Enhanced use of AMSU-A over land

Stu Newman and Bill Bell
Met Office, Exeter, UK

Contact
Stu Newman (stu.newman@metoffice.gov.uk)

Extending use of ATOVS data

ATOVS radiances have been assimilated directly into the Met Office 4D-Var system for some years, with demonstrable impact on forecast skill. However, to date the most extensive use of observations has been over ocean where the surface emissivity can be calculated to reasonable accuracy. Until now the higher-peaking AMSU-A temperature sounding channels 6-14 have been assimilated over land, while channels 4 and 5 have not due to their greater surface sensitivity (see Fig. 1).

It is essential to represent accurately the land surface emissivity at microwave frequencies in order to exploit AMSU-A channels 4 and 5 over land. We describe below the use of an emissivity atlas as a first-guess in the Met Office data assimilation system.
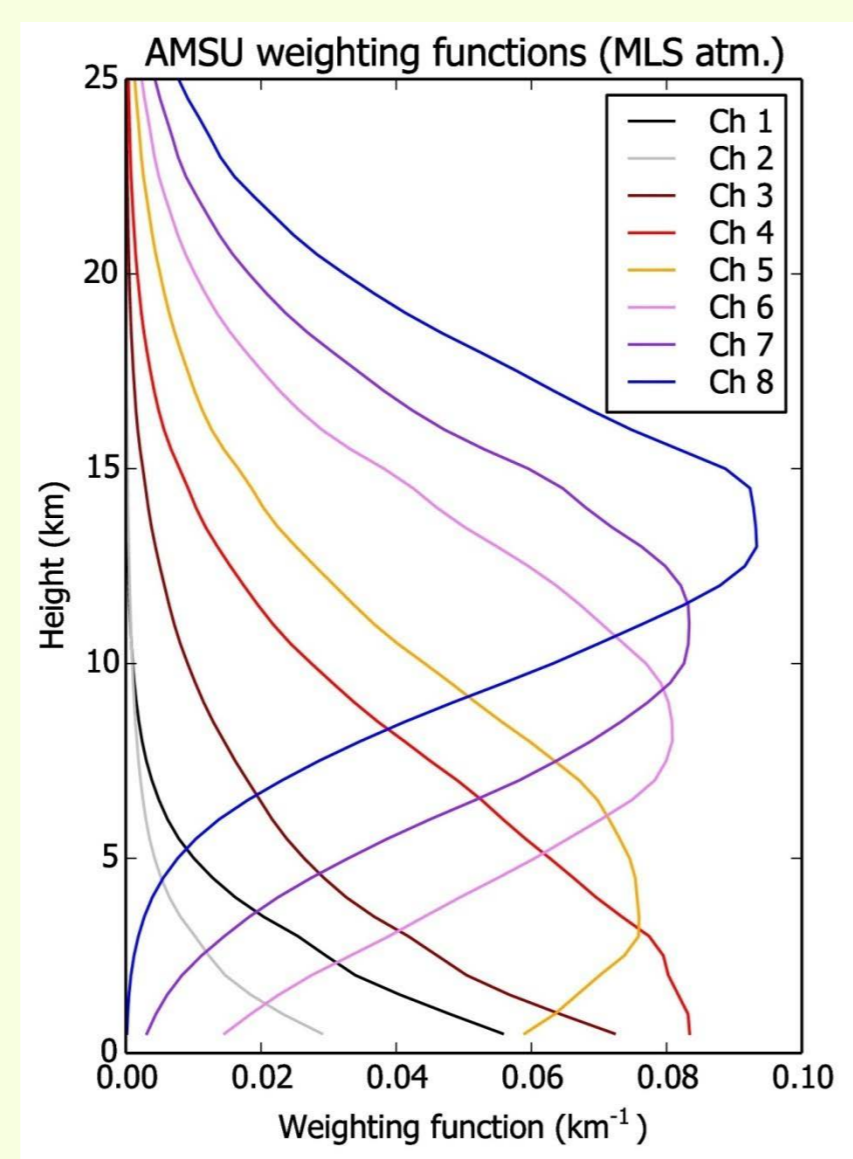

Fig. 1 Sample weighting functions (midlatitude summer atmosphere) for AMSU-A channels 1-8.

Emissivity atlas

The Met Office employs a 1D-Var pre-processor for quality control of satellite radiances and initial retrieval of state vector parameters. Here our approach is to retrieve simultaneously the emissivity over land for four surface-sensing AMSU channels at 23.8, 31.4, 50.3 and 89 GHz along with the surface skin temperature. As a background for the emissivity we use the atlas developed for AMSU-A (Karbou et al., 2005, see Fig. 2). The emissivity at 50.3 GHz is then used for the AMSU temperature sounding channels in the 52.8-57.3 GHz range.
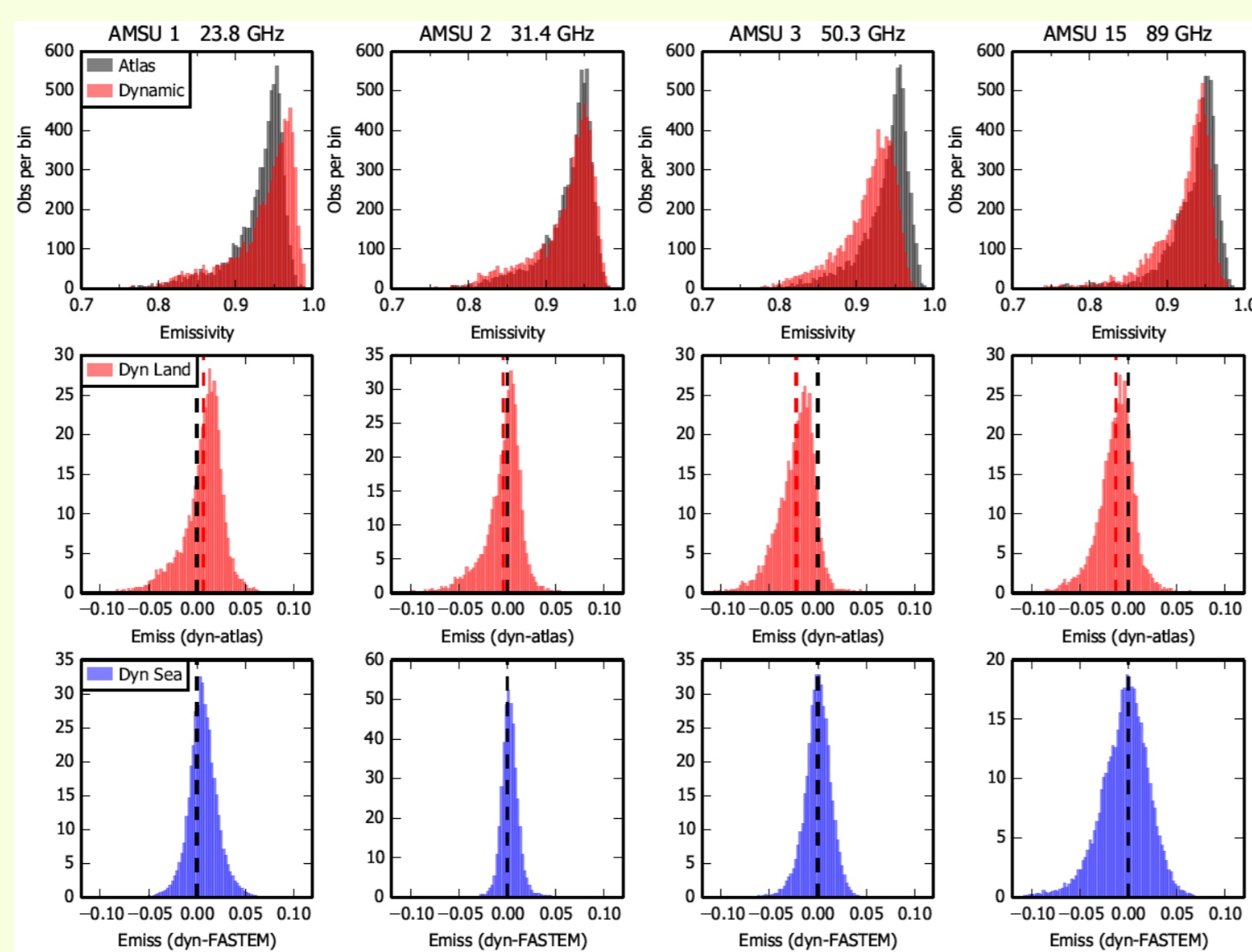

Fig. 2 AMSU-A channel 3 emissivity (50.3 GHz) for March, gridded at 0.25° spatial resolution according to the atlas of Karbou et al. (2005).

Studies aimed at validating the Karbou et al. atlas were performed within the 1D-Var framework. Given an estimate of the atmospheric state it is possible to invert the radiative transfer equation to derive a "dynamic" estimate of the emissivity ε (Eq. 1):

$$\varepsilon(v,\theta) = \frac{T_b(v,\theta) - T_a^\uparrow(v,\theta) - T_a^\downarrow(v,\theta)\Gamma(v,\theta)}{\{T_s - T_a^\downarrow(v,\theta)\}\Gamma(v,\theta)} \quad (1)$$

Here, as a function of frequency v and observation angle θ, T_b is the measured satellite brightness temperature, $T_a^\uparrow$ and $T_a^\downarrow$ are respectively the upwelling and downwelling atmospheric temperature terms at the surface, and Γ is the transmittance of the atmosphere. T_s is the surface skin temperature. All terms are derived from a short-range forecast of the Met Office global model. We restrict our validation to night-time scenes only, since a number of studies have demonstrated a poorer representation of model skin temperature during daytime.

Fig. 3 Validation of Karbou et al. (2005) emissivity atlas within a 1D-Var framework. Columns show data for each of AMSU-A channels 1, 2, 3 and 15. Top row: histograms of emissivity for selected clear-sky ATOVS observations over land, for atlas (grey) and dynamic retrieval (red). Middle row: difference between dynamic estimate and atlas (mean difference as vertical dashed red line). Bottom row: for comparison, difference over ocean between dynamic emissivity and FASTEM.

Fig. 3 shows aggregate data for several single cycle forecast experiments. The dynamic (RT inversion) emissivity correlates well with the atlas spatially, but some systematic differences between them are apparent. For example, on average the AMSU channel 3 dynamic estimate is approximately 0.02 lower than the atlas.

Uncertainties in the emissivity atlas are strongly dependent on location and season (see Fig. 4). We have extended the observation-dependent error model used for ATOVS at the Met Office to account for these uncertainties, so that observations with a poor first guess emissivity are assigned a higher observation error in the data assimilation according to the channel transmittance.
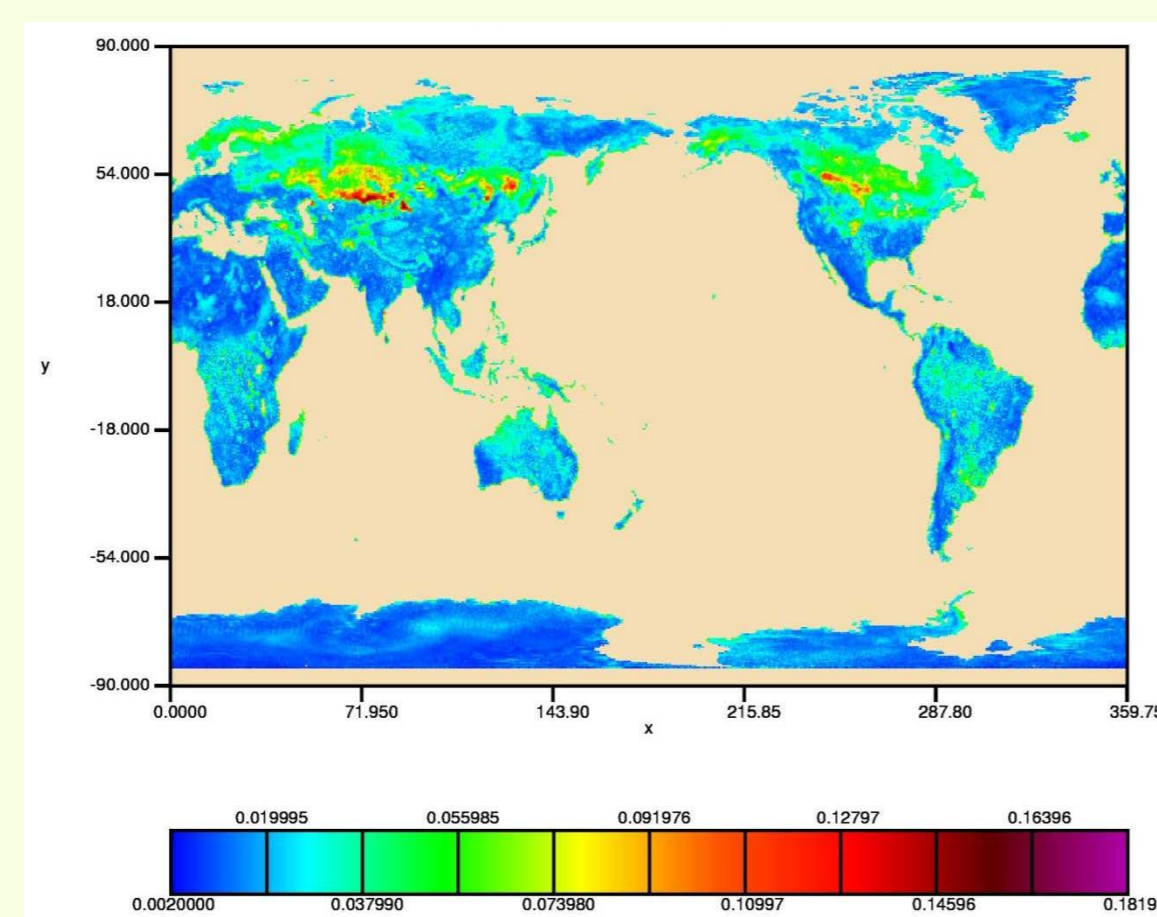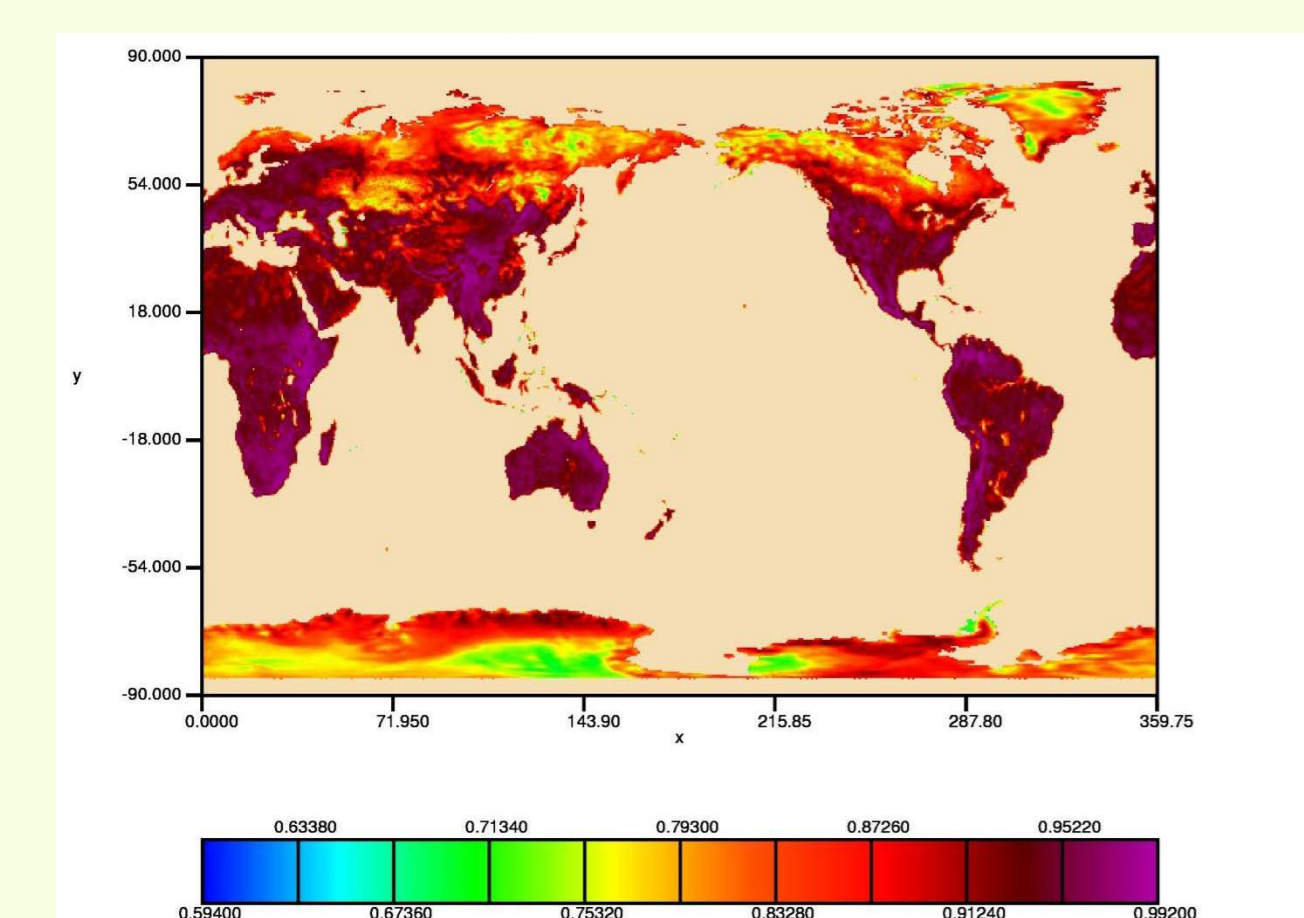

Fig. 4 Uncertainty in AMSU-A channel 3 emissivity for March, according to the atlas of Karbou et al (2005).

NWP assimilation trials

Retrievals of emissivity and skin temperature over land from 1D-Var are passed as fixed parameters to the full 4D-Var data assimilation (termed VAR at the Met Office). AMSU-A channels 6-14 are assimilated operationally over land (7-14 over high terrain). The additional assimilation of AMSU-A channels 4 & 5 has been tested within a global trial suite on top of the full observing system. The suite configuration was N320L70 Unified Model, N108-N216 VAR.

The trialling of this scheme was carried out in parallel to the introduction of variational bias correction (VarBC) for all the satellite sounding data. Fig. 5 illustrates the spin-up of VarBC parameters relative to a control: as expected, the total number of assimilated observations increases for AMSU-A channels 4 & 5, while the predictor coefficients gradually adjust to new stable values.
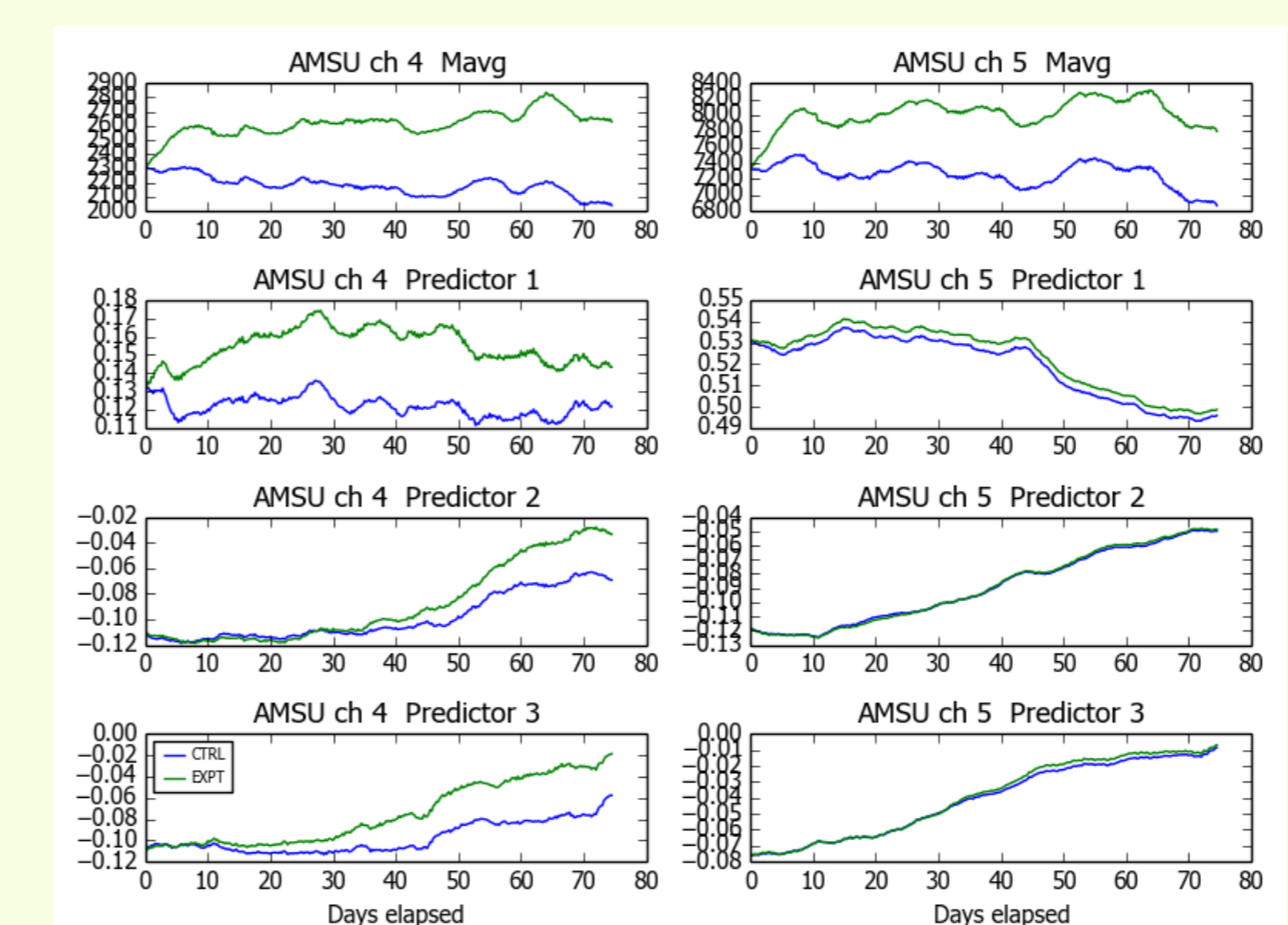

Fig. 5 Evolution of VarBC parameters for AMSU-A channels 4 (left) and 5 (right). The control is in blue, the trial with assimilation of AMSU 4 & 5 over land is in green. Top row: adaptive number of observations used by VarBC per channel each cycle; second row: VarBC predictor 1 (constant term); third row: predictor 2 (850-300 hPa thickness); fourth row: predictor 3 (200-50 hPa thickness). Time elapsed is days since 5 April 2015.

Results are presented here for a VarBC-enabled experiment spanning the period 5 April to 18 June 2015. Examination of background fits (first guess departures, O-B) shows that the experiment results in small but consistent reductions in O-B standard deviations for microwave channels peaking in the mid-troposphere (Figs. 6 and 7).
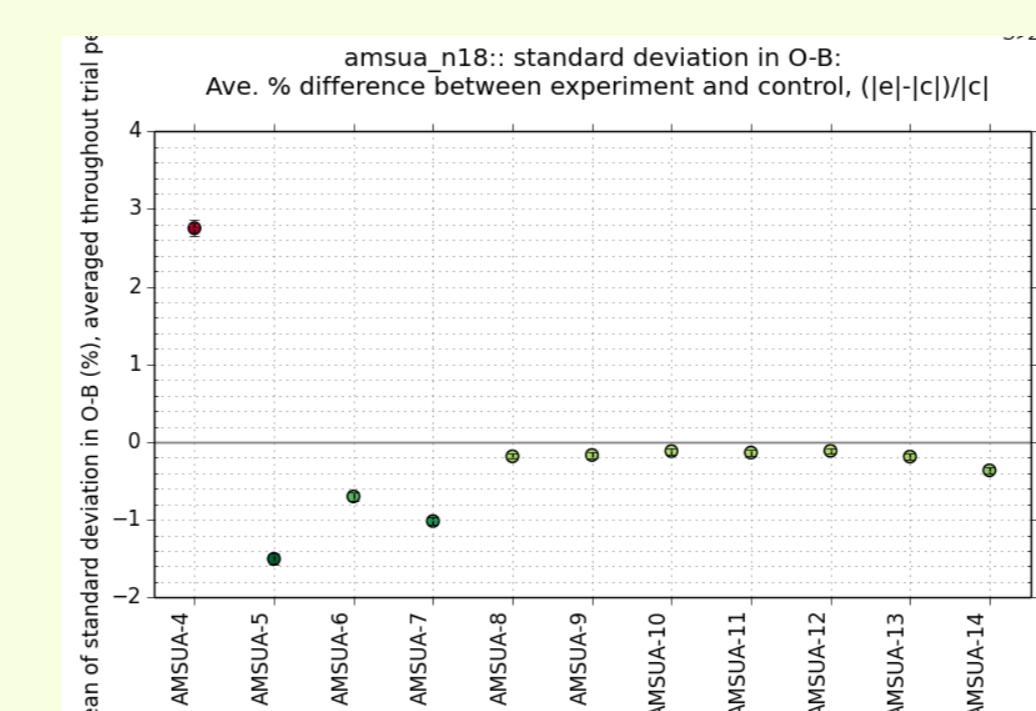

Fig. 6 Change in standard deviation of O-B for NOAA-18 AMSU-A channels for experiment relative to control, expressed as a percentage.
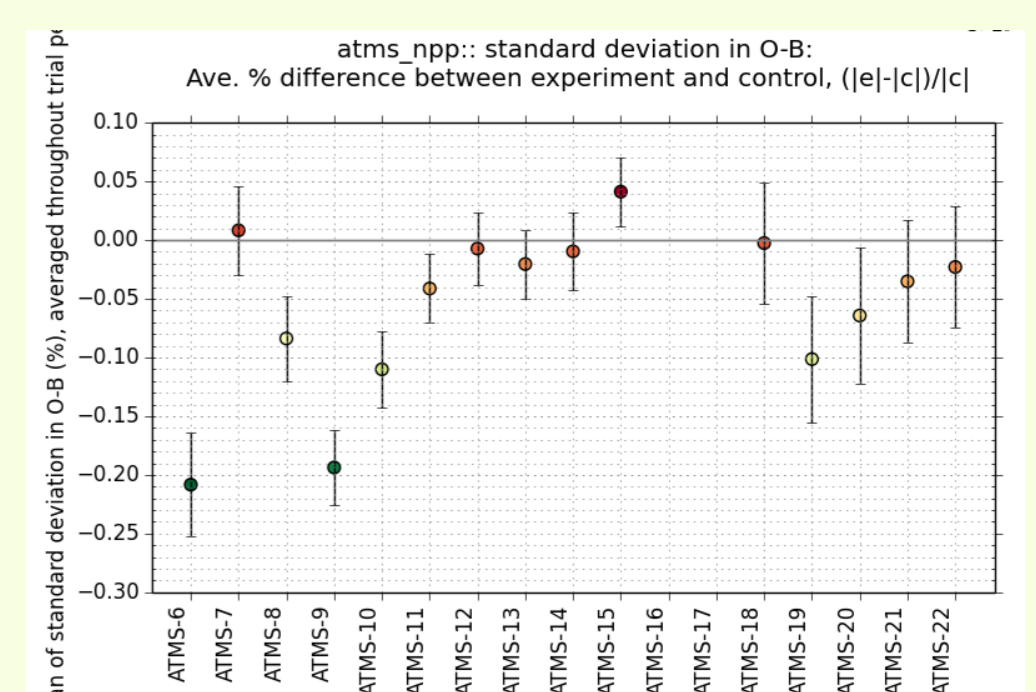

Fig. 7 Change in standard deviation of O-B for SNPP ATMS channels for experiment relative to control, expressed as a percentage.

The observation count for AMSU-A channels 4 & 5 is increased in the experiment by approximately 29% and 16% respectively for the statistics in Fig. 6, while other channel counts show small increases. The degraded background fits for AMSU channel 4 are likely due to assimilating more scenes over land where the background is less accurate than over ocean. The improved fits for ATMS (Fig. 7), though smaller in magnitude, are an independent measure because ATMS channels 5 and 6 remain unused over land. Statistics for the hyperspectral IR sounders show little benefit from the experiment.

The Met Office uses an NWP Index as a headline score for trial verification: the index is a weighted combination of skill scores for a basket of parameters. This experiment recorded an improvement of **+0.13** on the newer version of the NWP Index (against observations). For an older version of the index a slight degradation of **-0.10** was seen against observations, but an improvement of **+0.30** was recorded against analysis. Looking in more detail at the constituent parts of the NWP Index (Fig. 8) there are encouraging reductions in root mean squared error (RMSE) for short-range forecasts of fields such as 500 hPa geopotential height.
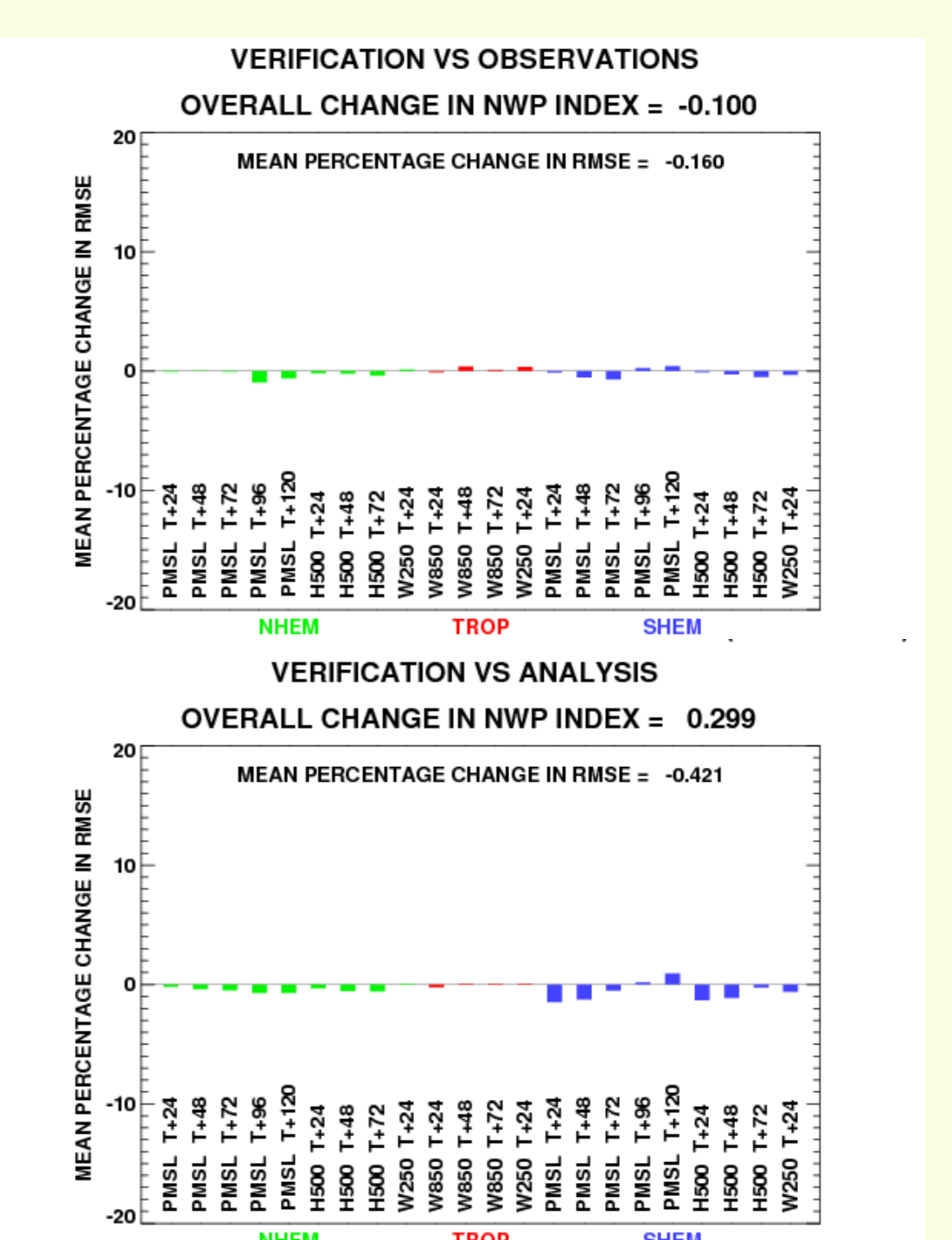

Fig. 8 Verification for experiment versus control, against observations (top) and analysis (bottom).

Summary

An emissivity atlas has been used at AMSU-A frequencies as a background for the 1D-Var retrieval of emissivity and skin temperature over land. These surface parameters are passed to 4D-Var with the aim of assimilating AMSU-A channels 4 and 5. A global NWP trial, when compared with a control run of the full observing system, results in improved background fits to mid-troposphere peaking microwave channels.

Small reductions in RMSE for short-range forecasts of 500 hPa geopotential height are also seen in the experiment relative to the control. A further trial will be run on the new Cray XC40 supercomputer at the Met Office for a different season to test reproducibility.

Reference

Karbou, F. et al. (2005), Microwave land emissivity calculations using AMSU measurements, *IEEE Transactions on Geoscience and Remote Sensing*, **43**(5), 948-959.