Evaluation and comparisons of FASTEM versions 2 to 5

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Abstract

The latest version of FASTEM, the fast ocean surface emissivity model for microwave frequencies, is evaluated in the ECMWF system and compared against earlier versions. The evaluation is done in terms of a comparison between observed and simulated brightness temperatures for a range of sensors.

FASTEM-5 shows significantly different bias characteristics compared to earlier versions. For the microwave imagers, the change in the foam cover parameterisation leads to an altered dependence of the biases on the 10m wind speed compared to FASTEM-4. At high 10m wind speeds, the behaviour is closer to FASTEM-2, as expected from reverting the change to the foam cover model. For low wind speeds, the behaviour is similar to FASTEM-4 for vertically polarised channels, and similar to FASTEM-2 for horizontally polarised channels. At high wind-speeds, standard deviations of First-Guess departures suggest a small benefit from using FASTEM-4 rather than FASTEM-5, but overall the results do not clearly favour one parameterisation over the other.

For the microwave sounders, FASTEM-5 leads to an overall reduction of biases compared to FASTEM-3 or -4, with a smaller dependence on the 10m wind speed. The impact on departure statistics is primarily confined to the window channels which are not assimilated in the ECMWF system, but used for quality control of the sounding channels. For these channels, a positive bias in terms of brightness temperatures remains.

Introduction

Different versions of the fast ocean surface emissivity model for microwave frequencies are evaluated and intercompared for microwave imagers (AMSR-E, TMI, SSMIS) and sounders (AMSU-A/MHS). The different versions are used with RTTOV-10 (Hocking et al. 2012) in radiative transfer computations, and we present results from comparisons between observations and simulated values in brightness temperature space.

The evolution of FASTEM and the differences between the versions considered here can be summarised as follows:

- FASTEM-1 calculated an effective surface emissivity, based on a fast fit to emissivities calculated from a geometric optics (GO) model. Foam cover was modelled as a function of 10m wind speed following Monahan and O'Muircheartaigh (1986). More details can be found in English and Hewison (1998).

- FASTEM-2 added a correction to the reflectivities, dependent on the surface-to-space transmittance (Deblonde and English 2001). The fitting coefficients used the same underlying GO model as in FASTEM-1, but with a more sophisticated parameterisation.
- FASTEM-3 added a parameterization for the azimuthal variation of emissivity, and is otherwise identical to FASTEM-2.
- FASTEM-4 provided a number of updates, including a new permittivity parameterisation, an altered foam cover model (Tang 1974), an improved roughness parameterisation based on a two-scale emissivity model. In a two-scale model, waves with length scales large compared to the wavelength of the observations are still treated using GO, but small-scale waves are assumed to modify the emissivity of each large-scale facet in the GO calculation based on scattering theory. FASTEM-4 was included in the RTTOV-10 release, as evaluated in Bormann et al. (2011), and further details on FASTEM-4 can be found in Liu et al. (2011).
- FASTEM-5 is a modified version of FASTEM-4. The change to the foam cover parameterisation introduced in FASTEM-4 is reverted from Tang (1974) to the model of Monahan and O'Muircheartaigh (1986) used in earlier FASTEM versions. Also, the regressions for the reflectance parameterisations are now constrained to give the same emissivity for vertical and horizontal polarisations at nadir. Furthermore, to reduce the fitting error, the user has the option to use a look-up-table for the large-scale correction part rather than the previously applied regressions. Further details on FASTEM-5 can be found in Liu et al. (2012).

Versions 2 to 5 of FASTEM are intercompared here and only the main characteristics are summarised. Further details, including results from assimilation trials with different FASTEM versions can be found in Bormann et al. (2012).

Method

In the following we will evaluate different versions of FASTEM in terms of observation departure statistics, that is in terms of differences between observed and simulated brightness temperatures. The simulations are performed within ECMWF's data assimilation system from short-term forecasts using the fast radiative transfer model RTTOV-10 (Bormann et al. 2011). The statistics are derived over the period 5-25 July 2010 (unless indicated otherwise), with the short-term forecasts originating from a T511 (≈40 km), 91 levels setup of the IFS. Different versions of FASTEM will be evaluated using the same short term forecasts, so there is no interaction between the different FASTEM versions and the data assimilation.

Results: Microwave imagers

For microwave imagers, departure statistics have been obtained from ECMWF's all-sky system in which microwave imager data are used in clear as well as cloudy/rainy conditions. Statistics are based on the data after super-obbing to a T255 Gaussian grid resolution (e.g., approx. 80 km). The azimuthal dependence of emissivity is ignored, and versions FASTEM-2, -4, and -5 are intercompared.

There are significant differences in biases for different sensors, so there is not one version that performs best for all sensors and all channels (Fig. 1). The differences between the sensors are largely due to short-comings in the absolute calibration of these instruments. This means that it is difficult to say which version performs best, as one version might lead to smaller absolute biases for one channel on one instrument, but larger absolute biases for another. Nevertheless, differences between FASTEM-4 and other versions are most marked for the horizontally polarised channels (Fig. 1, Fig. 2). There are also notable differences between the LUT-based and the regression-based versions of FASTEM-5 (Fig. 2), and these differences are comparable to the differences between FASTEM-5 and FASTEM-2.

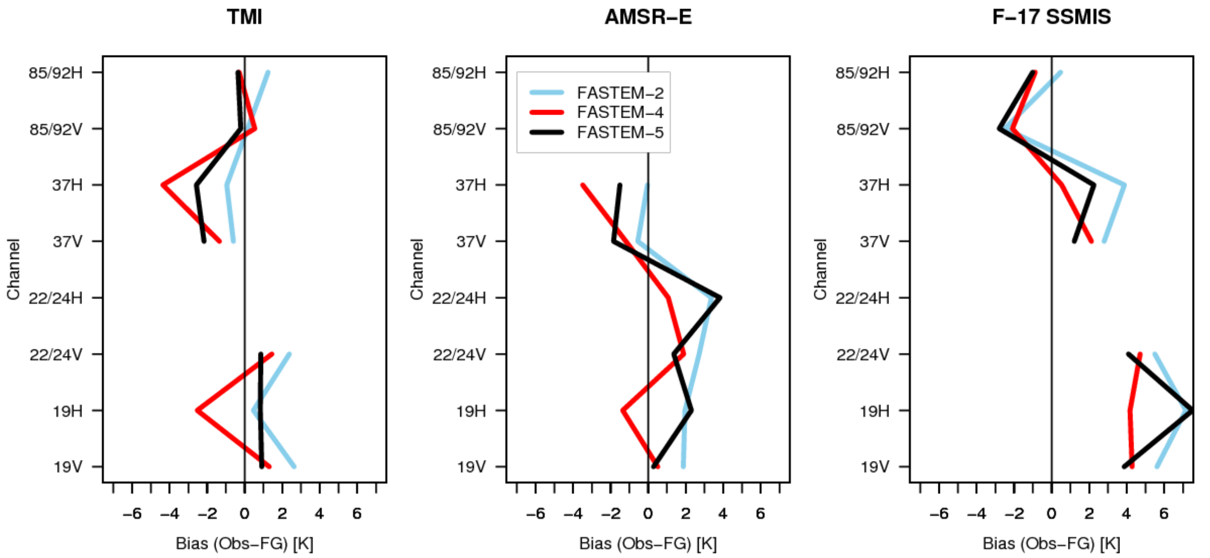

Fig. 1: Mean biases (observation minus FG) for different FASTEM versions for the three microwave imagers considered here: TMI (left), AMSR-E (middle), and the F-17 SSMIS (right). Data are for a quality-controlled sub-sample for the period 5-31 January 2011.

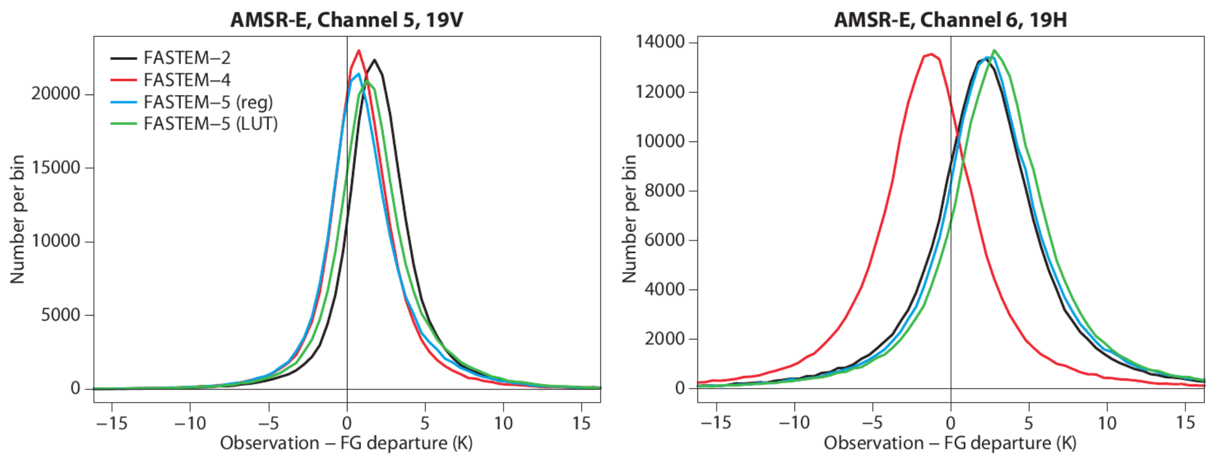

Fig. 2: Histograms of FG departures before bias correction for the 19 GHz AMSR-E channels (channels 5 and 6) for different versions of FASTEM for all observations over sea over the period 5-25 July 2010.

The wind-speed dependence of biases is significantly different for the versions considered, especially at high wind speeds (Fig. 3). For high 10m wind-speeds, FASTEM-5 follows the behaviour of FASTEM-2, as expected from sharing the same foam-cover parameterisation. For low 10m wind-speeds, FASTEM-5 follows FASTEM-4 for vertically polarised channels, and FASTEM-2 for horizontally polarised channels. FASTEM-4 shows the smallest standard deviations for high wind speeds among the three versions, and this is considered a positive aspect as it suggests an improved simulation of the variability introduced by foam cover. It is therefore not clear that the reversal of the foam cover model from FASTEM-4 to -5 leads to a better performance. Parameterisations for foam cover as a function of 10m wind speed show large spread (e.g., Anguelova et al. 2009), suggesting considerable uncertainty in this area. Furthermore, the parameterisation of foam cover as a function of 10m wind speed alone is rather simplistic, and in reality the foam cover will depend on a variety of factors, including the past evolution of the state of the ocean surface (e.g., Anguelova and Webster 2006). A more complex modelling of the foam cover used in FASTEM may well be beneficial.

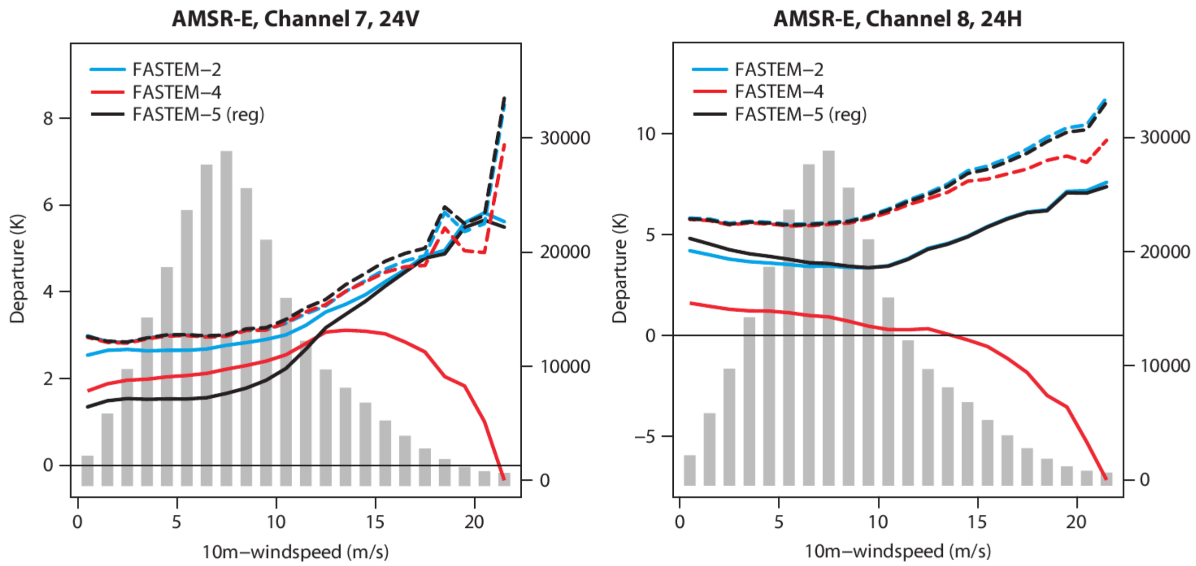

Fig. 3: First Guess departure statistics before bias correction for the 24 GHz AMSR-E channels (channels 7 and 8) as a function of the model's 10m-wind speed, calculated for the period 5-25 July 2010 and based on all observations over sea. Biases (Obs - FG) are displayed in solid lines, standard deviations with dashed lines. Also shown in grey is the population of data considered in the statistics as grey bars (right-hand x-axis).

Results: Microwave sounders

For microwave sounders, departure statistics have been obtained from assuming clear-sky conditions in the radiative transfer. Changes to biases or standard deviations are confined to the window channels that are not commonly assimilated. Here we will discuss the results for AMSU-A only.

FASTEM-5 shows improvements in biases compared to FASTEM-3 or -4, and in terms of the wind speed dependence of the biases (e.g., Fig. 4). Fig. 4 shows 2-dimensional histograms of FG departures for all data. Note that cloud-affected observations will cause positive departures here, as the raditive transfer simulations neglect cloud effects, and the mode of the FG departures is hence a better estimate for the true bias. Despite the improvements, Fig. 4 also suggests that a significant positive bias remains with FASTEM-5, of the order of 1-2 K for AMSU-A channel 3.

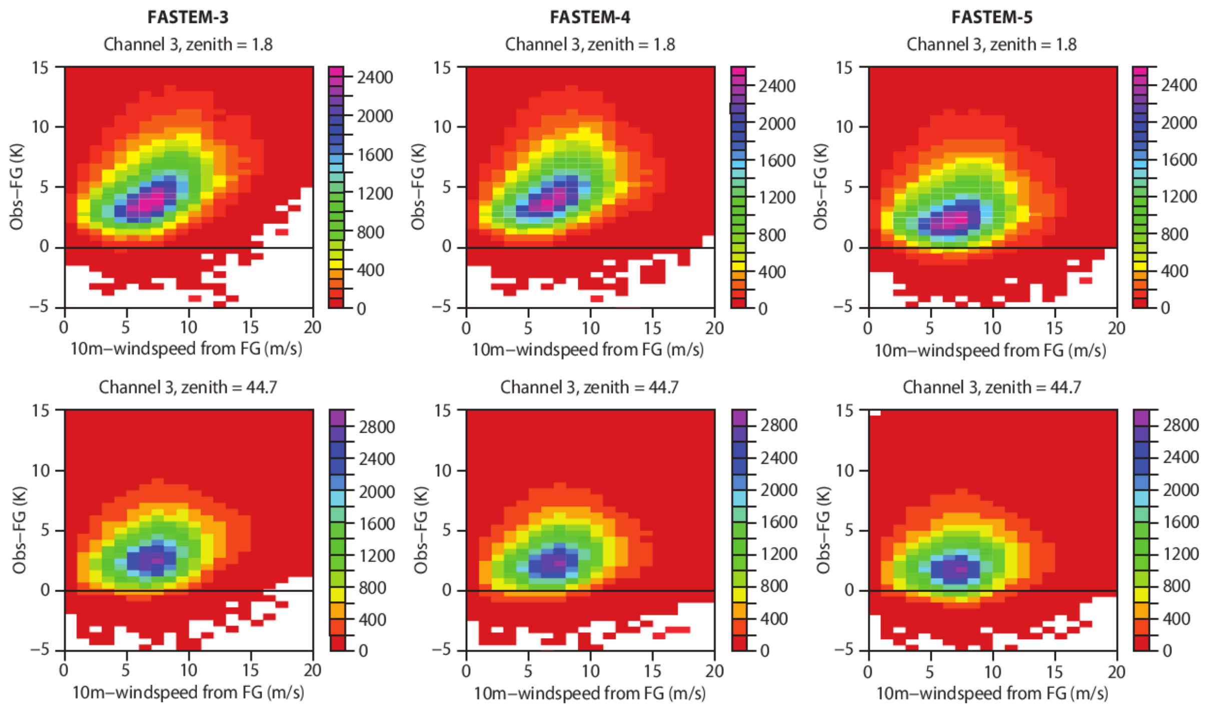

Fig. 4: Two-dimensional histograms of the differences between observed and simulated brightness temperatures before bias correction for channel 3 (50.3 GHz) of NOAA-18 AMSU-A as a function of the 10m-wind speed taken from the FG. The data is for the period 5-25 July 2010, over sea within ± 60° latitude, showing all data before quality control and thinning. The microwave emissivity model is FASTEM-3 (left), FASTEM-4 (middle), and FASTEM-5 (right). The top row shows data for the central scan positions (zenith angle around 1.8°), whereas the bottom row shows results for the outermost scan positions considered for assimilation at ECMWF (zenith angle around 44.7°).

Conclusions

FASTEM-5 is the latest update of the fast ocean surface emissivity model for microwave frequencies. The main findings from a comparison between observed and simulated brightness temperatures are:

- FASTEM-5 leads to bias characteristics for horizontally polarised lower frequency imager channels that are similar to those for FASTEM-2, whereas FASTEM-4 gives significantly different biases.
- FASTEM-5 leads to a significantly different wind-speed dependence of bias characteristics for microwave imagers and sounders.
- For microwave sounders (AMSU-A), FASTEM-5 produces smaller biases and an improved wind speed dependence compared to earlier FASTEM versions.
- For microwave imagers, FASTEM-4 leads to the smallest standard deviations of the departures at high wind-speeds, related to the changes in the foam cover parameterisation.

The evaluation of the FASTEM versions in terms of brightness temperatures is limited by the presence of large inter-sensor biases, so an absolute determination of biases is not possible. Nevertheless, the change in the foam cover model from Monahan and O'Muircheartaigh (1986) to Tang (1974) in FASTEM-4 and its reversal in FASTEM-5 have highlighted the sensitivity of biases in high wind speed regions on the foam cover parameterisation. Our study does not find clear evidence that one parameterisation is preferred over the other for microwave imager channels. Given the large spread of models for foam cover as a function of 10m wind speed, and given that actual foam cover is dependent on many more factors than 10m wind speed, it appears worthwhile to enhance the sophistication of foam cover modelling in FASTEM. For instance, better information may be available directly in NWP systems that include a wave model.

FASTEM-5 will be introduced in the ECMWF operational system in summer 2012.

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