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Assimilation of MWHS data over land

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Abstract

ECMWF have been assimilating the FY-3B MWHS (Microwave Humidity Sounders) data over sea in the operational forecasting system since the September 24th, 2014. It is more difficult to assimilate microwave observations over land and sea ice than over the open ocean due to higher uncertainty in land surface temperature, surface emissivity and less effective cloud screening. We compare approaches in which the emissivity is retrieved dynamically from MWHS channel 1 (150GHz (V)) with the use of an evolving emissivity atlas from 89 GHz observations from the Microwave Humidity Sounders (MHS) on NOAA and EUMETSAT satellites.

The assimilation of the additional data over land improves the fit of short-range forecasts to other observations, notably ATMS humidity channels, and the forecast impacts are mainly neutral to slightly positive over the first 5 days. The forecast impacts are better in boreal summer and the Southern Hemisphere. These results suggest that all of the techniques tested allow for effective assimilation of MWHS/FY-3B data over land.

1. Introduction

Since September 24th, 2014, MWHS/FY-3B data has been actively used in the ECMWF operational forecasting system (Chen et.al, 2015). The data is assimilated over sea only, excluding all data over land and sea ice.

Assimilation of MWHS over land needs an estimate of emissivity. One option is to use microwave land emissivity models (Weng et. al., 2001), another is to use an emissivity atlas (Karbou et. al., 2005), and a third is to retrieve emissivity dynamically from microwave window channels (Karbou et. al., 2006).

Physical land emissivity models require a number of inputs that must be estimated or derived from the NWP model or taken from climatology. However, many input values are not usually available from land surface models. Therefore most assimilation systems retrieve the land surface emissivity directly from the microwave observations at 50 GHz for temperature sounders (e.g. AMSU-A) and 89 GHz for humidity sounders (e.g. MHS) (Karbou et. al. 2006). For the latter, the 150 GHz channel is at times used for emissivity retrieval over snow or sea-ice surfaces (e.g., Di Tomaso et al 2013).

In this study, we consider an approach in which emissivity is retrieved dynamically from MWHS/FY-3B channel 1 (150GHz (Vertical polarization)), as no 89 GHz channel is available, and compare this with the use of an emissivity atlas based on 89 GHz observations from other sensors.

The structure of the paper is as follows: section 2 describes the emissivity and experiment settings for adding data over the snow-covered surfaces; section 3 presents the results, and conclusions are included in section 4.

2. Quality control and surface characterization

2.1 Emissivity estimation

In order to assimilate MWHS/FY-3B over land, two approaches to specifying surface emissivity have been compared. One is to use an 89 GHz emissivity atlas derived from instruments on other satellites. This evolves over time using a Kalman filter and the emissivity is parameterized as a polynomial of the scan angle θ to account for the different effective polarization within the swath, assuming that the emissivity changes occur slowly (Krzeminski 2009). The other is to retrieve emissivity from the 150 GHz (Vertical Polarization) channel; MWHS/FY-3B does not have an 89 GHz channel (Table 1). 150 GHz is more sensitive to water vapor than 89 GHz, so is useful when the total column water vapor is low, e.g. at high latitude (e.g., Di Tomaso et al 2013), but more problematic at low latitudes. Figure 1 shows the difference between the retrieved dynamic emissivity from 150 GHz (V) of MWHS/FY-3B and the 89 GHz emissivity atlas at 00Z on the October 3rd, 2013. For most locations the differences are within 0.05. Larger differences are found over the snow covered surfaces as would be expected as the emissivity of snow is more variable both in time and frequency than that of snow-free surfaces. This means we have low confidence in the emissivity estimate in these regions, as we do not know whether to trust the atlas or the 150 GHz dynamic emissivity estimate more. 150 GHz is more sensitive to the atmosphere, but the retrieved emissivity is also more representative of the emissivity at 183 GHz, due to being closer in frequency. We therefore compare using the atlas alone to using the retrieved 150 GHz emissivity. To ensure that the 150 GHz has sufficient surface sensitivity to perform a reliable emissivity retrieval, we require that the surface-to-space transmittance is larger than 0.5. If this condition is not fulfilled (e.g., in tropical areas) the emissivity atlas is used instead. In addition, the dynamic emissivity is only used when the estimate differs from the emissivity atlas by less than 0.2. This threshold is designed to remove outliers for which the differences are much larger than what would be expected given typical uncertainties in the dynamic emissivity and the atlas emissivity.

Channel number		Frequency (GHz)	
MHS	MWHS	MHS	MWHS
1		89(V)	150(V)
2		150(H)	
3		183.31$\pm$1(V)	
4		183.31$\pm$3 (V)	
5		190.31 (V)	

Table 1. MHS and MWHS channel frequency.

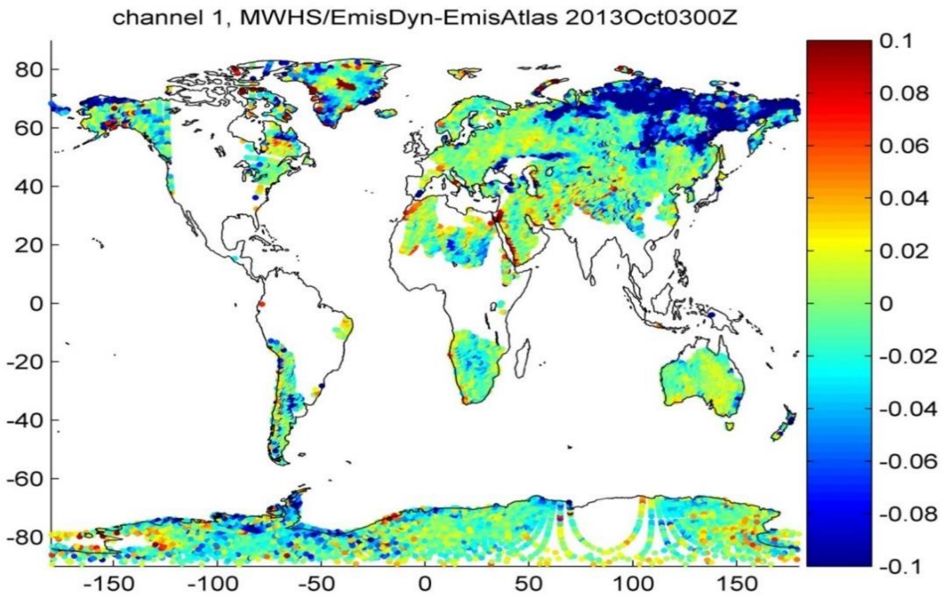


***Figure 1**. The difference between the retrieved dynamic emissivity from 150GHz (V) of MWHS/FY-3B and the 89 GHz emissivity atlas at 00Z on the October 3rd, 2013. Only regions where a successful 150 GHz retrieval could be performed are shown (see main text for details).*

2.2 Quality control over snow covered surfaces

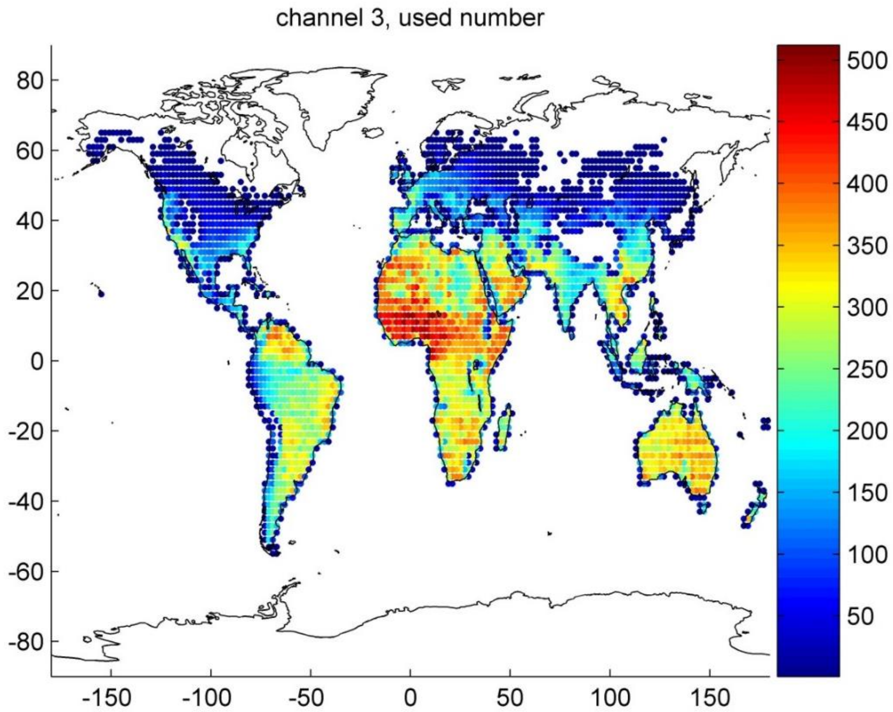
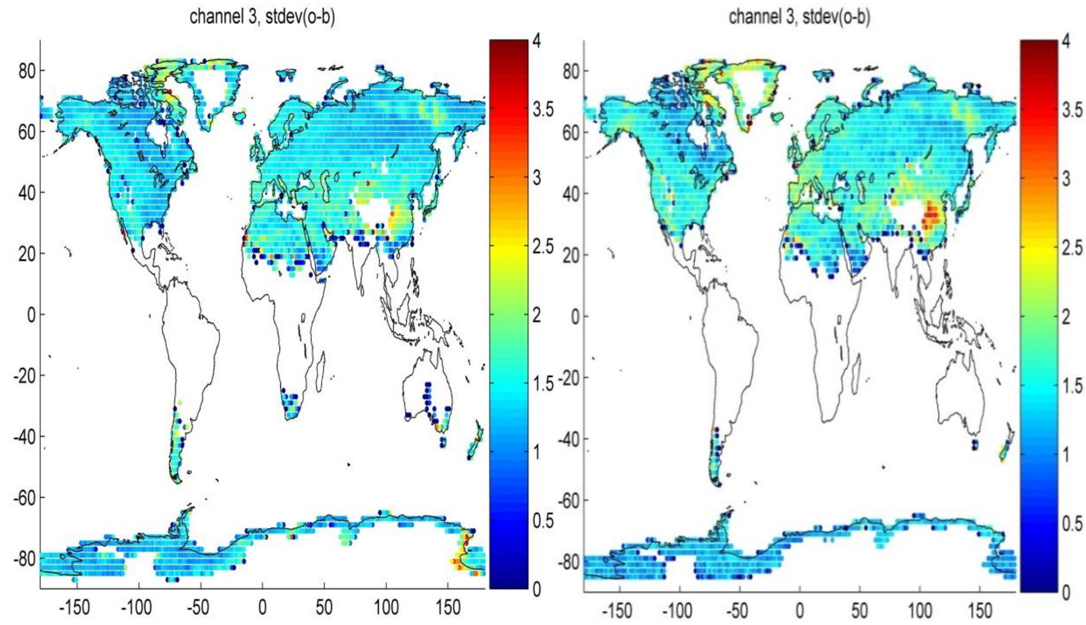


Figure 2. *MWHS/FY-3B channel 3 averaged used data number in Northern Hemisphere boreal winter without using the dynamic emissivity. Time period is from 2015010100Z to 2015033112Z.*

Noting the high level of uncertainty in the emissivity estimates over snow, MWHS/FY-3B observations were initially excluded where the skin temperature is lower than 278K. 278 K was taken as a proxy for snow, but clearly also rejects many snow free scenes. An example of the winter data coverage is shown in figure 2, taken from the first three months of 2015. Subsequent analysis has shown that this quality control criterion is too conservative for some channels. Figure 3 shows the first-guess departure standard deviations of the MWHS/FY-3B channel 3 which is sensitive to upper tropospheric humidity, with peak sensitivity around 400 hPa. The channel 3 clear data (Chen, et.al., 2015) are comparable to those of the MHS/NOAA-18 equivalent channel for scenes where the skin temperature is less than or equal to 278K (i.e. the observations rejected by this quality control check). No abnormally large standard deviations are found for snow-covered surfaces. Therefore, for the MWHS/FY-3B channel 3, the skin temperature check is unnecessary and data can be assimilated in snow covered regions. This is equivalent to the use of MHS in the present ECMWF operational system.



(a) (b)

***Figure 3**. The time averaged channel 3 first-guess departure standard deviations of MHS/NOAA-18 clear data (a) and MWHS/FY-3B clear data (b) over land where the orography is lower than 1500 meters and the skin temperature is no larger than 278K. Time period is from 2015010100Z to 2015033112Z.*

For channel 4, the weighting function peaks at lower altitude, close to 600hPa for a standard US atmosphere at nadir view. However due to the broad weighting functions the impacts of the surface on this channel are significant (Figure 4c and 4d). The investigations suggested that unlike channel 3 there is value to retaining a skin temperature check. However the value can be set to a low value. The final choice was 255K based on examining first-guess departure standard deviations of the MWHS/FY-3B channel 4 clear data (Figure 4b). These are comparable to MHS (Figure 4a) for the skin temperatures between 255K and 278K, except that the MWHS observations have higher noise due to higher NEDT and some points with gross error that the general QC procedure in 4D-var can easily remove (Chen et. al., 2015). As for the regions where the skin temperatures are lower than 255K, the first-guess departure standard deviations of both MHS/NOAA-18 and MWHS/FY-3B are quite large (Figure 4c and 4d). The reason why it is worse for the skin temperatures lower than 255K is not yet understood, but may reflect changes in snow morphology that make the atlas less representative, or larger skin temperature errors in these extreme conditions may lead to poorer emissivity retrievals and larger departures.

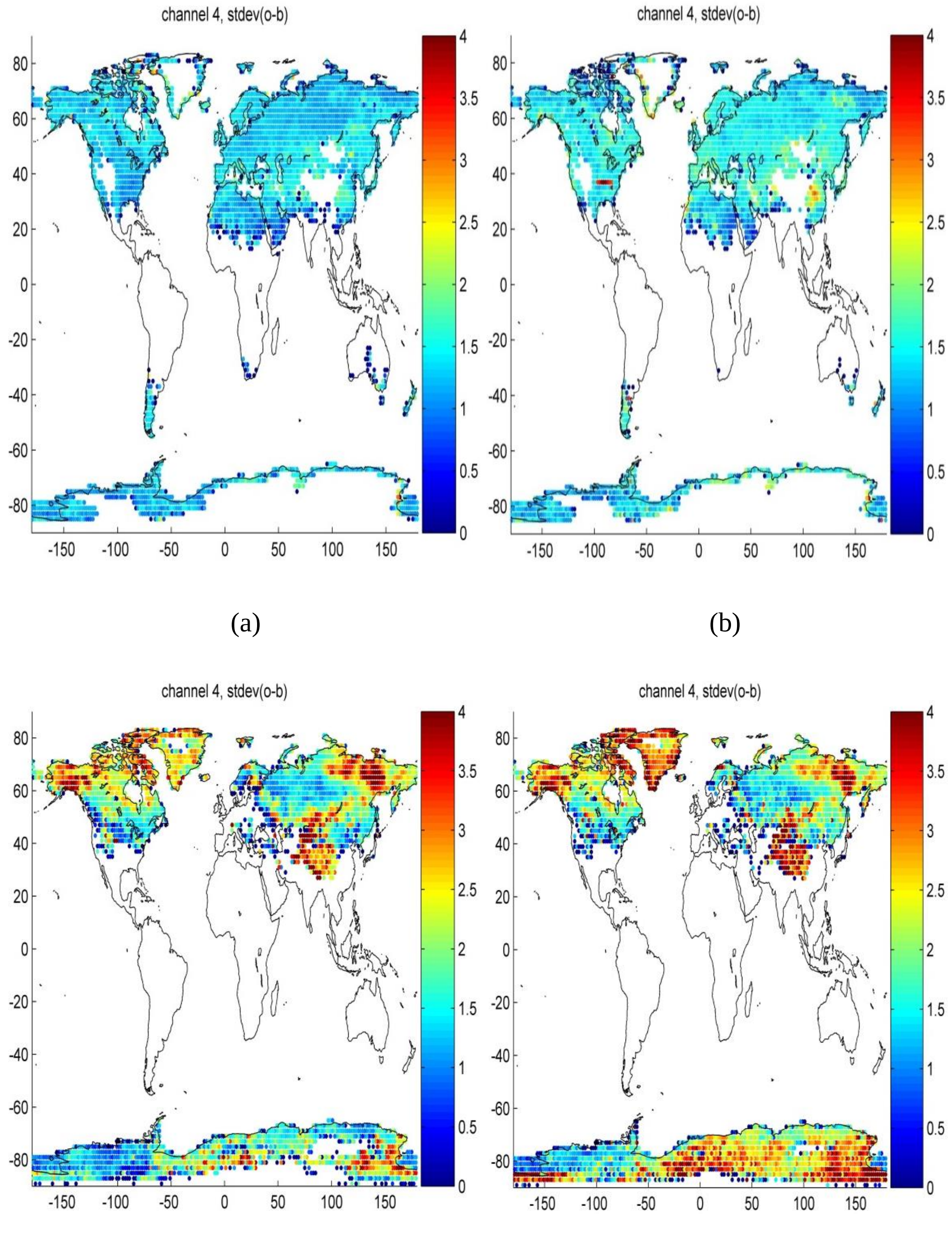


Figure 4*. The time averaged first-guess departure standard deviations of MHS/NOAA-18 (a) MWHS/FY-3B (b) channel 4 clear data over land where the orography is smaller than 1000 meters and the skin temperatures are between 255K and 278K; the time averaged first-guess departure standard deviations of MHS/NOAA-18 (c) MWHS/FY-3B (d) channel 4 clear data over land where the skin temperatures are below 255K. The emissivity is using the emissivity atlas. Time period is from 2015010100Z to 2015033112Z.*

So to summarize there are three scenarios being tested, testing sensitivity both to choice of emissivity estimate and quality control checks, and these are described in the next section.

2.3 Experiment settings

Assimilation experiments have been conducted using ECMWF's 12-hour 4DVAR assimilation system, with a model spatial resolution of around 40 km, a final incremental analysis resolution of about 80km, and 91 levels in the vertical. The control experiment was run from January 1st, 2015 to March 31st, 2015, and 10-day forecasts were run at 00Z and 12Z each day, which provides 180 forecast samples in total. The control run assimilates the same observations used operationally by ECMWF on these dates i.e. including MWHS/FY-3B data over sea. Scan positions 12-81 are assimilated for channel 5 whereas the full scan is used for other channels (see Chen et al. 2015). To remove observations strongly affected by ice cloud and precipitation, a 5K check on the absolute value of the first-guess departure of channel 1 is made (Chen et. al., 2015). This definition of "clear sky" will be used in this paper: it does not mean no clouds, but rather that the radiative impact of clouds is considered to be small, and is not analyzed. Note that this criterion will also reject data for which the emissivity or skin temperature estimate is significantly in error.

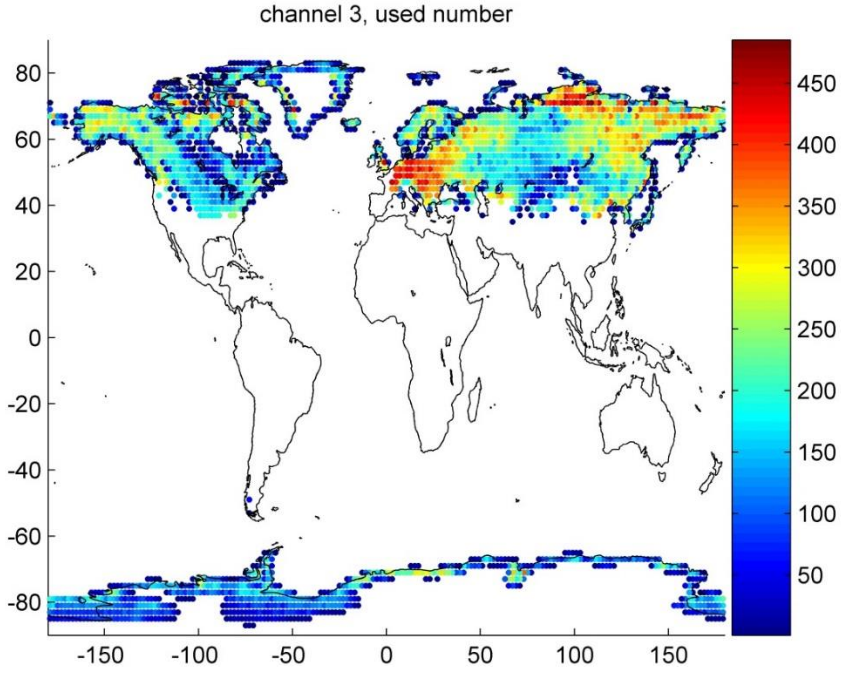
The thresholds of the orography for channel 3 is 1500m; that for channel 4 is 1000m and that for channel 5 is 800m for both MHS/NOAA-18 and MWHS/FY-3B in order to avoid observations that are too sensitive to the surface, i.e. where errors in the surface emissivity or the skin temperatures play a large role. These thresholds reflect the different surface sensitivities of the sounding channels, tighter for the lowest channel (channel 5) and less tight for the higher channels.

Based on the control run settings, the BasicAtlas experiment assimilates MWHS/FY-3B over land using the emissivity atlas without adding data over the snow-covered surfaces; in the SnowAtlas experiment MWHS/FY-3B is assimilated over land using the emissivity atlas with adding data over the snow-covered surfaces (ie using the relaxed skin temperature check); the SnowDynamic experiment is the same as the SnowAtlas run but uses the dynamic emissivity retrieved from 150GHz(V). For the SnowDynamic run, the MWHS channel 1 observations cannot be used for both the clouds and precipitation screening and retrieving the emissivity. We therefore use channel 5 to identify clear observations, as it is the next available lowest-peaking channel with the strongest cloud sensitivity. The criterion for "clear data" remains absolute first-guess departures below 5K and the MWHS channel 5 observations are not assimilated. In addition, the same series of experiments are repeated for the Northern Hemisphere summer from July 1st, 2014 to September 30th, 2014 to test seasonal differences.

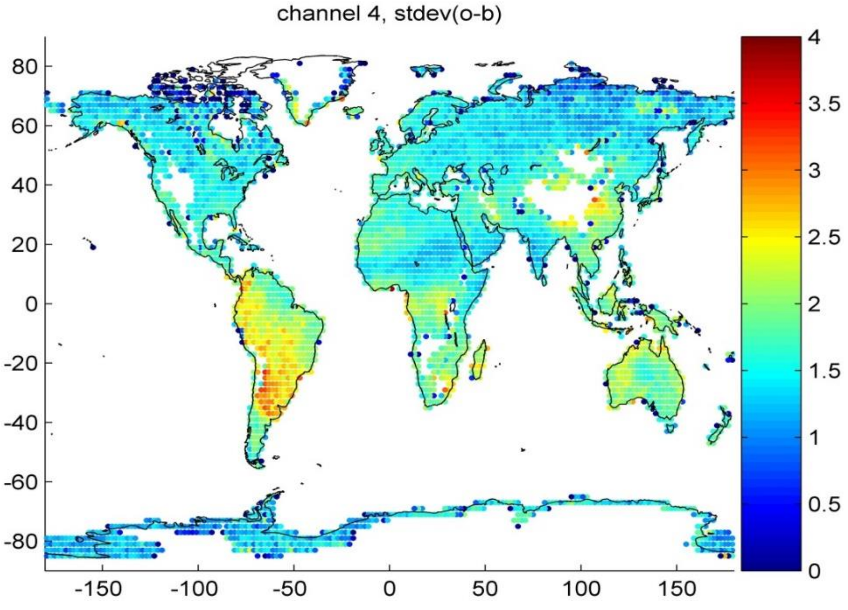
3. Results

3.1 Change in the number of used data

Compared to the control run many additional observations are assimilated over land in the BasicAtlas experiment (Figure 2), and even more channel 3 observations are added in the SnowAtlas experiment (Figure 5a). The time-averaged first-guess departure standard deviations of MWHS/FY-3B channel 4 used data in the SnowAtlas experiment are reasonable over the snow-covered surfaces (Figure 5b), validating that the updated quality control is a good choice. The used data is further increased in snow covered areas in the SnowDynamic experiment (Figure 6), which indicates that adopting the retrieved 150GHz emissivity does allow more observations over the snow covered surfaces being used.



(a)



(b)

Figure 5*. The averaged increased data use coverage of the MWHS/FY-3B channel 3 over the snow-covered surfaces in the SnowAtlas experiment relative to the BasicAtlas experiement (a) and the time averaged first-guess departure standard deviations of MWHS/FY-3B channel 4 used data in the SnowAtlas experiment (b). Time period is from 2015010100Z to 2015033112Z.*

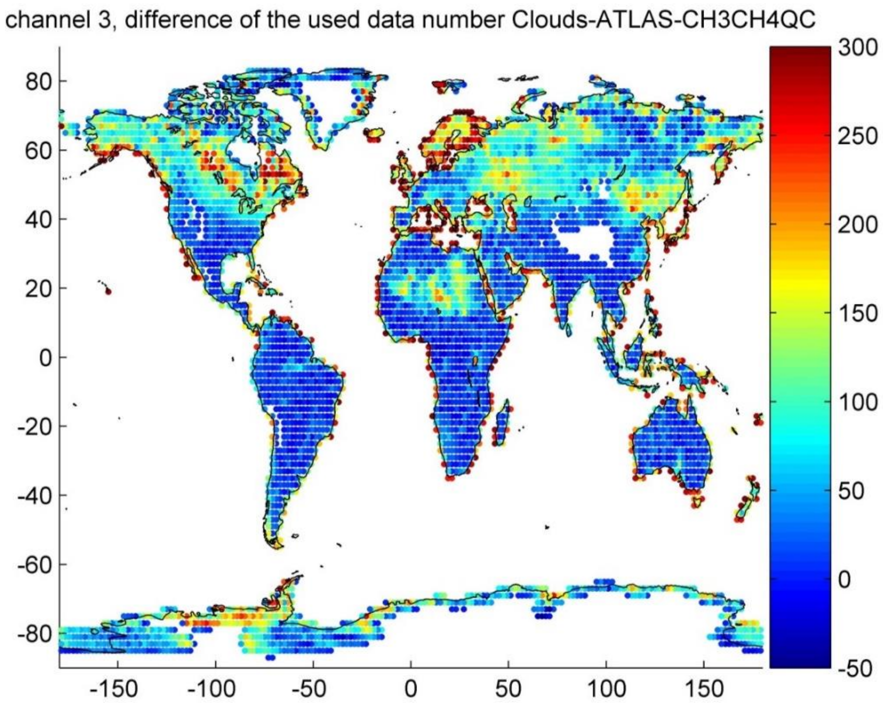


Figure 6. *The averaged used number difference of the MWHS/FY-3B channel 3 between the SnowDynamic experiment and the SnowAtlas experiment. Time period is from 2015010100Z to 2015033112Z.*

3.2 Analysis and Forecast Impact

3.2.1 Analysis impact

We will now discuss the impact of adding MWHS/FY-3B data over land in the context of the full observing system used operationally at ECMWF at the time. This provides a stringent test of using the data in the “clear sky” case considering that the full system has many humidity observations over both sea and land.

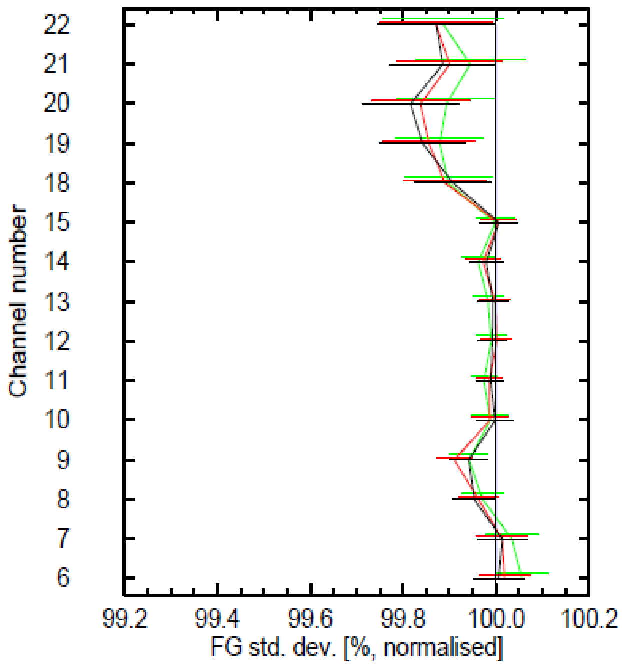


***Figure** 7. Standard deviations of the first-guess departures of used ATMS data in Northern Hemisphere, normalized by values for the control experiment. Horizontal bars indicate 95% confidence intervals. The green line is for the BasicAtlas experiment; the red line is for the SnowAtlas experiment; the black line is for the SnowDynamic experiment. The period merges 1 July 2014 to 30 September 2014 and 1 January 2015 to 31 March 2015 together.*

Assimilating MWHS/FY-3B observations over land does not show any negative impacts on the FG fit to other instruments in the ECMWF observing system. Departure statistics for ATMS are shown in figure 7. Results are combined for the winter and summer trials, providing 364 samples in total. Adding data over land (BasicAtlas experiment) shows positive impacts on the first-guess departures, especially over the Northern Hemisphere (green line). Compared to the BasicAtlas experiment, the experiments with adding data over the snow-covered surfaces indicate more positive impacts on the first-guess departures, but these differences are not statistically significant. The impacts are more neutral for the Southern Hemisphere and the Tropics as there is less land (not shown). Improvements were also found in first-guess departures of the humidity channels of other instruments, such like HIRS and SSMIS (not shown).

3.2.2 Forecast Impacts

With both seasons combined, the SnowDynamic experiment shows significantly positive forecast impacts for the vector wind in the Southern Hemisphere out to day 3 or 4 of the forecast, a positive impact at day 2 in the Northern Hemisphere, and neutral results in the Tropics (Figure 8). The stronger positive forecast impact over the Southern Hemisphere is somewhat unexpected, given the smaller amount of data added in these regions. A possible reason might be that the Southern Hemisphere is less well constrained by other observations, particularly conventional ones, so even smaller amounts of data can have a notable impact. There is some indication of a negative impact at longer forecast range in the Northern Hemisphere in days 5-9 but this is not statistically significant. Neutral results were found in the BasicAtlas or SnowAtlas experiment. The scores are verified against the ECMWF operational analyses. Similar conclusions can be obtained not only for the vector wind, but also for the geopotential height, temperature and humidity (not shown). Figure 9 shows the vertical structure of the forecast impact showing again the statistically significant positive impact in the Southern Hemisphere, but inconclusive results in the Northern Hemisphere. The two seasons have also been examined individually, and the results in both periods were broadly consistent.

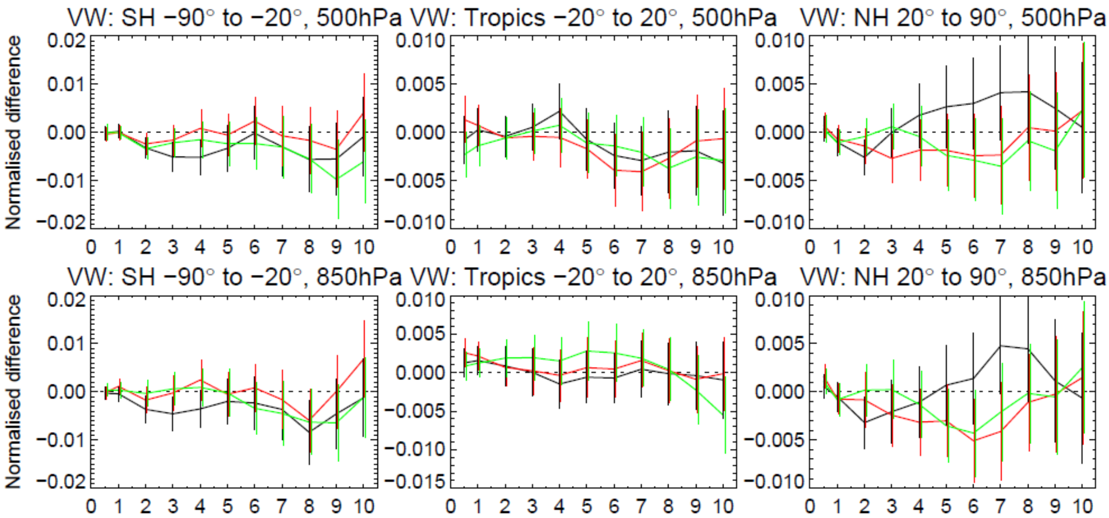


***Figure 8**. Normalized difference in the root mean squared vector wind error at 500hPa (top) and 850hPa (bottom) as a function of forecast range [days] over the Southern Hemisphere (left), Tropics (middle) and Northern Hemisphere (right) of the BasicAtlas experiment (green line), and of the SnowAtlas experiment (red line), and of the SnowDynamic experiment (black line). Negative normalized differences indicate an improvement in forecast quality. Vertical bars show the 95% confidence range. The period merges 1 July 2014 to 30 September 2014 and 1 January 2015 to 31 March 2015 together. Statistics are based on a total of 364 forecasts and verified against the ECMWF operational analysis.*

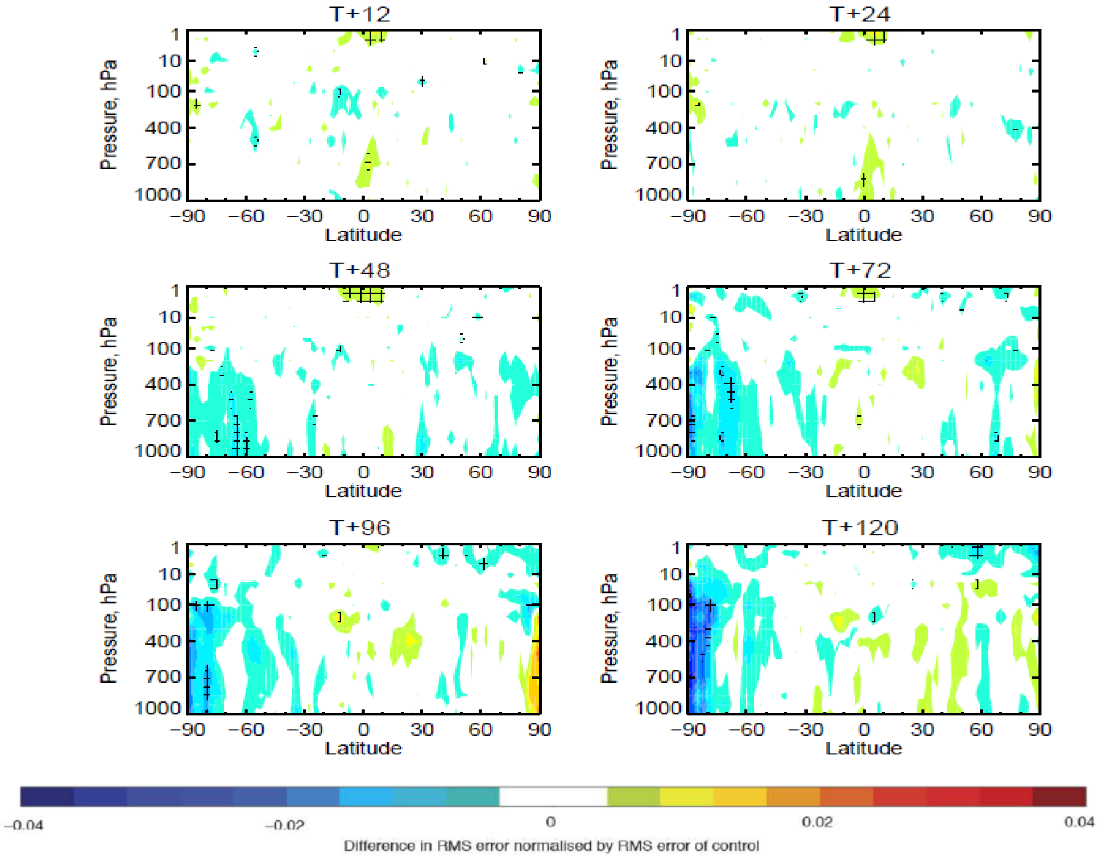


Figure 9*. Zonal means of the difference in forecast errors of the vector wind with time between the SnowDynamic experiment and the control run, normalized by the control run. The period merges 1 July 2014 to 30 September 2014 and 1 January 2015 to 31 March 2015 together. Statistics are based on a sample of 364 forecasts over the study period and verified against the ECMWF operational analysis.*

4. Conclusions

Observations over land from the microwave humidity sounding instrument on the FY-3B satellite have been tested in the ECMWF Integrated Forecasting System (IFS). The MWHS data quality has been demonstrated by Chen et.al. (2015). Assimilation of satellite sounder radiances over land is very sensitive to the choice of emissivity and quality control procedures and hence different approaches have been studied. The experiments assimilating MWHS/FY-3B data over land by using the emissivity atlas improves the first-guess departures of the ATMS humidity channels, despite the lack of observations in snow covered areas. The forecast impacts from these experiments are however found to be more neutral.

The quality control used initially rejected most data for the snow-covered surfaces. A revised QC procedure that allows more data over the snow-covered surfaces to be assimilated was tested. The analysis of the first-guess departures statistics indicates that assimilating more MWHS/FY-3B data over land, particularly in snow covered areas, again significantly improves the fit of short-range forecasts to other observations in the Northern Hemisphere, notably the ATMS humidity channels. However the forecast impact of this configuration was again found to be neutral.

Finally the configuration using 150 GHz (V) dynamic emissivity was found to give broadly similar results to the emissivity atlas with less stringent quality control in terms of FG fit to ATMS, but this configuration did show some positive forecast impacts, especially in the Southern Hemisphere.

To summarize the forecast impact from MWHS over land is strongest when 150 GHz emissivity is used with the less stringent skin temperature QC option, to increase data coverage in snow covered regions.

5. Acknowledgements

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