

Assimilation of SSMIS humidity sounding channels over sea-ice at ECMWF

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ABSTRACT

We have recently explored the existing FASTEM parametric models for microwave emissivity over sea-ice in order to evaluate the possibility of using them for satellite data assimilation in numerical weather prediction systems. To guide our study we used retrievals of emissivity derived from SSMIS observations. We found that the observed ice emissivity spectrum decreases as a function of frequency, but at 183 GHz it starts to increase again. This is in contrast with the ice FASTEM models which, according to the surface category, predict a little variation or a decrease in the emissivity in the 150-183 GHz range. This result encouraged us to revisit the approach of using the emissivity retrieved from observations at 150 GHz for the humidity sounding channels. To have a better estimate of emissivity for the 183 GHz channels, we studied the relationship between SSMIS retrievals at 183 ± 7 and 150 GHz and we found possible to approximate the emissivity at 183 GHz as a linear function of the emissivity at 150 GHz. Results show that the linear model is capable of removing the systematic positive biases which affect the 183 GHz first-guess departures when the too low emissivity from 150 GHz is used. We also ran assimilation experiments to evaluate the use of the new sea-ice emissivity modelling. The impact on the forecast scores is generally neutral. However, the better estimate of the surface emissivity improves the fit to the observations and consequently the standard deviation of first-guess departures for SSMIS channel 10 and 11 are reduced (more than 2% reduction in channel 10 in the Northern hemisphere). The number of assimilated observations is also increased: in the winter season at about 85°N the number of SSMIS channel 10 and 11 observations actively assimilated is roughly three times more than in the control experiment which uses the emissivity retrieved at 150 GHz for the humidity sounding channels. With these beneficial results, we hope the emissivity boost method can be adopted for operational use at ECMWF.

1 Introduction

The ice emissivity spectral signature from SSMIS measurements was thoroughly investigated by Baordo and Geer (2015a). In this study, they used the all-sky path of the ECMWF Integrated Forecast System (IFS) which is capable to process SSMIS data and also retrieve the surface emissivity directly from satellite observations (Baordo and Geer, 2015b). The emissivity spectrum obtained from SSMIS observations (19.35, 37.0, 50.3, 91.65, 150.0 and 183 ± 7 GHz) was compared with that from the FASTEM emissivity model for 5 different ice surface categories among those available from Hewison and English (1999). The result of this comparison is summarised in Fig. 1 which shows mean and standard deviation of retrieved emissivities as a function of frequency and the spectral variation of the FASTEM ice emissivity across the 19-183 GHz range for all the 5 surface types. Fig. 1 demonstrates that the observed ice emissivity in the 150-183 GHz range increases in contrast with the FASTEM parametric models which predict an almost constant emissivity or a slight decrease. This outcome encouraged us to explore a different approach to assimilate SSMIS humidity sounding channels over sea-ice. The proposed method is documented in this paper.

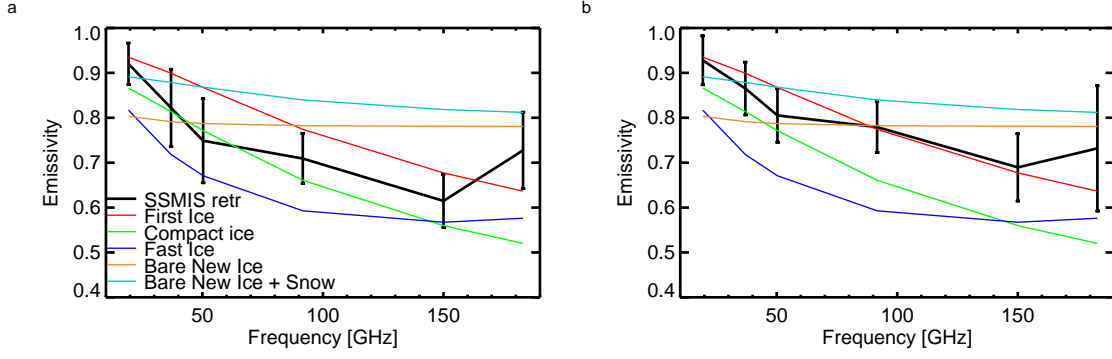


Figure 1: Mean and standard deviation (error bars) of emissivity retrieved from SSMIS channels (19.35, 37.0, 50.3, 91.65, 150.0 and 183±7 GHz) where the IFS sea-ice concentration is equal to 1. Statistics are computed considering SSMIS observations for the Northern (NH) and the Southern (SH) hemisphere respectively in January 2015 (a) and June 2015 (b). Colored lines indicate models of ice emissivity (FASTEM) from different surface categories as in Hewison and English (1999) for SSMIS incidence angle.

2 The ice emissivity boost approach

In our approach we developed a simple model which can linearly increase the emissivity estimated at 150 GHz. Relying on the SSMIS emissivity retrievals we searched for a linear regression which satisfies the relation:

$$\epsilon_{retr_183} = m\epsilon_{retr_150} + q. \quad (1)$$

To estimate m and q we used the sample of SSMIS retrievals according to different seasons and geographical region (e.g. North or South Pole) with the following conditions verified simultaneously:

- a) $0 < \epsilon_{retr_183} < 1$,
- b) $0 < \epsilon_{retr_150} < 1$,
- c) IFS sea-ice fraction equal to 1,
- d) $\tau_{183} > 0.4$.

Basically a, b and c are for looking at successful retrievals most likely not contaminated by open water and d, which uses the transmittance at 183±7 provided by the model, can preserve a good visibility of the surface rejecting those observations which are presumably affected by water vapour and/or cloudy conditions. The relationship between the retrievals at 183±7 and 150 GHz is examined through Fig. 2 which summarise the results of the linear regression providing the values for the coefficients m and q . The Pearson correlation coefficient is also shown. The relation is separately evaluated for the Northern and Southern hemisphere also considering 2 different seasons (winter and autumn). The relationship between the retrievals at 183±7 and 150 GHz appears to have a seasonal and geographical dependency and consequently the emissivity at 183 GHz computed from boosting the emissivity at 150 GHz varies with the estimated set of coefficients. Assuming a constant surface temperature, we calculate the sea-ice emissivity at a specific frequency ν and incidence angle θ as the contribution of the open water emissivity (from RTTOV) and the ice emissivity weighted by the IFS sea-ice concentration (C_{ice}):

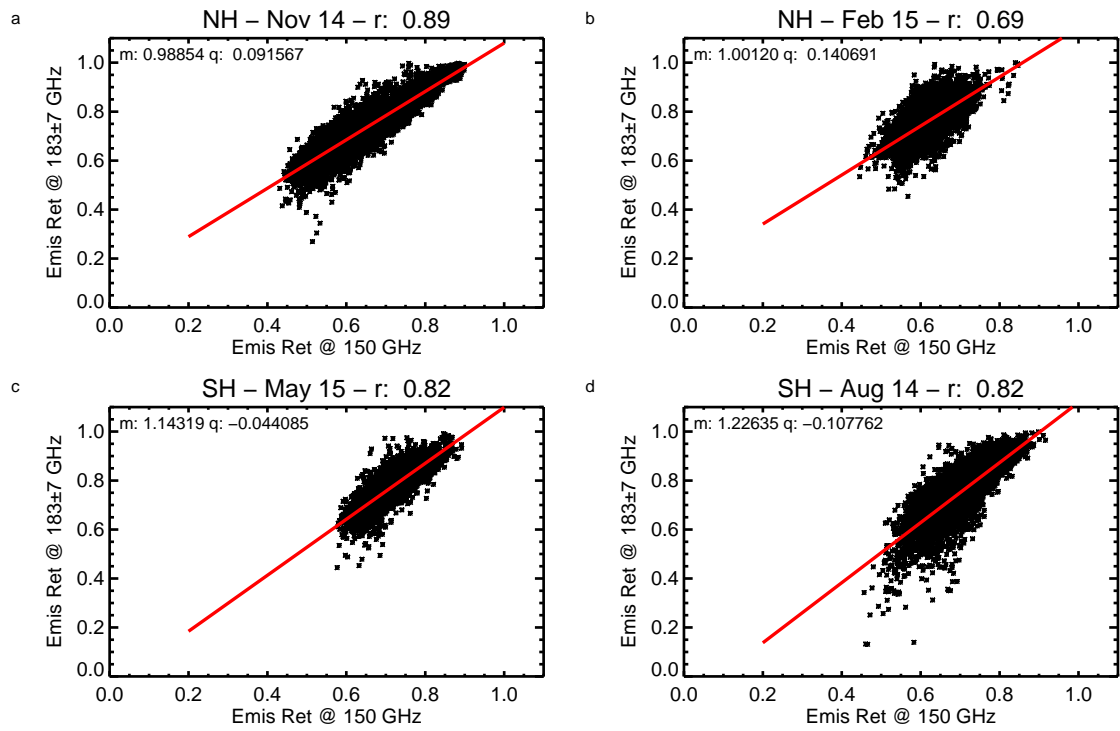


Figure 2: Relationship between retrieved emissivity at 183 ± 7 and 150 GHz obtained from SSMIS observations in autumn (a and c) and winter (b and d) in the Northern (NH) and the Southern (SH) hemisphere. Retrievals are selected considering locations where model values of sea-ice concentration and transmittance at 183 ± 7 GHz are respectively equal to 1 and greater than 0.4. Plots also show the Pearson correlation coefficient (r) and the coefficients (m and q) from the linear regression.

$$\varepsilon(\theta, \nu) = (1 - C_{ice})\varepsilon_{ocean}(\theta, \nu) + C_{ice}\varepsilon_{ice}(\theta, \nu). \quad (2)$$

Considering Eq. 2, the emissivity over sea-ice for the SSMIS 183 GHz channels is computed according to the following 3 steps:

1) Using the emissivity retrieved at 150 GHz, we can calculate the ice emissivity from Eq. 2:

$$\varepsilon_{ice_150} = [\varepsilon_{retr_150} - (1 - C_{ice})\varepsilon_{ocean_150}]/C_{ice}.$$

2) Boost the ice emissivity at 150 GHz to obtain an estimate at 183 GHz:

$$\varepsilon_{ice_183} = m\varepsilon_{ice_150} + q.$$

3) Calculate the emissivity at 183 GHz over sea-ice from Eq. 2:

$$\varepsilon_{183} = (1 - C_{ice})\varepsilon_{ocean_183} + C_{ice} \varepsilon_{ice_183}.$$

3 Assimilation experiments

In order to assess the ice emissivity boost approach we ran 2 assimilation experiments:

1) the ‘Control’ experiment which is the unchanged version of the ECMWF cycle 41r2. In this experiment the emissivity over sea-ice for the humidity sounding channels is that retrieved at 150 GHz;

2) the ‘Emis Boost’ experiment which is equivalent to the Control, but in this case the emissivity over sea-ice for the SSMIS 183 GHz channels is computed according to the methodology described in the previous section.

In this paper we present assimilation experiments which implemented the ‘ice emissivity boost approach’ using m and q derived from the autumn season (e.g. Fig. 2 a and c). The full assimilation system was run using 137 levels in the vertical and a horizontal resolution of approximately 32 km (T639) and covering more than 6 months: 1 January-30 April 2015 and 1 June-11 August 2015. The analysis of the first-guess departures at 183 ± 7 GHz, which is the channel with stronger surface-sensitivity, is a good way to check the effectiveness of the boosting approach. This is done through Fig. 3 and Fig. 4 which respectively show mean maps and histograms of first-guess departures for SSMIS channel 9 over sea-ice and compare the 2 experiments for the winter season in the Northern and Southern hemisphere. Channel 9 is not actively assimilated and the sample of data in Fig. 3 and Fig. 4 is represented by 1 month of SSMIS observations where the IFS sea-ice fraction is greater than zero. Clearly the boosting approach is doing a good job in shifting the magnitude of the first-guess departures in the right direction and reducing the systematic positive biases which are incorrectly generated when the too low emissivity retrieved at 150 GHz is assigned to the 183 ± 7 GHz.

Another way to analyse the quality of the new emissivity computation is also looking at the behaviour of first-guess departures for assimilated observations. This is done by Fig. 5, which is equivalent to Fig. 3, but this time maps of first-guess departures are plotted only considering actively assimilated observations

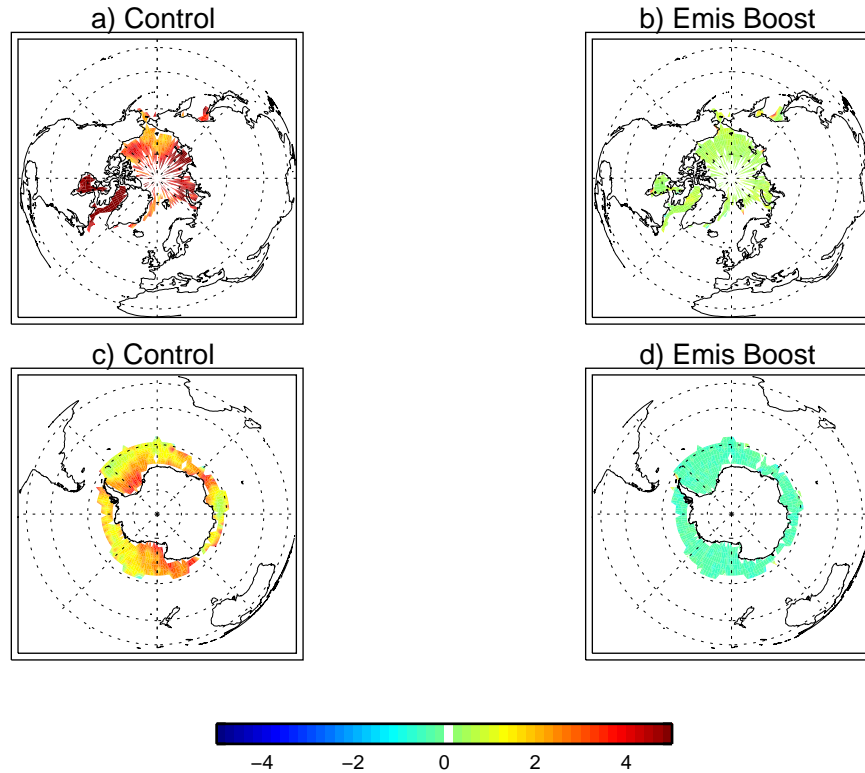


Figure 3: Mean maps of first-guess departures for SSMIS channel 9 where IFS sea-ice concentration is greater than 0. Results from control experiment (a and c) are compared to those provided by the ‘emis boost’ experiment. Winter season is examined in the Northern (a and b, January 2015) and in the Southern hemisphere (c and d, June 2015).

over sea-ice for SSMIS channel 10 (183 ± 3 GHz). The control experiment is still affected by remaining positive biases which on the contrary appear to be removed in the boosting experiment. Results for SSMIS channel 11 actively assimilated observations are similar (not shown). Forecast scores computed considering the whole experimental period (1 January-30 April 2015 and 1 June-11 August 2015) show that the new emissivity computation has a general neutral impact (not shown). However, in comparison with the control experiment, there are 2 important results in favour of the boosting approach: 1) the larger number of SSMIS channel 10 and 11 assimilated observations; 2) the improved fits to SSMIS observations. Fig. 6 shows number of SSMIS channel 10 actively assimilated observations (per 2° latitude bin) in 1 month comparing the control with the boosting experiment. Basically the new surface emissivity approach is capable to double and in some regions even triple the number of assimilated observations. Exception to this behaviour is visible in the austral winter where the number of assimilated observations appear roughly the same. The overall impact of the new approach can be summarised through Fig. 7 which show standard deviation of first-guess departures for SSMIS observations as a percentage relative to the control. Statistically significant changes are clearly observed for channel 10 and 11 in the Northern hemisphere. This result is most likely driven by the improved estimate of the surface emissivity which consequently generates better simulated observations. In the Southern hemisphere there is also a clear signal that the standard deviation of first-guess departures are decreased although the magnitude is not as large as the reduction observed in the North Pole. This is probably connected with the number of assimilated observations, which for some reasons in the South Pole, has not extensively increased respect to the control. We can conclude that the boosting approach has generally improved the quality of the surface emissivity at 183 GHz over sea-ice although dependency on season and geographical location might be important to take into account for the optimal derivation

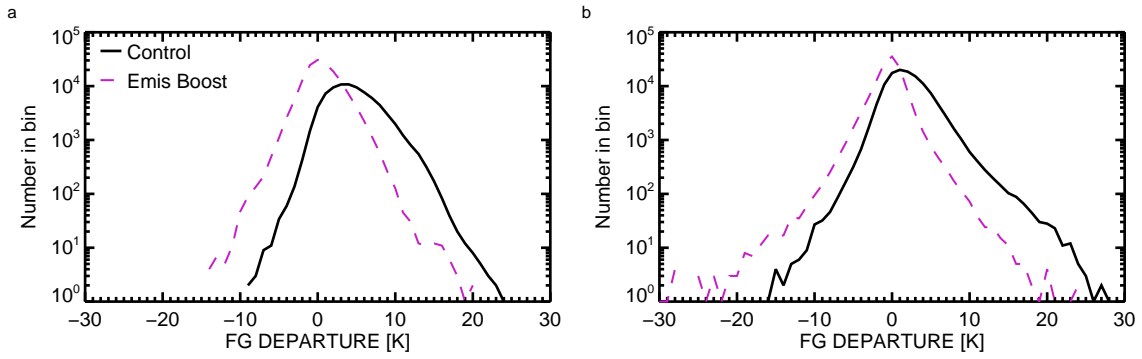


Figure 4: Histograms of first-guess departures for SSMIS channel 9. Plots a and b show respectively the first-guess departures of Figure 3a–3b and 3c–3d.

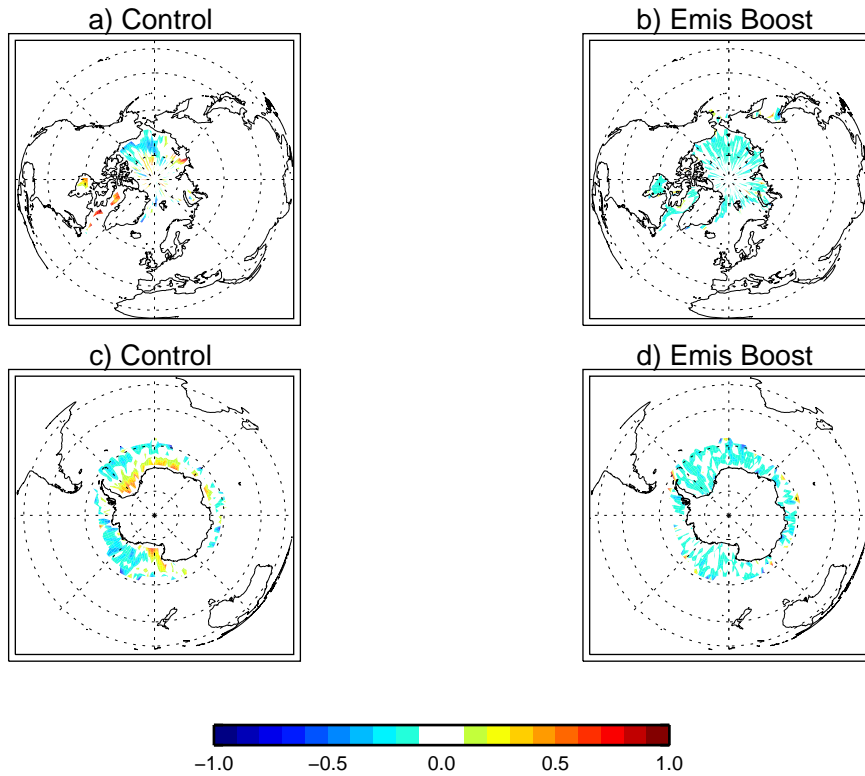


Figure 5: As Figure 3, but showing actively assimilated observations for SSMIS channel 10 (183 ± 3 GHz).

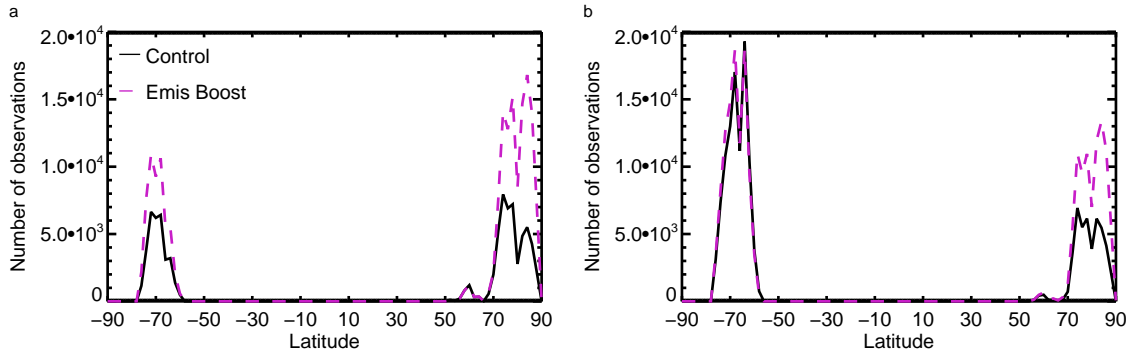


Figure 6: Number of SSMIS channel 10 actively assimilated observations from control experiment are compared to that provided by the ‘emis boost’ experiment: a, January 2015 and b, June 2015. Latitude bin is 2° .

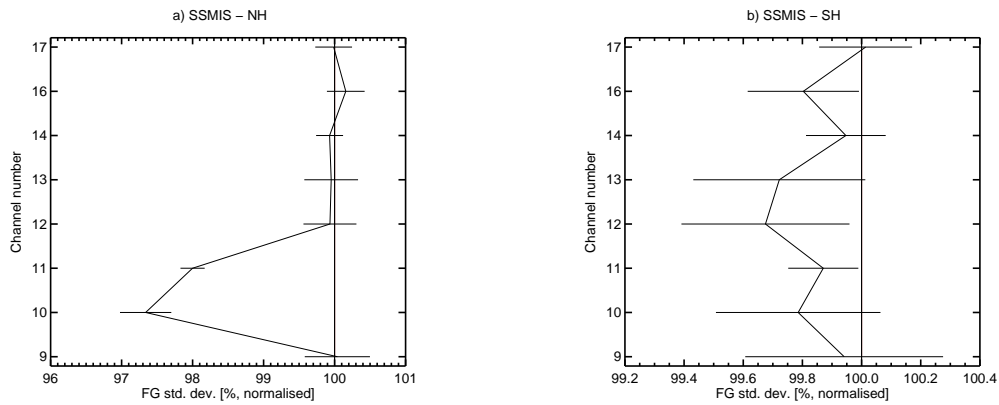


Figure 7: Standard deviation of first-guess departures for SSMIS observations as a percentage relative to the control. Error bars indicate the 95th percentile of the experimental period (1 January-30 April 2015 and 1 June-11 August 2015) for the Northern (a) and the Southern (b) hemisphere.

of the coefficients of the linear model.

4 Conclusions

The assimilation of SSMIS humidity sounding channels over sea-ice is treated in this study. We found that the observed ice emissivity at 150 GHz is constantly lower than that at 183 GHz and this result suggested to revisit the approach of using the retrievals at 150 GHz to model the 183 GHz channels. Firstly, through the relationship between the SSMIS retrievals at 183 ± 7 and 150 GHz we built a simple model which can calculate the ice emissivity at 183 GHz as a linear function of the ice emissivity at 150 GHz. Secondly, we estimate the sea-ice emissivity as the contribution of the open water emissivity and the ice emissivity weighted by the IFS sea-ice concentration. The new surface emissivity approach was analysed evaluating the impact on the first-guess departures at 183 ± 7 GHz, which is the channel with stronger surface-sensitivity, and also the impact on the actively assimilated observations at 183 ± 3 and

183±1 GHz. Results demonstrate that the linear model generally helps in reducing the large positive first-guess departures which are incorrectly generated when the too low emissivity retrieved at 150 GHz is assigned to the humidity sounding channels. The assimilation experiments show a neutral impact on the forecast scores, but the new sea-ice emissivity model largely improves fits to SSMIS channel 10 and 11 observations as well as the number of assimilated observations. We demonstrated that the new sea-ice emissivity strategy developed in IFS for SSMIS is effective and it might be considered as a valid alternative to update the approach used in the ECMWF operational system. However, it might be worth revisiting the derivation of the coefficients of the linear model in order to improve the modelling according to the season and geographical location. It is also important to mention that polarization and incidence angle are two critical parameters for the variability of the ice emissivity spectrum: retrievals derived from MHS observations at smaller zenith angles (less than 25°) show that the emissivities in the 150-183 GHz range have similar increase (if not in magnitude) to that observed for SSMIS.

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