All-sky assimilation of the SAPHIR microwave sounder on-board Megha-Tropiques within the ECMWF data assimilation system

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Introduction

Data assimilation experiments of the radiances from the microwave sounder SAPHIR on-board the Megha-Tropiques satellite are conducted within the ECMWF "all-sky" framework. This system offers the unique capability of directly assimilating observations affected by clouds and precipitation within a 4D-Var system. In order to successfully assimilate these observations, a "symmetric error model" is used, which prescribes observation errors as function of identified cloudy and precipitating regions. The adaptation of this error model to SAPHIR 183.31GHz channels is presented below. Then, the results of data assimilation experiments conducted over a six-month period from January to June 2015 are shown. In particular, the impact of SAPHIR data assimilation is illustrated through data denial experiments of other available mw sounders in the Tropics.

An observation error model for the SAPHIR instrument

The SAPHIR instrument sounds the atmosphere with 6 channels along the 183.31GHz water vapour absorption band. Hence, one of the main difference with a AMSUB/MHS-like sounder is that is sounds the atmosphere with twice more channels, at the cost of a lack of window channels like the 89GHz or the 157GHz channels available from AMSUB/MHS.

Within the ECMWF all sky framework (Geer et al., 2016), a brightness temperature based cloud predictor is used to prescribe observations errors used in the 4D-Var data assimilation system. The symmetric cloud predictor currently used over Oceans for MHS all sky assimilation is based on the Scattering Index defined as follows (Geer et al., 2014):

$$\text{SI MHS} = (TB_{90GHz} - TB_{150GHz}) - (TB_{90GHz}{}^{clr} - TB_{150GHz}{}^{clr})$$

$$\text{Symmetric Cloud Predictor for MHS} = .5 \times ((\text{SI MHS})_{model} + (\text{SI MHS})_{obs})$$

Defining a cloud predictor:

A simple study was performed to select a scattering index for SAPHIR which would behave similarly to the one already for MHS: (i) Forward RTTOV SCATT simulations of both MHS and SAPHIR channels have been performed on the same sample of atmospheric model profiles ($3.8.10^6$ of AROME profiles in the Indian Ocean) ; (ii) the SI MHS was computed as well as different combinations of SAPHIR channels ; (iii) correlations are computed between SI MHS and the potential cloud predictors for SAPHIR.

Correlation with	SI MHS	Correlation with	SI MHS	Correlation with	SI MHS	Correlation with	SI MHS	Correlation with	SI MHS	Correlation with	SI MHS
$TB_1 - TB_1^{clr}$	-0.62										
$TB_2 - TB_2^{clr}$	-0.71	$(TB_1-TB_2) - (TB_1^{clr}-TB_2^{clr})$	0.75								
$TB_3 - TB_3^{clr}$	-0.81	$(TB_1-TB_3) - (TB_1^{clr}-TB_3^{clr})$	0.83	$(TB_2-TB_3) - (TB_2^{clr}-TB_3^{clr})$	0.85						
$TB_4 - TB_4^{clr}$	-0.85	$(TB_1-TB_4) - (TB_1^{clr}-TB_4^{clr})$	0.86	$(TB_2-TB_4) - (TB_2^{clr}-TB_4^{clr})$	0.87	$(TB_3-TB_4) - (TB_3^{clr}-TB_4^{clr})$	0.87				
$TB_5 - TB_5^{clr}$	-0.88	$(TB_1-TB_5) - (TB_1^{clr}-TB_5^{clr})$	0.88	$(TB_2-TB_5) - (TB_2^{clr}-TB_5^{clr})$	0.89	$(TB_3-TB_5) - (TB_3^{clr}-TB_5^{clr})$	0.88	$(TB_4-TB_5) - (TB_4^{clr}-TB_5^{clr})$	0.88		
$TB_6 - TB_6^{clr}$	**-0.90**	$(TB_1-TB_6) - (TB_1^{clr}-TB_6^{clr})$	0.90	$(TB_2-TB_6) - (TB_2^{clr}-TB_6^{clr})$	0.90	$(TB_3-TB_6) - (TB_3^{clr}-TB_6^{clr})$	0.89	$(TB_4-TB_6) - (TB_4^{clr}-TB_6^{clr})$	0.88	$(TB_4-TB_6) - (TB_5^{clr}-TB_6^{clr})$	0.87

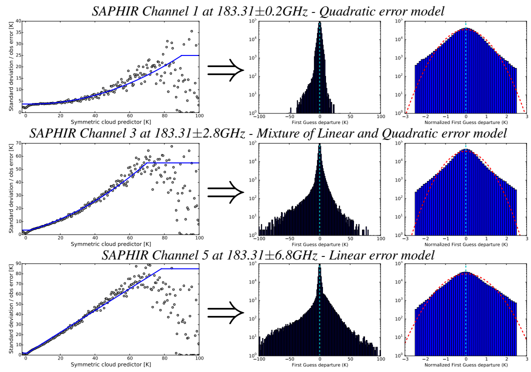
The correlations shown above between SI MHS and potential cloud predictors for SAPHIR indicate that a simple difference between SAPHIR channel 6 (183.31±11GHz) simulated with and without scattering effects provides a highly consistant behaviour with MHS' predictor (81% of SI MHS variance explained). This cloud predictor was hence implemented and used for the rest of the study.

Defining an observation error model:

First guess departures of SAPHIR' six channels have been collected over a 10-day period in January 2015 and categorized using the symmetric cloud predictor defined previously. Then, either a linear, a quadratic or a mixture of linear and quadratic error models have been fitted to standard deviations of first guess departures in order to end up with modeled observation errors following Geer and Bauer (2011).

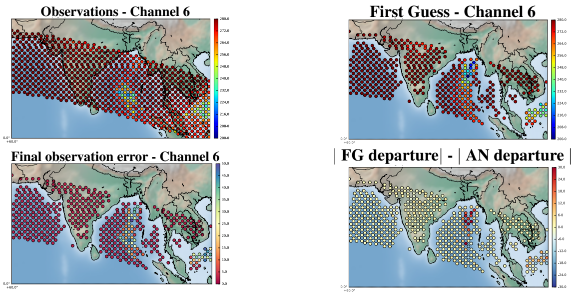
As shown in the next figure (left column), observation errors increase with the symmetric cloud predictor value thus taking into account larger radiative transfer errors in strong scattering conditions as well as cloud displacement in the model with respect to the observations.

As can be seen on the figure below as well (right column), applying a varying observation error as function of a scattering index improves the Gaussianity of normalized first guess departure distributions.



Example for a cloudy situation over the Bay of Bengal:

The figures below show a case of predicted cloud in the North of Bay of Bengal on January 2^{nd} 2015 but which was observed further South by SAPHIR. The departure reduction map (bottom, right) indicates that after assimilation of SAPHIR, departures have been reduced, only in the North of Bay of Bengal though.



Results from assimilation experiments

A data denial framework:

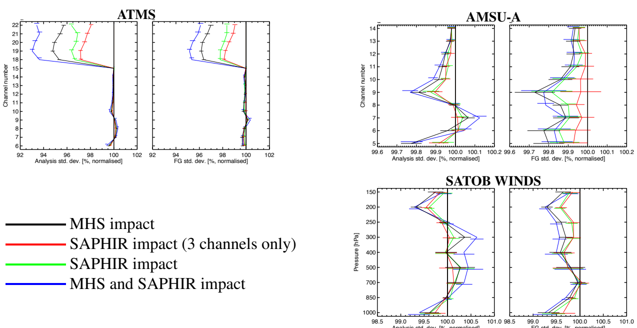
The effect of assimilating new observations in a state of the art data assimilation system, ingesting already millions of observations, is often highly neutral. Nonetheless it is important to understand and quantify how the new observations behave within the assimilation system. To this endeavour, the framework which was selected in the case of Megha-Tropiques was to perform data denial experiments of similar instruments in the Tropics. The baseline that was defined is a denial experiment of MHS data (4 satellites), between 30N and 30S, but still assimilating all other observations routinely used at ECMWF. Experiments using either MHS in the Tropics, SAPHIR or both are then all compared to this baseline.

Selected Period : January 1^{st} to June 30^{th}, 2015

IFS resolution used for the experiments: T511 (~35 km), 137 levels

Impact on short term forecasts in the observation space:

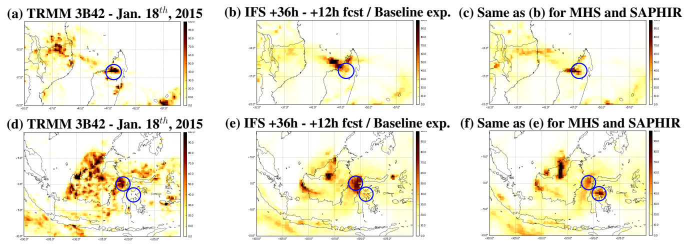
Comparisons of analysis and first guess departures statistics for each of the experiments with respect to the baseline show highly consistant improvements between MHS impact and SAPHIR impact in the Tropics



As can be seen on the figures above, MHS and SAPHIR have a positive impact on humidity forecasts (e.g. ATMS channels 18 to 22), temperature forecasts (e.g. AMSU-A channels 5 to 11) as well as wind forecasts (e.g. SATOB observations between 400 and 200hPa as well as at 1000hPa)

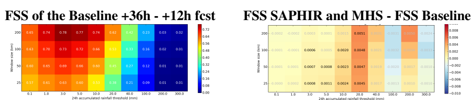
Impact on precipitation forecasts:

Whether precipitation forecasts have been improved by assimilating new observations or not is a question of interest for end users of ECMWF products. Achieving such an assessment is a difficult task, in particular in the Tropics where ground networks are very sparse. An alternative reference to ground instrumentation are satellite-based rainfall products which offer rain accumulation estimations, retrieved over both land and ocean surfaces. Among the different existing products, the TRMM 3B42 V7 (Huffman et al., 2007) product has been extensively validated, in particular in the Tropics (e.g. Roca et al., 2010; Gosset et al., 2013).



The (a), (b) and (c) daily rainfall accumulation maps show that the assimilation of both MHS and SAPHIR in the Tropics improved the prediction of rain over North Madagascar for this particular day by better locating accumulations of over 100mm of rain (the blue circle has a 150km radius). The (d), (e) and (f) maps shows another example where a rain prediction over Indonesia, in the Makassar Strait and the Sulawesi island, are both degraded for the same particular day when assimilating MHS and SAPHIR.

Indeed performing global analyses lead to trade offs which either improve or degrade forecasts over the globe. Nonetheless, the question that can still be addressed is whether if, on average, rainfall forecasts have been improved or not. To this endeavour, Fraction Skill Scores have been computed over the whole Tropics and for the entire 6 months period with TRMM 3B42 daily accumulations as reference.



Comparisons show that the FSS is statistically significantly (at the 95% confidence level) improved by roughly 1% for daily rain accumulations ranging from 3 to 20mm.

Conclusions:

The experiments shown above have demonstrated the good behaviour of SAPHIR observations assimilation within the ECMWF all sky assimilation system. The denial experiments have shown that MHS and SAPHIR instruments both impact the IFS analyses and forecasts in a consistent way. Tests are ongoing of SAPHIR assimilation in cy43r1 which are likely to lead to its operational assimilation at ECMWF in 2017.