Extending the use of surface-sensitive microwave channels in the ECMWF system

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Abstract

This paper gives an overview on the use of microwave sounding observations for Numerical Weather Prediction (NWP) at ECMWF with a focus on the assimilation of surface-sensitive radiances.

The assimilation of AMSU-A and MHS radiances in the ECMWF system is currently limited over high orography, snow covered surfaces and sea ice due to large uncertainties in the estimated surface emission. We have investigated an enhancement of the use of MHS and AMSU-A surface-sensitive data, namely over sea ice surfaces. MHS observations are currently assimilated operationally only over surfaces with skin temperature TS $\geq$ 278 K and over low orography. The constraint on the skin temperature means that there is no humidity sounding coverage in most of the areas of the globe with latitudes larger than $\pm$ 60 degrees which include sea ice.

The assimilation of humidity sounding observations from MHS has been extended in research experiments over sea ice and over sea at any skin temperature, with dynamically retrieved emissivities used over sea ice for both MHS and AMSU-A. As for the assimilation of microwave sounder data over land, the dynamic retrieval of emissivities improves the simulation of microwave sounding also over sea ice, compared to the static retrieval scheme currently used at ECMWF for sea ice surfaces. However, care must be taken within the dynamic retrieval scheme as emissivity spectra vary with the type of sea ice.

Assimilation experiments were run in the summer season and the results are significantly positive for the forecast of the temperature, geopotential and winds in the Southern Hemisphere.

INTRODUCTION

ECMWF is currently assimilating microwave sounding data from six polar orbiting satellites (NOAA-15, NOAA-17, NOAA-18, NOAA-19, MetOp-A, and Aqua) for a total of five AMSU-A and three MHS.

MHS observations from channel 3, 4 and 5 (the 3 channels in the 183 GHz water vapour band) are assimilated operationally only over surfaces with skin temperature TS $\geq$ 278 K and over low orography. The constraint on the skin temperature means that there is no humidity sounding coverage in most areas polewards of $\pm$ 60 degrees which include sea ice. The other two MHS channels (namely window channels) are used for emissivity retrieval over land (channel 1 at 89 GHz) and quality control purposes (channel 2 at 157 GHz).

AMSU-A observations from channel 5 to 14 are assimilated operationally over low orography, sea and sea ice, but with channel 5 not active south of 60S. Other channels are either discarded or used for emissivity retrieval over land (channel 3 at 50.3 GHz), and quality control purposes over land (channel 4 at 52.8 GHz) and over sea (channel 3 at 50.3 GHz). Emissivities over sea ice for AMSU-A are calculated

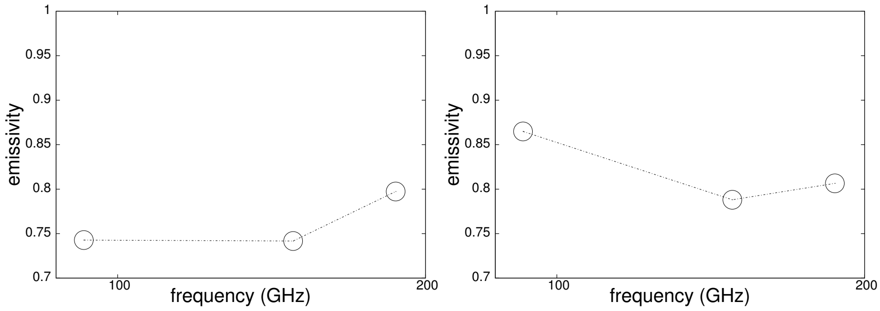

Figure 1: **Emissivity spectra for two different types of sea ice, where the emissivities are dynamically retrieved from MHS observations at 89, 157 and 190.311 GHz.**

with a static scheme based on a classification of the surface type and an appropriate parametric model per surface type (Kelly and Bauer 2000).

As for the assimilation of microwave sounder data over land, the dynamic retrieval of emissivities provides a good basis to improve the use of microwave sounding over sea ice, as shown also in (Bouchard et al. 2010). The dynamic retrieval of emissivities is based on re-arranging the radiative transfer equation for window channel observations and using the ECMWF model background field (Karbou et al. 2005). Over land the assumption is made that the error introduced by using, for a given frequency, emissivities calculated at a different frequency, is small. As shown in Di Tomaso and Bormann (2011), MHS departure statistics show that emissivities retrieved at 89 GHz can be used over land for the water vapour channels without introducing a relevant bias. Over sea ice the situation is more complex as the emissivity spectra vary greatly with the type of ice (Harlow 2011). There are surfaces for which the emission at 89 GHz might be quite different than the one at 157 GHz or 183 GHz. Figure 1 shows an example of two emissivity spectra for different types of sea ice where the emissivities are dynamically retrieved from MHS observations at 89, 157 and 190.311 GHz. These issues have been taken into account in the experiments described in the next section.

ENHANCED ASSIMILATION OF MICROWAVE SOUNDING DATA OVER SEA AND SEA ICE

Assimilation experiments

We have run assimilation experiments with the active usage of additional MHS observations over sea and sea ice, and with dynamically retrieved emissivities used in the simulation of both AMSU-A and MHS radiances over sea ice.

Experiments were run at a low resolution (T319) with cycle CY37R3 from June to September 2011 with MHS channel 3, 4 and 5 active over sea with any skin temperature, and channel 3 and 4 active also over sea ice. The current constraint on the skin temperature has been left unchanged over land (i.e. MHS observations are assimilated only over surfaces with skin temperature $TS \geq 278$ K to exclude snow-covered surfaces). The assimilation of MHS channel 5 over land is included in these experiments as in the control experiment (which was not yet implemented in cycle CY37R3).

For MHS we have considered two cases: the use of emissivities retrieved from channel 2 observations (at 157 GHz) (experiment EXP1) and the use of emissivities retrieved from channel 1 observations (at 89 GHz) (experiment EXP2). Note that at high latitudes the surface contribution to the observed radiation is relevant also at 157 GHz. In both experiments the additional data over sea with $TS < 278$ K are simulated with FASTEM emissivities (Liu at al. 2011) (as it is done for all the other MHS observations over sea). Emissivities for AMSU-A over sea ice are retrieved, in both experiments, from channel 3 observations (at 50.3 GHz), similarly to land observations. These two experiments are identical to the

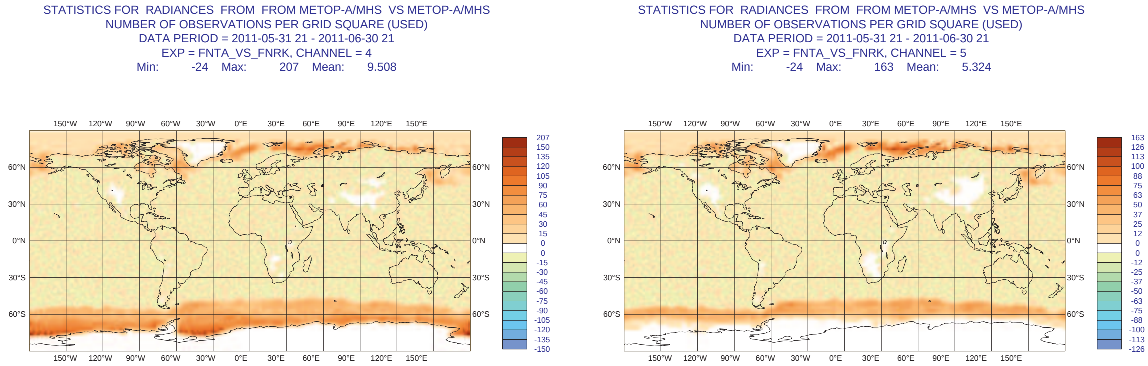

Figure 2: **Count differences for MHS channel 4 (left), channel 5 (right) observations per grid box used in the atmospheric analysis between experiment EXP1 and the control experiment in June 2011.**

control experiment (experiment CTL) except for the usage of observations over cold sea and sea ice.

The emissivities at 89 GHz might differ considerably from the ones at 183 GHz over certain surfaces. Therefore emissivities retrieved over sea ice at 89 GHz need to be corrected before being used to simulate the water vapour channels. We have applied as correction term the one currently used in the Meteo France system based on the brightness temperature difference between MHS channel 2 and 1 (Bouchard et al. 2010). The emissivities retrieved at 157 GHz are used without correction for the water vapour channels as these differences are in general smaller for emissivities retrieved at 157 GHz. We have also run an experiment (experiment EXP3) which uses over sea ice emissivities calculated with an old scheme (Kelly and Bauer 2000). As stated earlier, this static scheme is based on a classification of the surface type and an appropriate parametric model per surface type. Table 1 summarises the settings used for MHS in the assimilation experiments described above.

In all the experiments sea ice is identified as a surface having land-sea mask less than 0.1 and surface skin temperature $TS < 271.45$ K.

Results

Figure 2 shows the difference in counts between the observations actively assimilated in experiment EXP1 and the control for MHS channel 4 and 5 (the plot for channel 3 is quite similar to the one for channel 4). A considerable number of additional MHS observations is assimilated in particular below -50 degrees latitude, where there is no humidity sounding coverage in the control experiment (and similarly in the operational configuration).

Many observations over sea ice are rejected in EXP3 due to very high departures between the observations and the first-guess, proving that the dynamic emissivities over sea ice are more accurate than the

Experiment name	Experiment ID	Emissivity estimation over sea ice	Emissivity correction over sea ice	Channel used for QC over sea ice
EXP1	fnta	Retrieved from Channel 2	correction for Channel 1	Channel 1
EXP2	fnv8	Retrieved from Channel 1	correction for Channel 2-5	Channel 2
EXP3	fmqy	static scheme	NA	Channel 2

Table 1: **MHS settings for the assimilation experiments on the enhanced use of microwave sounders over sea and sea ice.**

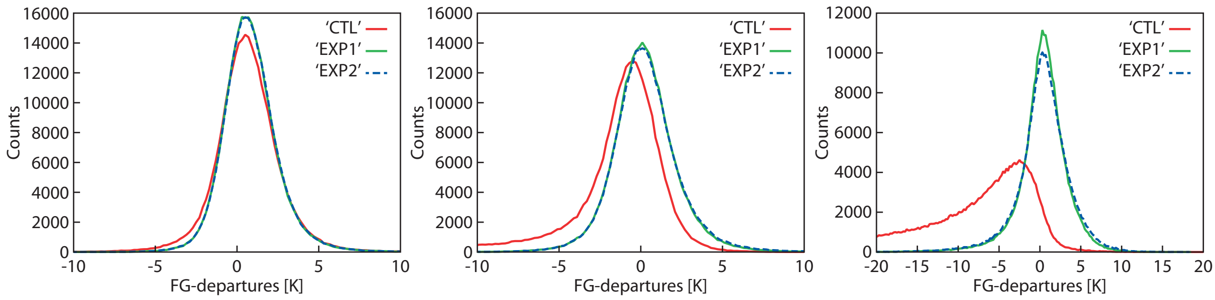

Figure 3: **Histograms of first-guess departures for MHS channel 3 (left), channel 4 (centre) and channel 5 (right) over sea ice in July 2011 when emissivities are estimated by an old static scheme (CTL, red), are retrieved dynamically from observations at 157GHz (EXP1, green) or from observations at 89 GHz and with a correction for the variation of emissivities with frequency (EXP2, blue).**

static ones.

As for the assimilation of microwave sounder data over land, using the dynamically retrieved emissivities over sea ice provides a better representation of model-estimated brightness temperatures than a static scheme. Figure 3 shows histograms of first-guess departures for MHS channel 3 (left), channel 4 (centre) and channel 5 (right) observations over sea ice when emissivities are estimated by the old static scheme (CTL, red), are retrieved dynamically from observations at 157 GHz (EXP1, green) or from observations at 89 GHz and with a correction for the variation of emissivities with frequency (EXP2, blue). Here all data have been considered, i.e. before any screening and quality control stage and before bias correction. Therefore, in the control experiment, emissivities over sea ice are estimated by the static scheme, though are not actively assimilated. The dynamic emissivities lead to improved simulations for the 183 GHz sounding channels (histograms for EXP1 and EXP2 are narrower and more centred around 0 than for the control experiment). Similar is the case for histograms of first-guess departures for AMSU-A surface-sensitive channels over sea ice (not shown). Furthermore using the 157 GHz channel for MHS emissivity retrieval appears to perform best (the histogram for EXP1 is slightly narrower than for EXP2).

Bias and standard deviation of first-guess departures for assimilated MHS channel 4 measurements over the Southern Hemisphere are slightly smaller (and a greater number of observations is assimilated) in experiment EXP1 than in experiment EXP2. Global maps of first-guess departure statistics show that this is the case particularly over sea ice (see Figure 4). This suggests that the emissivities calculated from 157 GHz, and used without a correction, might be more accurate than the ones calculated from 89 GHz, after a correction is applied to them.

Forecast results are computed for different variables and regions for 92 days of assimilation experiments. The results in the Southern Hemisphere for EXP1 are very positive for the forecast of the temperature, geopotential and winds. The positive impact for forecast of the temperature appears statistically significant at 95% confidence level for all the forecast days at 1000 hPa and from day 2 to 6 at 850 hPa, when averaged over the Southern Hemisphere (see Figure 5 and Figure 6). Also experiment EXP2 shows a positive impact in the Southern Hemisphere for the forecast of all the relevant variables.

Forecast scores show a considerable negative impact for relative humidity in the short range at the location of the additional data assimilated in both experiment EXP1 and experiment EXP2 (see Figure 7). As argued in Geer et al. (2009), this is likely an apparent degradation in the forecast error of the relative humidity due to adding humidity observations in a data-poor area and verifying using the experiment own-analysis as proxy of the true state of the atmosphere. The degradation is in fact not observed for the other atmospheric parameters, or in verification of short-term forecasts against observations.

Results on the forecast impact are very encouraging towards a more extensive exploitation of MHS observations over sea and sea ice and better simulation of AMSU-A observations over sea ice surfaces.

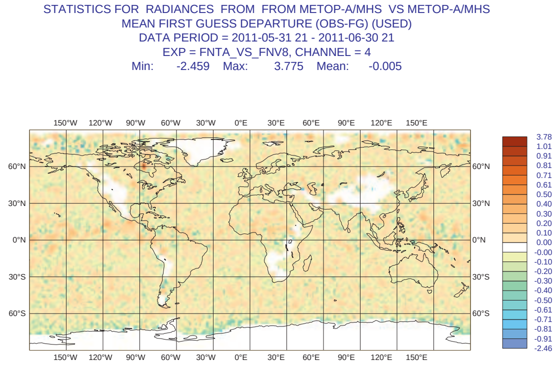

Figure 4: **Global difference of mean first-guess departures for MHS channel 4 on MetOp-A between experiment EXP1 (fnta) and experiment EXP2 (fnv8) in June 2011.**

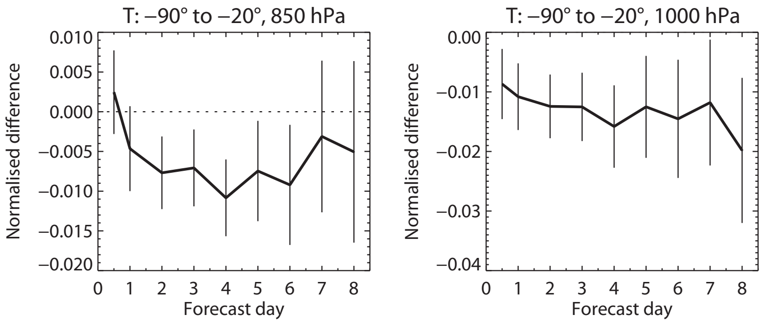

Figure 5: **Normalised differences in the root mean squared forecast error between the experiment EXP1 (fnta) and the control experiment (fnrk) for the 0Z forecast of the 850 hPa and 1000 hPa temperature. Verification is against the experiment own-analysis.**

Experiments have been run at a low resolution and will require some further testing at higher resolutions and over different seasons.

CONCLUSIONS

The use of dynamically retrieved emissivities over sea ice has allowed the assimilation of a considerable amount of humidity and temperature sounding observations in data sparse areas of the globe. Furthermore, removing the current skin temperature constraint on the assimilation of MHS measurements over sea has allowed a great number of additional observations to be used at high latitudes.

We have tested different ways of retrieving the emissivities over sea ice for the simulation of the actively assimilated MHS and AMSU-A measurements. Dynamically retrieved emissivities over sea ice provides a better representation of model-estimated brightness temperatures, for both AMSU-A and MHS, than a static scheme currently implemented at ECMWF. In particular, retrieving emissivities at 157 GHz and using them (without any correction) for the water vapour channels allows the assimilation of MHS high peaking channels over sea ice with a clear improvement to the fit of MHS channel 3 and 4 observations both in the Northern and Southern Hemisphere.

Results of assimilation experiments are encouraging towards a more extensive exploitation of MHS observations over sea and sea ice and a better usage of AMSU-A over sea ice surfaces.

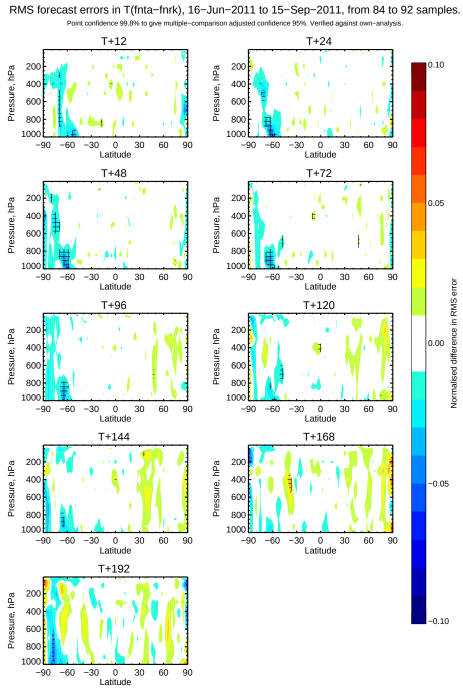

Figure 6: **Normalised differences in the root mean squared forecast error between the experiment EXP1 (fnta) and the control experiment (fnrk) for the 0Z forecast of temperature at different pressure levels. Verification is against the experiment own-analysis.**

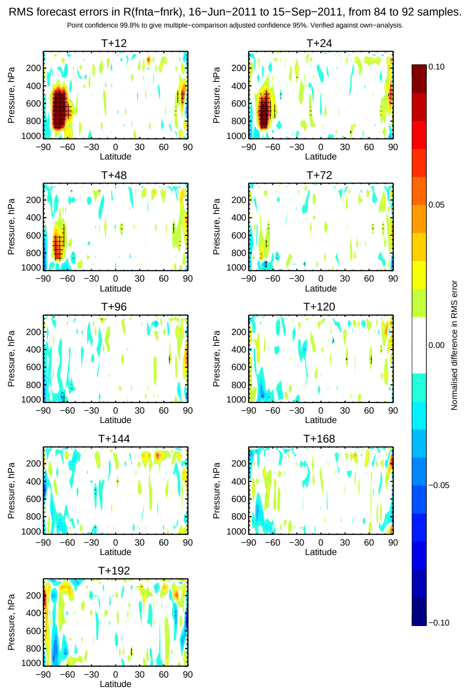

Figure 7: **Normalised differences in the root mean squared forecast error between the experiment EXP1 (fnta) and the control experiment (fnrk) for the 0Z forecast of the relative humidity at different pressure levels. Verification is against the experiment own-analysis.**

ACKNOWLEDGEMENTS

Enza Di Tomaso is funded by the EUMETSAT Fellowship Programme.

REFERENCES

Bouchard, A., F. Rabier, V. Guidard, F. Karbou (2010), Enhancements of Satellite Data Assimilation over Antarctica, Monthly Weather Review, 138(6), 2149-2173.

Di Tomaso, E., N. Bormann (2011), Assimilation of ATOVS radiances at ECMWF, In Proceedings of of the 2011 EUMETSAT Meteorological Satellite Conference, Oslo, Norway.

Geer, A. J., P. Bauer and P. Lopez (2009), Direct 4D-Var assimilation of all-sky radiances. Part II: Assessment, Q. J. R. Meteorol. Soc., 00, 1-27.

Harlow, R.C. (2011), Sea Ice Emissivities and Effective Temperatures at MHS Frequencies: An Analysis of Airborne Microwave Data Measured During Two Arctic Campaigns, IEEE Transactions on Geoscience and Remote Sensing, 49(4), 1223-1237.

Karbou, F., E. Grard, F. Rabier (2005), Microwave land emissivity and skin temperature for AMSU-A and -B assimilation over land. Q. J. R. Meteorol. Soc., 132, 2333-2355.

Kelly, G. and Bauer, P. (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, Budapest, Hungary, 167-179.

Liu, Q., F.Weng and S.J. English (2011), An Improved Fast Microwave Water Emissivity Model. IEEE Trans. Geosci. Remote Sens., 49, 1238–1250.