Improved use of ATOVS over land

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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.

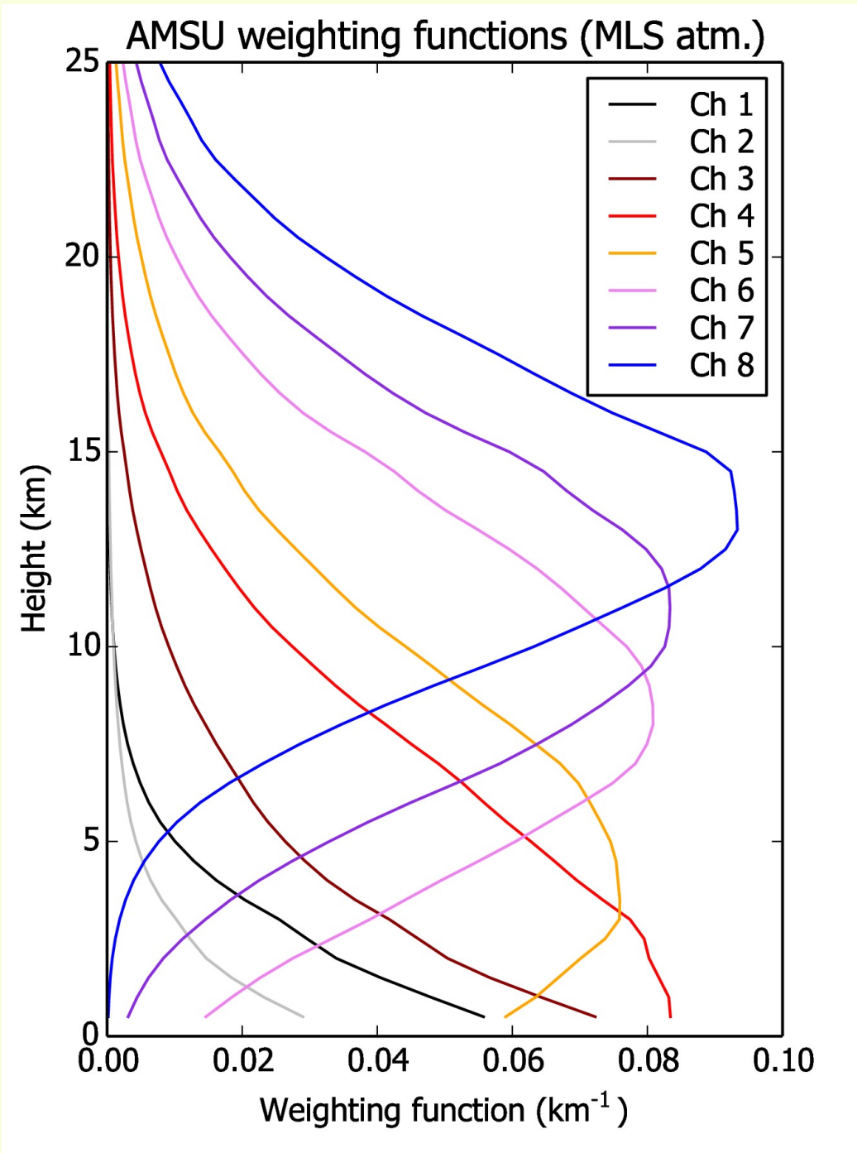

Fig. 1 Sample weighting functions (midlatitude summer atmosphere) for AMSU-A channels 1-8.

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 (1,2,3 and 15 at 23.8, 31.4, 50.3 and 89 GHz respectively) 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.

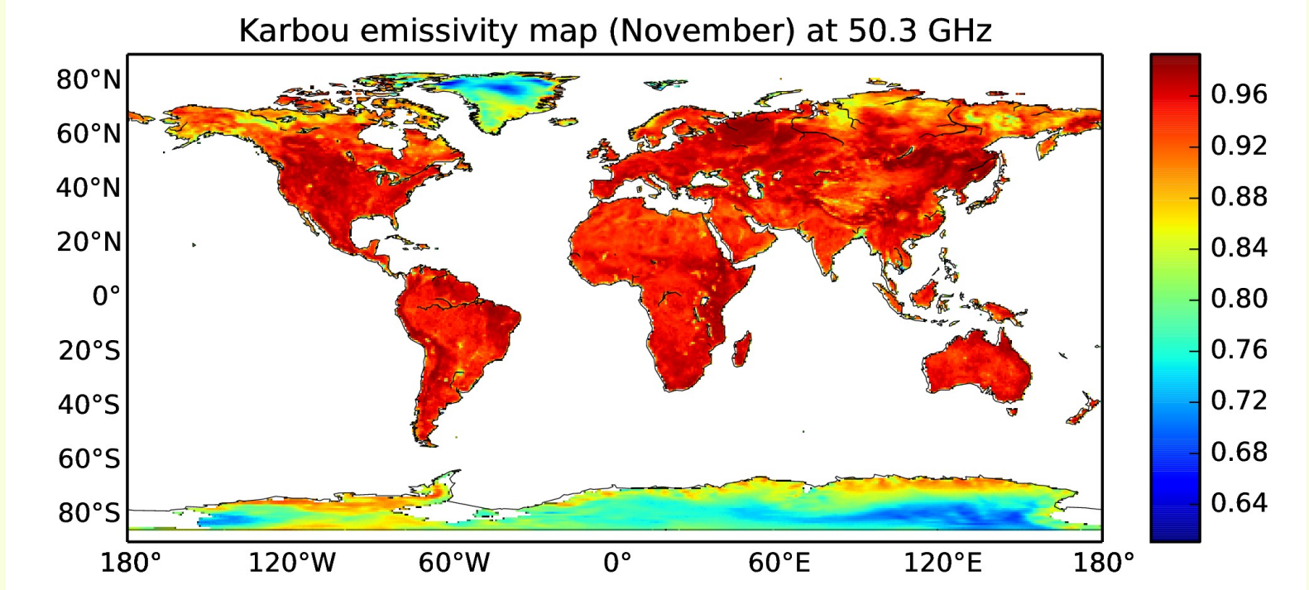

Fig. 2 AMSU-A channel 3 emissivity (50.3 GHz) for November, gridded at 0.25º spatial resolution according to the atlas of Karbou et al. (2005).

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):

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

Here, as a function of frequency ν 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.

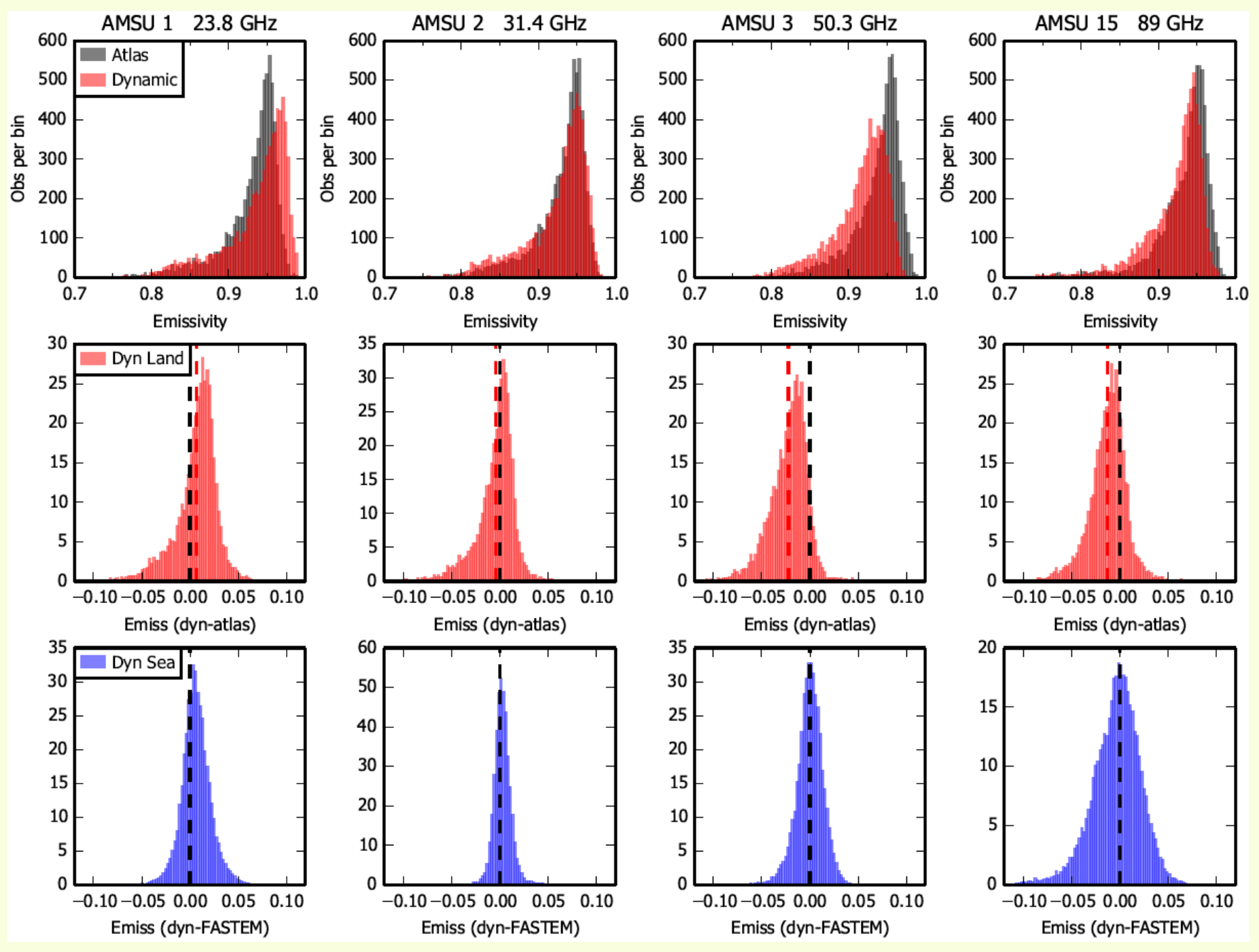

Fig. 3 Validation of Karbou et al. (2005) emissivity atlas within a 1D-Var framework. Columns show data for each of AMSU-A channels 1, 2, 3 and 15. Top row: histograms of emissivity for selected clear-sky ATOVS observations over land, for atlas (grey) and dynamic retrieval (red). Middle row: difference 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. Analysis of these differences as a function of satellite zenith angle (Fig. 4) reveals a dependence which may be related to the mixing of vertical and horizontal polarisations as AMSU scans cross-track. Only low angle (0-40º) data from the atlas were used, but Fig. 4 suggests a correction by angle is desirable.

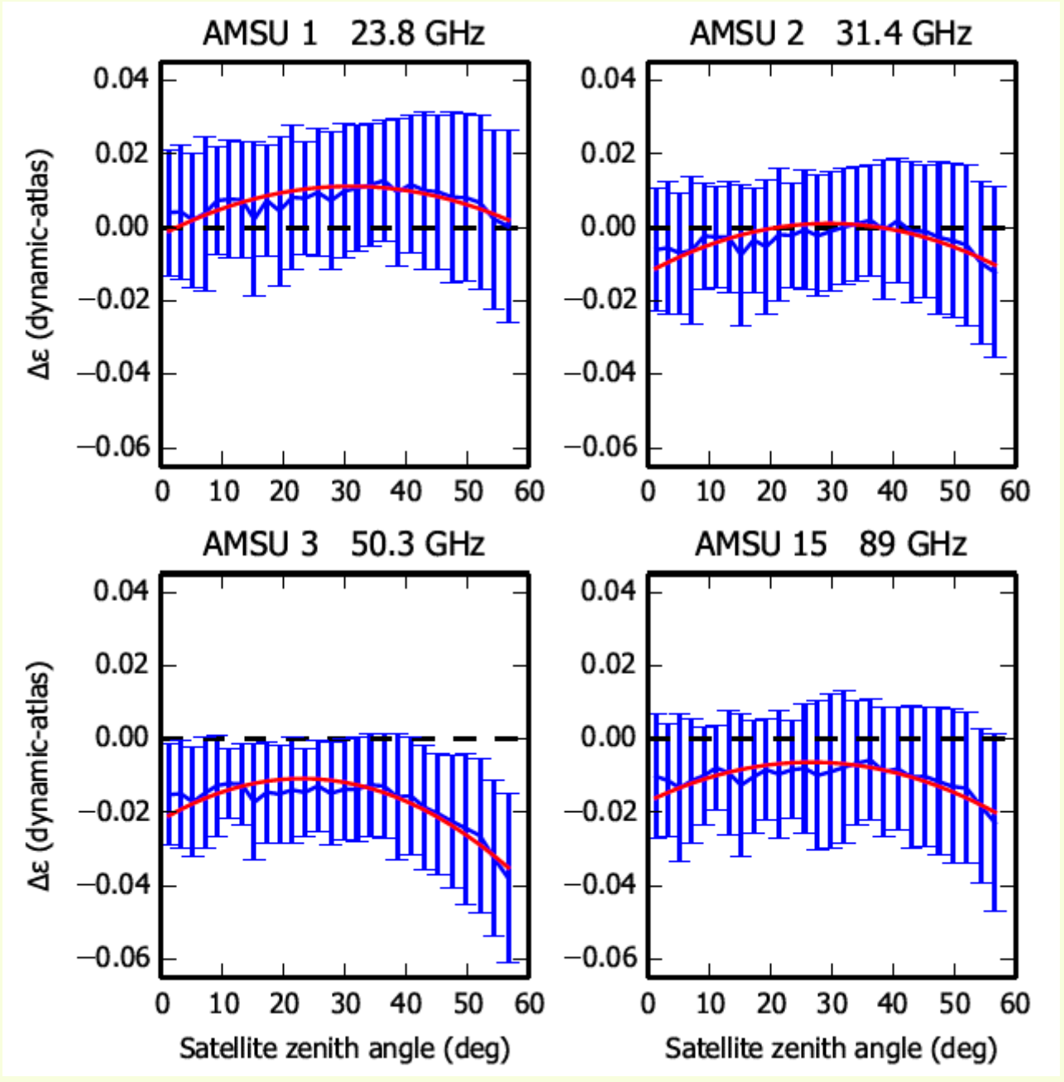

Fig. 4 Difference between dynamic emissivity estimate and atlas for four AMSU window channels, binned by satellite zenith angle (blue). Polynomial fit is in red.

VAR experiments

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). The results shown here use a modified atlas in 1D-Var, with a zenith angle correction as implied by Fig. 4 and emissivity background error covariances estimated from the dynamic - atlas differences. However, the VAR results are only weakly sensitive to the choice of atlas.

The current operational VAR configuration is to use AMSU-A channels 6-14 over land (7-14 over high terrain). Single cycle VAR experiments were performed to test the introduction of AMSU-A channels 4 and 5 over land with the improved representation of surface emission.

We expect a successful introduction of low-peaking AMSU channels to produce VAR analysis increments that are broadly consistent with other observation types. Figs. 5 and 6 compare VAR analysis increments of potential temperature due to assimilation of either surface station observations or ATOVS radiances. In each case no other observations are assimilated. For ATOVS (land footprints only) assimilation of AMSU-A channels 4 and 5 have been tested separately, as well as combining 4 and 5.

Fig. 5 shows a reasonable degree of consistency between the two sets of increments, e.g. the pattern of negative Θ increments over Russia.

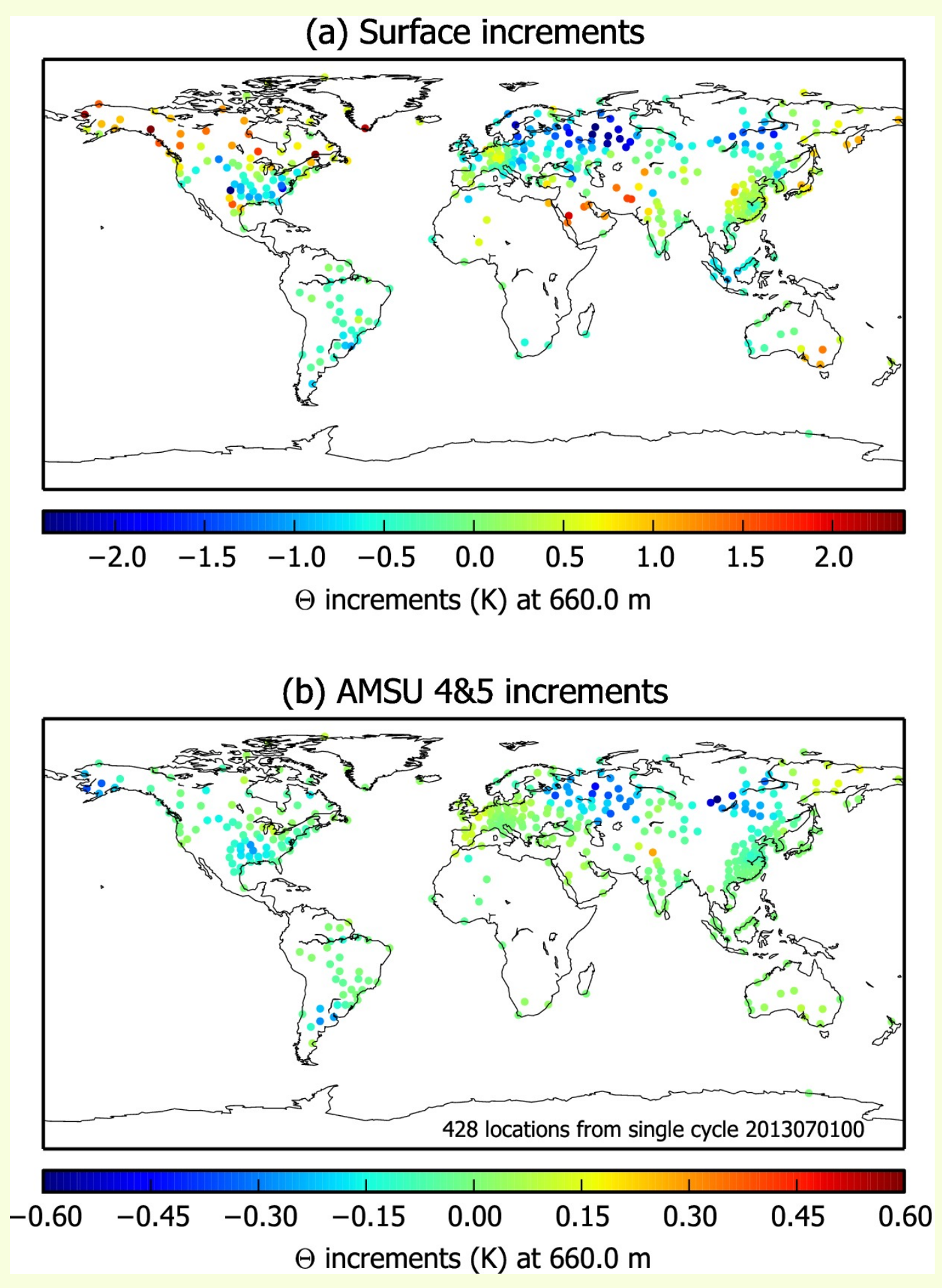

Fig. 5 Analysis increments of potential temperature Θ due to assimilation in VAR of single observation types: (a) surface observations, (b) AMSU-A channels 4 and 5 over land. Locations have been selected where both sets of observations are closely collocated. Increments are plotted here at a nominal height of 660 m.

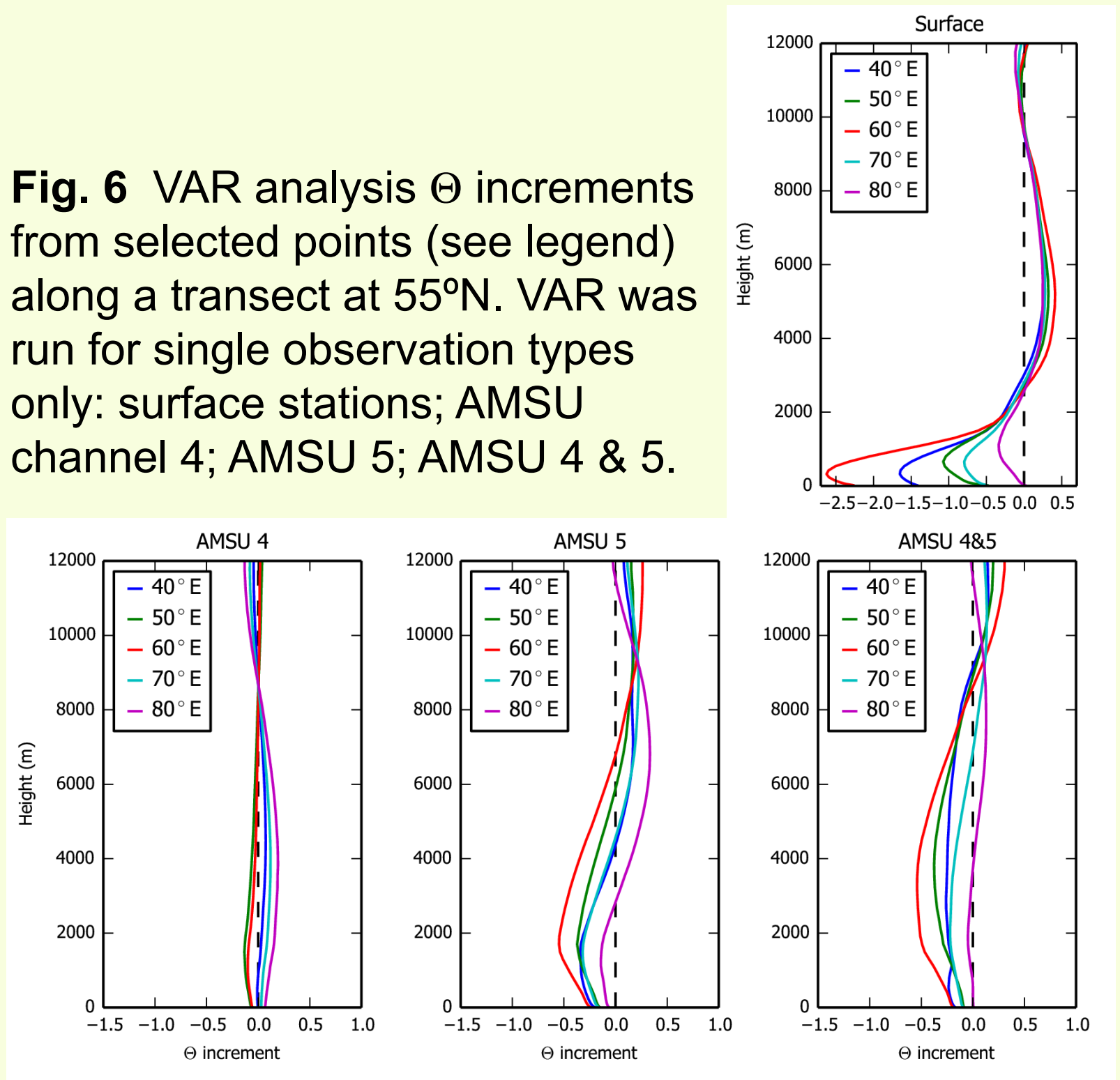

Fig. 6 VAR analysis Θ increments from selected points (see legend) along a transect at 55ºN. VAR was run for single observation types only: surface stations; AMSU channel 4; AMSU 5; AMSU 4 & 5.

Fig. 6 shows how the surface increments are concentrated (as expected) in the lowest part of the troposphere. Although the data types have different vertical sensitivity, there is some support for consistent behaviour, e.g. AMSU and surface increments are both markedly negative for the location at 60º E.

One method of judging the correspondence of different increments is to calculate a correlation coefficient at each model level, as shown in Fig. 7.

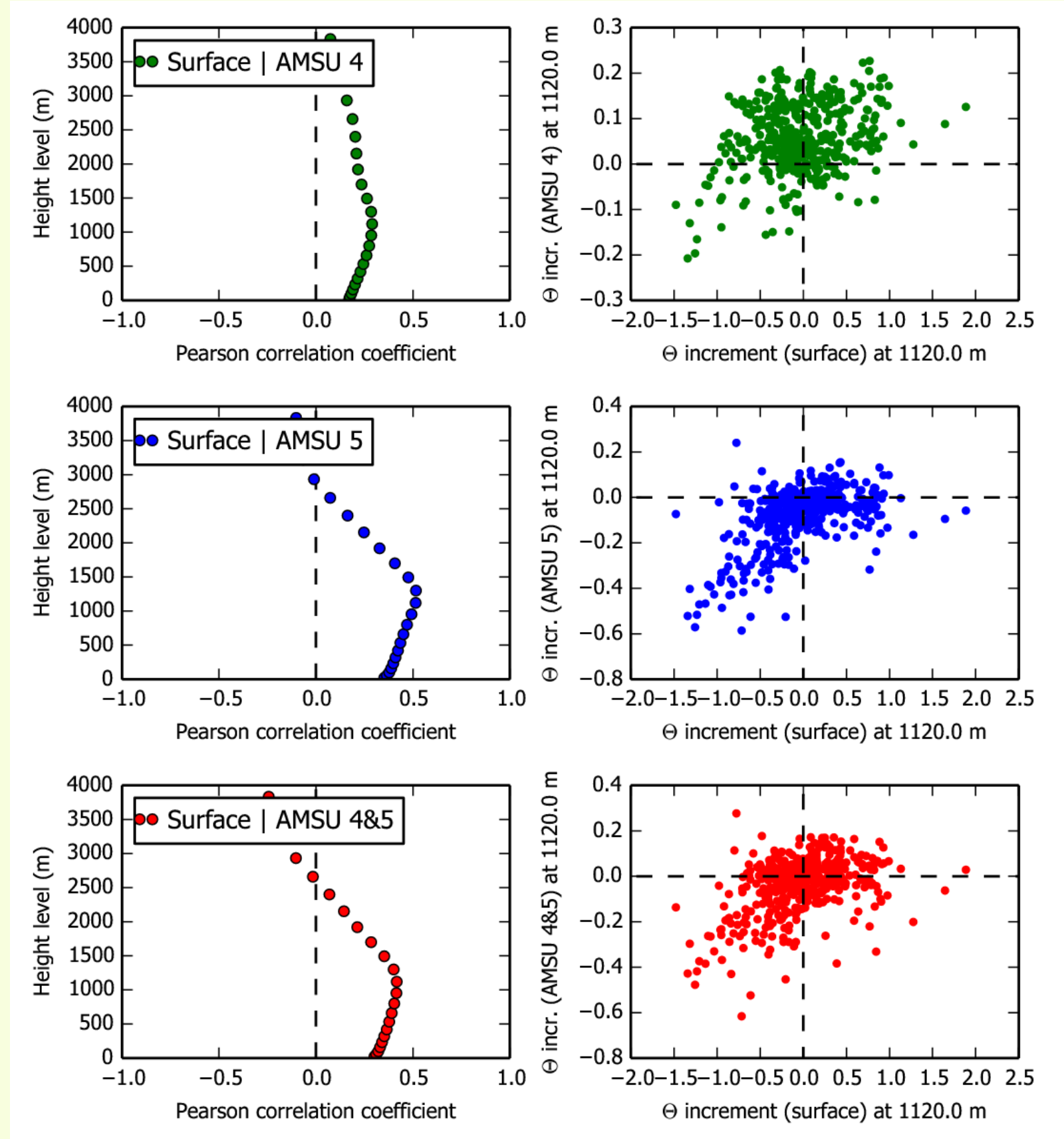

Fig. 7 (Left) Pearson correlation coefficient between surface and AMSU VAR analysis increments over land, plotted for each model level. Coefficients are shown separately for assimilation of AMSU 4 only, AMSU 5 only, and AMSU 4 & 5. (Right) scatter plot of surface and AMSU Θ increments at single model level (1120 m) approximating the level of maximum correlation.

At best a correlation coefficient of around 0.5 between the surface and AMSU increments is achieved in Fig. 7 at model levels near 1120 m. Assimilating AMSU channel 5 in isolation, or conjunction with channel 4, seems to produce a more robust correlation than channel 4 alone. Successful assimilation of the lower-peaking AMSU 4 in an operational configuration is more ambitious than AMSU 5 for which the surface sensitivity is less.

Summary

An emissivity atlas has been used at AMSU frequencies as a background for the 1D-Var retrieval of emissivity alongside skin temperature over land. These surface parameters are passed to 4D-Var with the aim of assimilating AMSU channels 4 and 5. In initial experiments, analysis increments due to AMSU near the surface show reasonable consistency with those due to surface observations.

Future work will include tuning of observation errors to maximise correlations between ATOVS and other assimilated observations. Global suite trials should test assimilation of AMSU 5 as well as AMSU 4 and 5 combined.

Reference

Karbou, F., C. Prigent, L. Eymard, and J. R. Pardo (2005), Microwave land emissivity calculations using AMSU measurements, *IEEE Transactions on Geoscience and Remote Sensing*, **43**(5), 948-959.

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