THE ASSIMILATION OF SURFACE-SENSITIVE MICROWAVE SOUNDER RADIANCES AT ECMWF

Enza Di Tomaso and Niels Bormann

European Centre for Medium-range Weather Forecasts
Shinfield Park, Reading, RG2 9AX, United Kingdom

Abstract

This paper gives an overview of recent work towards enhancing the use of microwave sounder data in the ECMWF system with a focus on the assimilation of surface-sensitive radiances.

ECMWF is currently assimilating microwave sounder data from five polar orbiting satellites (NOAA-15, NOAA-18, NOAA-19, MetOp-A, and Aqua) for a total of five AMSU-A and three MHS. The assimilation of the above observations is currently limited to measurements with no or weak contribution from the surface because of uncertainties in the estimated surface emission, and because cloud screening over land is more difficult. These uncertainties are particularly relevant over land and sea ice surfaces. The recent implementation of a dynamic retrieval of surface emissivities has led to a better representation of model-estimated brightness temperatures over land, providing a good ground for the exploitation of additional surface-sensitive measurements.

Here we discuss the impact in NWP of enhancing the use of observations which are sensitive to the low part of the atmosphere and provide valuable information on low-level temperature and humidity. The assimilation of additional MHS observations over land (from the lowest-peaking channel in the water vapour band) has in fact a relevant impact on the mean humidity analysis which is consistent with independent GPS observations.

Additionally, we show the results of using dynamically retrieved emissivities for MHS observations also over sea ice. As for the assimilation of microwave sounder data over land, using dynamically retrieved emissivities over sea ice provides a better representation of model-estimated brightness temperatures than a static scheme. We show that dynamic emissivities retrieved at 157 GHz lead to improved simulations for the 183 GHz sounding channels over sea ice allowing the assimilation of a considerable amount of humidity sounding observations in data sparse areas of the Globe.

INTRODUCTION

ECMWF is currently assimilating ATOVS data from five polar orbiting satellites (NOAA-15, NOAA-18, NOAA-19, MetOp-A, and Aqua) for a total of five AMSU-A, three MHS and two HIRS sensors. Here we report on studies on the microwave humidity sounder MHS. This instrument plays an important role in NWP: MHS provides important information on the water vapor profile in the troposphere and in the lower stratosphere.

The first part of the paper describes the results on the assimilation over land of MHS observations in the water vapour band that are currently not active in the ECMWF system, while the estimation of emissivies for MHS observations over sea ice is described in the second part of the paper.

ACTIVE ASSIMILATION OF AMSU-B/MHS CHANNEL 5 OVER LAND

Microwave sounding observations with a strong contribution from the surface are not currently assimilated at ECMWF because of large uncertainties in the estimated surface emission. Emissivities for the simulation of microwave sounder radiances are calculated at ECMWF using a dynamic retrieval scheme, based on re-arranging the radiative transfer equation for window channel observations and using the ECMWF model background field (Karbou et al. 2005). The implementation of the dynamic retrieval of land surface emissivities has led to a better representation of model-estimated brightness temperatures over land (Bormann et al. 2009) compared to the previous static scheme, providing a good ground for the exploitation of additional surface-sensitive measurements. The lowest-peaking of the MHS channels in the 183 GHz water vapour band (channel 5) is currently assimilated only over sea and skin temperature greater than 278 K. Here we study the impact in ECMWF system of actively assimilating MHS channel 5 also over land. This work follows the one done by Fatima Karbou at Meteo-France (Karbou et al. 2010) where channel 5 is already actively assimilated over sea, low orography (less than 1000 m) and low latitudes (between $+/-$ 55 deg).

Assimilation experiments

We have run assimilation experiments with active AMSU-B/MHS channel 5 observations over land in two summer periods from July to September in 2006 and 2010, using the ECMWF 4D-Var assimilation system at a T511 resolution. In the “channel 5 exp (2006)” channel 5 is assimilated over sea and low orography (less than 800 m), while in the “ctl exp (2006)” channel 5 is assimilated only over sea. Both experiments reject MHS observations where the skin temperature is lower than 278 K, and were run with the additional assimilation of MERIS data (which were not active in 2006 in the ECMWF system). Experiments were run in the 2006 period to be able to validate the results against GPS measurements from the African Monsoon Multidisciplinary Analysis (AMMA) campaign (Bock 2008). Also GPS measurements from the IGS network (Dow 2009) were used for the validation of changes in the humidity field. The experiments run in the 2010 period, namely the “channel 5 exp (2010)” and the “ctl exp (2010)”, have the same settings for channel 5 as the 2006 experiments, but use a different observational system (for example they include the assimilation of MetOp-A and NOAA-19).

Results

The assimilation of AMSU-B/MHS channel 5 over land has a relevant impact on the mean humidity analysis in both the 2006 and 2010 period. Figure 1 shows the mean total column water vapour (TCWV) analysis differences between the “channel 5 exp (2006)” and the “ctl exp(2006)” averaged over a month. These differences are few percent of the total TCWV value, and affect mainly the Tropical region. Similar differences are also seen for the experiments run in the 2010 period. We have investigated whether these changes agree with the information provided by the independent GPS observations available in 2006. Figure 2a shows the correlation over time between the experiment analysis (“channel 5 exp (2006)” (blue asterisks) and “ctl exp (2006)” (black circles)) and the GPS TCWV at seven GPS stations, while Figure 2b shows their average differences. The effect of channel 5 on the TCWV is significant both in terms of correlation and mean TCWV at a few stations. We have identified a IGS station in Central Africa, in Gabon, where there is a relevant impact on the mean humidity analysis. We have estimated the TCWV diurnal cycle for the “channel 5 exp (2006)” and the “ctl exp (2006)” using analysis and short term forecast fields in the vicinity of the Gabon station (Figure 3). The shift in bias during the whole diurnal cycle in the “channel 5 exp (2006)” compared to the “ctl exp (2006)” indicates that the systematic drying over Central Africa is consistent with the GPS measurements in Gabon.

Departure statistics for the assimilated observing system were computed over the three month periods after the bias correction of satellite radiances. We show here for convenience only the results related

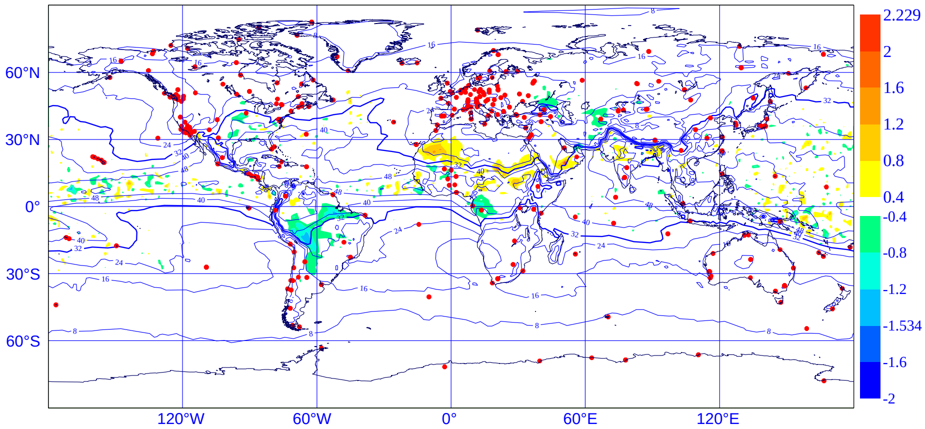

Figure 1: Mean TCWV analysis differences between the "channel 5 exp (2006)" and the "ctl exp(2006)" in kg/m^2. Contour lines represent mean TCWV analysis in the control experiment. The red dots indicate the locations of AMMA stations in Central Africa and IGS stations around the Globe.

to the 2010 experiments, as there were not relevant differences between the two periods. The standard deviation of the differences between MHS channel 4 observations and model background (a short term forecast) for the "channel 5 exp (2010)" (black) and the "ctl exp (2010)" (red) are in Figure 4. The small increase in the standard deviation for channel 5 in the "channel 5 exp (2010)" is due to the additional data over land for which the estimate for the surface emission is still poorer than that over sea. The assimilation of channel 5 improves slightly the fit to MHS channel 4 observations (there is a small improvement of in the standard deviation of channel 4 compared to the control experiment). Also the fit to radiosonde observations in an area of South America (where a relevant impact is observed in the analysis) is slightly improved in the lower levels: Figure 5 shows the mean and standard deviation of radiosonde humidity observation departures from model estimates in the "channel 5 exp (2010)" (black) and in the "ctl exp (2010)" (red).

The experiments's impact on the forecast has been studied for different variables and forecast ranges and results were computed for 92 days of assimilation experiments. The forecast impact is neutral in most cases and in both periods when channel 5 is actively assimilated over land, which is consistent with a relatively small impact of these observations on the analysis.

ENHANCED ASSIMILATION OF MICROWAVE SOUNDING DATA OVER SEA AND SEA ICE

MHS observations from channel 3, 4 and 5 (the 3 channels in the 183 GHz water vapour band) 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 60 deg 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).

As for the assimilation of microwave sounder data over land, the dynamic retrieval of emissivities provides a good basis for the use of MHS sounding over sea ice, as shown also in (Bouchard et al. 2010). The dynamic retrieval of emissivities is based on the assumption that the error introduced by using for a given frequency emissivities calculated at a different frequency is small. As shown earlier in this paper, this is the case for MHS observations over land: departure statistics show that emissivities retrieved at

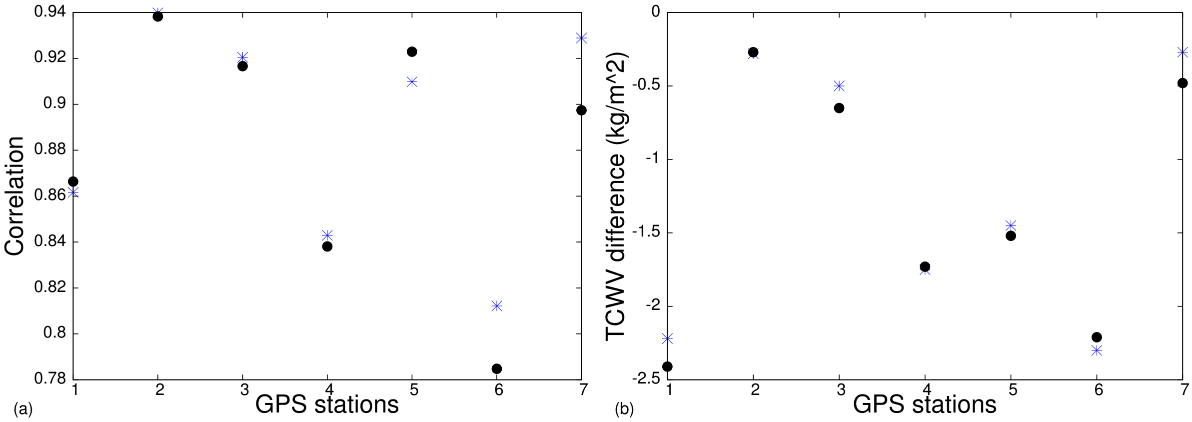

Figure 2: Correlation (a) and average differences (b) between the experiment analysis in the "channel 5 exp (2006)" (blue asterisks) and in the "ctl exp (2006)" (black circles) versus the GPS TCWV at six AMMA stations (Djougou (Benin), Niamey (Niger), Gao (Mali), Tamale (Ghana), Ouagadougou (Burkina Faso), Tombouctou (Mali)), and at the Gabon IGS station.

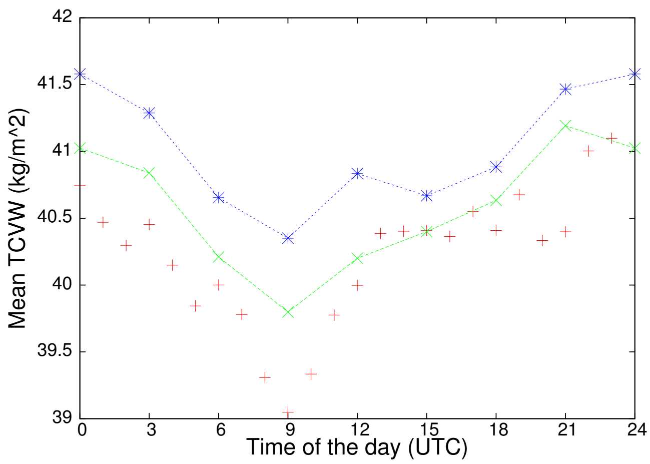

Figure 3: TCWV diurnal cycle at Gabon station for the "channel 5 exp (2006)" (green crosses), the "ctl exp (2006)" (blue asterisks), and GPS measurements (red pluses).

89 GHz can be used 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. These issues have been taken into account in the experiments described in the next section.

Assimilation experiments

We have run assimilation experiments with the active usage of additional MHS observations over sea and 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.

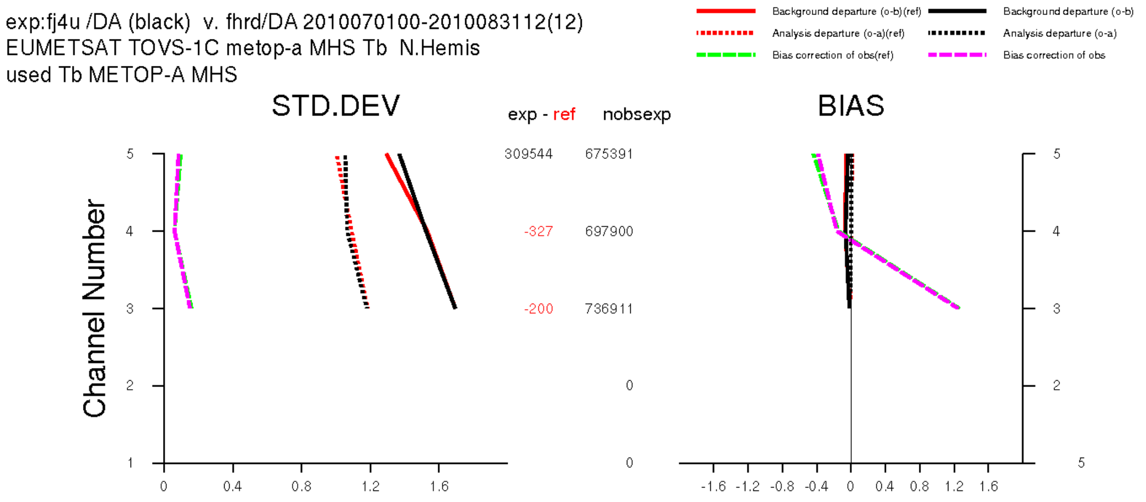

Figure 4: MetOp-A MHS brightness temperature departure statistics for the "channel 5 exp (2010)" (black) and the "ctl exp (2010)" (red) for the Northern Hemisphere.

The emissivities used in the simulation of radiances over sea ice are dynamically retrieved emissivities. 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). 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). These two experiments are identical to the 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 (known as the Kelly & Bauer scheme). This static scheme is based on a classification of the surface type and an appropriate parametric model per surface type.

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

Results

Figure 6 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 deg latitude, where there is no humidity sounding coverage in the control experiment (and similarly in the operational configuration).

Most 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 static ones calculated by the old Kelly & Bauer scheme.

As for the assimilation of microwave sounder data over land, using the dynamically retrieved emissivities

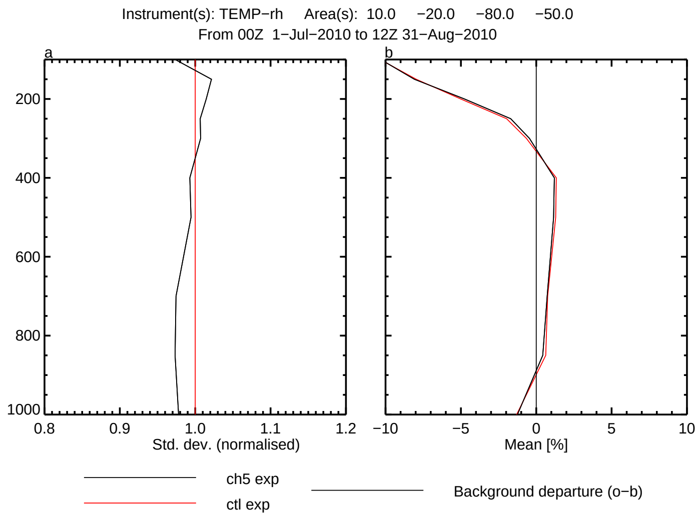

Figure 5: Radiosonde humidity departure statistics for the "channel 5 exp (2010)" (black) and the "ctl exp (2010)" (red) for an area of South America. The standard deviations have been normalised to the control experiments.

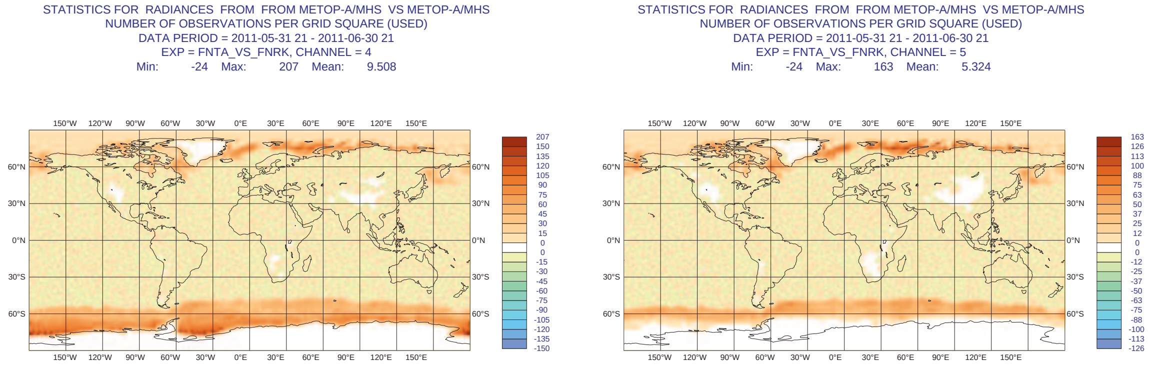

Figure 6: Count differences for MHS channel 4 (left), channel 5 (right) observations per grid box used in the atmospheric analysis between experiment EXP1 and the control experiment in June 2011.

over sea ice provides a better representation of model-estimated brightness temperatures than a static scheme. Figure 7 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 Kelly & Bauer 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 Kelly & Bauer 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), and using the 157 GHz channel for the 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 8). This suggests that the emissivities calculated from 157 GHz, and used without a correction, might be more accurate than the ones calculated from 89

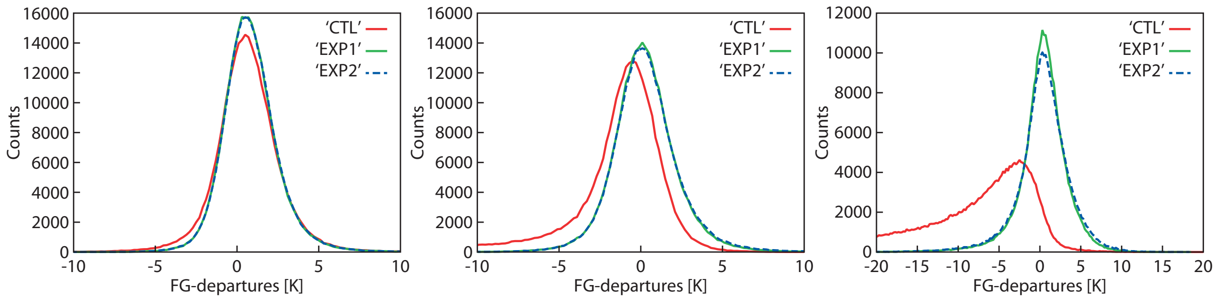

Figure 7: Histograms of first-guess departures for MHS channel 3 (left), channel 4 (centre) and channel 5 (right) over sea ice in July 2011 when emissivities are estimated by an old static scheme (known as the Kelly & Bauer scheme, CTL, red), are retrieved dynamically from observations at 157GHz (EXP1, green) or from observations at 89 GHz and with a correction for the variation of emissivities with frequency (EXP2, blue).

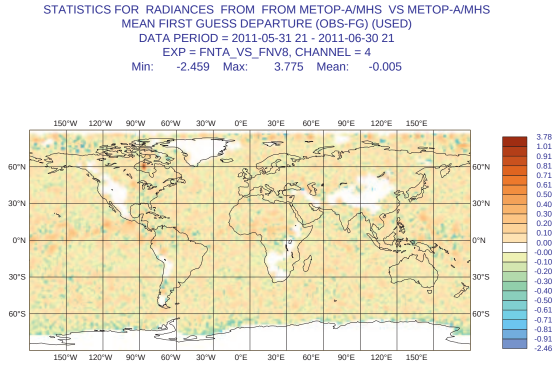

Figure 8: Global difference of mean first-guess departures for MHS channel 4 on MetOp-A between experiment EXP1 (fnta) and experiment EXP2 (fnv8) in June 2011.

GHz, after a correction is applied to them.

Preliminary results on the forecast impact are very encouraging towards a more extensive exploitation of MHS observations over sea and sea ice. Results of assimilation experiments are significantly positive for the forecast of the temperature, geopotential and winds in the Southern Hemisphere (not shown). Experiments have been run at a low resolution and will require some further testing at higher resolutions.

CONCLUSIONS

The active assimilation of MHS channel 5 over land provides low-level humidity information which has been positively evaluated against independent GPS measurements. Furthermore it improves the fit to other observations already in the system: in particular there is evidence of a better first-guess for MHS channel 4 (a channel also in the water vapour band, peaking above channel 5). The emissivities used for the simulation of MHS radiances are dynamically retrieved from MHS channel 1 (89 GHz) and the ECMWF background field. As result of these studies, MHS channel 5 is now actively assimilated over land in the latest ECMWF operational cycle (CY38R1).

The use of dynamically retrieved emissivities over sea ice has allowed the assimilation of a considerable amount of humidity sounding observations in data sparse areas of the Globe. Furthermore, removing the current skin temperature constrain 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 three ways of retrieving the emissivities over sea ice for the simulation of the actively assimilated MHS measurements. 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.

ACKNOWLEDGEMENTS

Enza Di Tomaso is funded by the EUMETSAT Fellowship Programme.

REFERENCES

Bock, O., M.N. Bouin, E. Doerflinger, P. Collard, F. Masson, R. Meynadier, S. Nahmani, M. Koit, K. Gaptia Lawan Balawan, F. Did, D. Ouedraogo, S. Pokperlaar, J.-B. Ngamini, J.P. Lafore , S. Janicot, F. Guichard, M. Nuret (2008), The West African Monsoon observed with ground-based GPS receivers during AMMA. J. Geophys. Res., 113, D21105.

Bormann, N., B. Krzeminski, P. Bauer (2009), Developments in the use of ATVOS data at ECMWF. Proceedings of the 2009 EUMETSAT Meteorological Satellite Conference, Bath, United Kingdom 21 - 25 September 2009, EUMETSAT P.55

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

Dow, J.M., Neilan, R. E., and Rizos, C. (2009), The International GNSS Service in a changing landscape of Global Navigation Satellite Systems, J. Geodesy, 83, 191198.

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., F. Rabier, J.-P. Lafore, J.-L. Redelsperger, O. Bock (2010), Global 4DVAR Assimilation and Forecast Experiments Using AMSU Observations over Land. Part II: Impacts of Assimilating Surface-Sensitive Channels on the African Monsoon during AMMA, Wea. Forecasting, 25, 2036.

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.

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