for the observed significant FG-departure variations are the diurnal tendencies in the operational land emissivity estimated with the regression formula (1). The day-night difference in the estimated emissivity is around 0.07, which translates to about 2K diurnal difference in the channel 4 FG-departures (fig.7). The new emissivity scheme removes these diurnal variations.

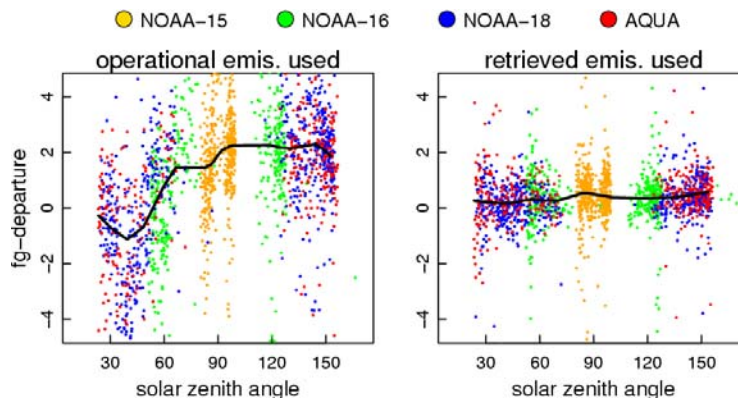


Fig.7: AMSU-A channel 4 FG-departures as a function of the solar zenith angle for the old and new emissivity scheme. Channel 3 was used on the second panel for the emissivity retrievals.

Impact on the forecasts

To assess the impact of the new emissivity scheme on the ECMWF forecast accuracy, a series of forecasts spanning a 2 month period, 26 Aug 2006 - 26 Oct 2006, was run. AMSU-A observations were assimilated with the emissivities estimated from either channel 2 or 3 (31.4 or 50.3 GHz respectively). For AMSU-B, channel 1 (89 GHz) was used for the emissivity retrievals. Response of the forecast system to the changes in the bias correction and quality control was also tested. Overall, all changes combined together resulted in the improved forecasts. Using 50.3 GHz emissivities for AMSU-A assimilation improves forecasts both over the northern and southern hemisphere for the first 3-4 days of the forecast (fig.8).

With the 31.4 GHz emissivities, impact over the northern hemisphere was neutral (not shown).

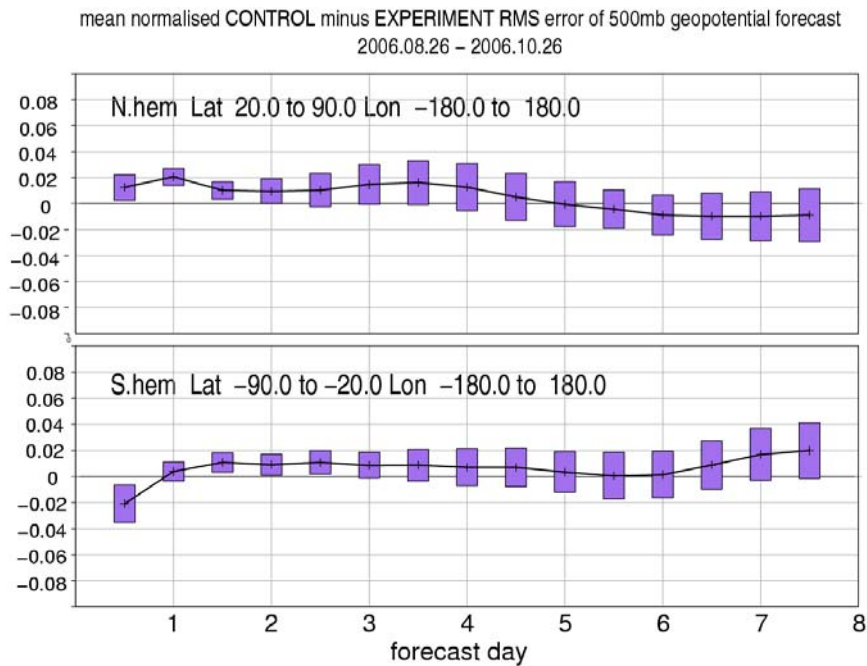


Fig.8: Normalized difference in 500mb geopotential RMS forecast error between the control and the experiment with revised emissivity, bias correction and QC schemes. Positive values mean smaller RMS errors in the experiment. A population of 62 forecasts was used to calculate the statistics (bars indicate 90% confidence level for the null-hypothesis that the RMS forecast errors of the two experiments were identical).

Summary and future work

Emissivity retrievals are a promising approach for the land emissivity estimation and have the advantage of being relatively simple to implement in the NWP model. Using the retrievals in the RT calculations of the First Guess brightness temperatures over land resulted in a significant reduction of noise and biases in the FG-departures of surface sensitive channels. Assimilation of these channels seems to improve the forecast accuracy.

Bias correction over land and ocean has been separated for the AMSU-A channels 4 and 5. As a result the residual bias over land for these channels has been significantly reduced.

Influence of the residual cloud contamination, errors in the atmospheric profiles and skin temperature on the quality of the emissivity retrievals should be addressed in the future. Time sequences of the emissivity estimations over the fixed geographical locations show high variability over short periods (not shown). Using the Kalman filter to reduce the random errors in the retrievals is currently being evaluated.

References

- Karbou, F., and C. Prigent, 2005: Calculation of microwave land surface emissivities from satellite observations: validity of the specular approximation over snow-free land surfaces. *IEEE Trans.Geosci. Remote Sensing Letters*, **2**, 3, 311-314
- Prigent, C., F. Chevallier, F. Karbou, P. Bauer and G. Kelly, 2005: AMSU-A surface emissivities for numerical weather prediction assimilation schemes, *Journal of Applied Meteorology*, **44**, 416-126

- Auligné, T., A.P. McNally and D. Dee, 2007: Adaptive bias correction for satellite data in a numerical weather prediction system. *Q.J.R.Meteorol.Soc.*, **133**, 631-642
- Kelly, G., and P. Bauer, 2000: The use of AMSU-A surface channels to obtain surface emissivity over land, snow and ice for numerical weather prediction. *In Proceedings of 11th International TOVS Study Conference*, 167-179, Budapest, Hungary.
- Huang, H.-L. And G. R. Diak, 1992: Retrieval of nonprecipitating liquid water cloud parameters from microwave data: A simulation study. *Journal of Atmospheric and Oceanic Technology*, **9**, 354-363
- Deblonde, G. and S. English, 2000: Evaluation of FASTEM and FASTEM2 fast microwave oceanic surface emissivity model. *Proceedings of the 11th International TOVS Study Conference*, 67-78, Budapest, Hungary.