Impact of Megha-Tropique's SAPHIR humidity profiles in the Unified Model Analysis and Forecast System

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Abstract

This paper discusses the impact of Microwave (MW) humidity sounder radiances from SAPHIR onboard Megha-Tropique (MT) satellite in the UK Met Office's Unified Model (UM) Data Analysis and Forecast system, which is being used at National Centre for Medium Range Weather Forecasting (NCMRWF), India. MT provides high frequency observations over a given area in the Tropics three to six times per day because of its orbital inclination (20º with the Earth's equatorial plane). SAPHIR, the six channel MW sounder, provides humidity information from the surface to around 10km, using frequencies near the absorption band of water vapor at 183 GHz. Assimilation of SAPHIR radiances increases the number of assimilated humidity sensitive MW and IR radiances from instruments onboard other satellites, especially over the Tropics. The standard deviations of the innovations of the overlapping channels of other instruments such as ATMS and AMSU-B/MHS are reduced by ~2% and the average number of observations assimilated from these instruments increased by ~1.5% with respect to the control experiment. Similar behavior has been noticed in the IR channel radiances from other instruments such as AMSU-A as well as in the hyperspectral radiances like IASI, AIRS, and CrIS. SAPHIR radiance assimilation in the UM system clearly shows improvement in the analysis and forecast system both globally and over the Tropics.

1. Introduction

Megha-Tropiques (MT) is an Indo-French joint satellite mission to study the water budget and energy exchange processes in the Tropics. Sondeur Atmosphérique du Profil d'Humidité Intertropicale par Radiométrie (SAPHIR) is a 6 channel microwave humidity profiler onboard MT. These 6 channels near the absorption band of water vapor at 183 GHz provide relatively narrow weighting function from the surface to 10 km, retrieving water vapor profiles in the cloud free troposphere. The scanning is cross-tracking up to an incident angle of 50º at a nadir resolution of 10 km. The other microwave humidity radiometers in this range, NOAA/MetOp-MHS measure water vapor in three levels. Advanced Technology Microwave Sounder (ATMS) flown on Suomi National Preparatory Polar (NPP) satellite has the similar 5 channels in the 183 GHz range, out of 22. The importance of MT and hence SAPHIR is its high repeativity over the tropics compared to other polar satellites mainly due to its orbital inclination of 20º.

Usefulness of SAPHIR radiances are investigated and reported by many researchers. A radiative transfer simulation based operational algorithm has been developed to retrieve layer-averaged relative-humidity (LARH) for six atmospheric layers from the surface to nearly 12 km using SAPHIR observations over land and ocean under non-rainy conditions by Mathur et al., (2013). They reported 15 -20 % deviation in the root mean square after bias correction in the LARH with respect to radiosonde and ECMWF data. Singh et al., (2013) compared the SAPHIR radiances with those simulated by the radiative transfer model using radiosonde measurements, Atmospheric InfraRed Sounder (AIRS) retrievals, and National Centers for Environment Prediction (NCEP) analyzed fields over the Indian subcontinent during January to November 2012. They also compared the SAPHIR radiances with the similar measurements from MHS on board MetOp-A and NOAA-18/19 satellites. Singh et al., (2013) also studied the quality of SAPHIR radiances by comparing the observations with Radiative Transfer Model (RTM) simulated radiances and MHS observed radiances. Their study show the impact of SAPHIR radiances on the Weather Research and Forecasting (WRF) 3D-VAR data assimilation system, with considerable improvements in the tropospheric analyzes and forecasts of moisture, temperature, winds, and precipitation forecast skill.

Chambon et al., (2014) investigated the impact of SAPHIR radiances in the NWP global model operational at Météo-France (ARPEGE) for the period June to August 2012. In their study, it was found that the combination of MT low inclined orbit with SAPHIR six channels increase the number of assimilated humidity sensitive microwave observations in the Tropics by a factor of 3.8, compared to the control experiment in which three AMSU-B/MHS microwave sounders are already assimilated. Chambon et al., (2014) also established the positive impact of SAPHIR on both analyzes through the 4D-Var system and forecasts. Clain et al., (2014) compared the SAPHIR L1A2 brightness temperature (Tb) observations with those simulated by RTTOV-10 (Radiative Transfer for the Television and Infrared Observation Satellite (TIOS) Operational Vertical Sounder), using in-situ radiosonde as input. They found that the magnitude of the bias depends on the observing channel, increasing from 0.18 K for the 183 +/- 0.2 GHz channel to 2.3 K for the 183 +/- 11 GHz channel.

Standard practice of the operational centres is to assess the quality of the new data with respect to NWP model fields and other similar instruments and to evaluate the data through data assimilation experiments before operational assimilation. Past studies (Bell et al. (2008), Lu et al. (2011), and Doherty et al. (2015)) had already shown the importance of using NWP fields to assess the data quality from microwave instruments. This paper presents a similar analysis of SAPHIR radiances with respect to Met Office NWP model. Section 2 of this paper introduces the SAPHIR instrument characteristics, followed by a brief overview of Met Office data assimilation scheme in Section 3. Section 4 briefly describes the data quality and the bias correction method. The assimilation experiments and the impact of SAPHIR radiance in the analysis and forecast system are described in section 5. Section 6 specifically describes the impact of MW radiances in other instruments. Discussion and conclusions from the present study are summarized in section 7.

2. SAPHIR Instrument characteristics

SAPHIR is the payload proposed to study the vertical distribution of water vapor in the tropical troposphere with two main objectives: analysis of the diurnal cycle of the water vapor distribution and the role of the space-time distribution of humidity on the development of deep convection. The urge of an instrument like SAPHIR on the MT was due to the scarcity of local measurement in tropical latitudes. Microwave sounders in the polar orbit provide insufficient sampling in the Tropics for investigating the convective system life.

Figure 1 shows the atmospheric opacity spectrum from Waters, 1976. In the atmospheric opacity spectrum, the first water vapor absorption line is centered at 22.235 GHz, and the second at 183.31 GHz. Between these two frequencies, the water vapor continuum slowly increases absorption by atmosphere with frequency. The first water vapor line is too low to profile the atmosphere, while the second line high enough to profile in the 10-12 km of the atmosphere. The sounding principle consists of selecting channels at different frequencies inside the absorption line, in order to obtain a maximal sensitivity to humidity at different heights. Previous microwave humidity sounders like MHS has three channels within the 183.31 GHz absorption line (at ±1, ±3 and ±7 GHz) and two window channels, at 150 and 89 GHz to provide information on the surface. SAPHIR is designed in such a way to have as many layers within the water vapor absorption line centered at 183.31 GHz with a horizontal resolution of 10 km at nadir. Unlike MHS, SAPHIR has the enlarged bandwidth of 183.31± 12 GHz in order to get information from the low atmosphere without adding a specific receiver for a window channel. Specification of SAPHIR channels and a comparison of similar Microwave instruments are provided in Table 1. Figure 2 shows the six channels of SAPHIR positioned versus the water vapor absorption line at 183.31 GHz (from Megha Tropics home page)

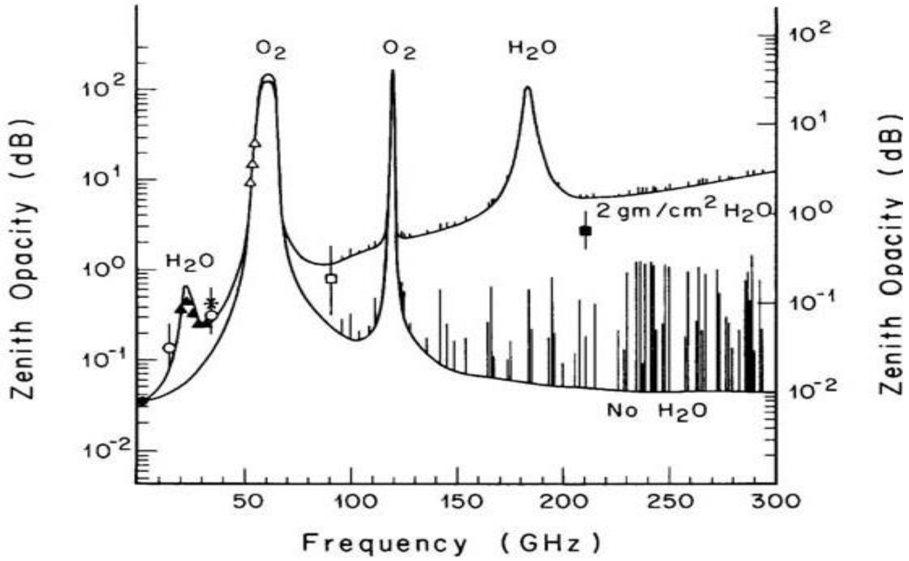

Figure 1 : Atmospheric opacity for a US standard atmosphere. The lower line is with no water vapor, and the upper line is for a 20 kgm^{-2} WV content (assuming an exponential decrease with height). From Waters, 1976.

Table 1: Channel Specifications of SAPHIR and the comparison of similar MW sensors

SAPHIR Channels	Central Frequencies (GHz)	Channel bandwidth (MHz)	ATMS channel number	ATMS central Frequencies	MHS channel number	MHS central Frequencies
S1	183.31 +/- 0.2	200				
S2	183.31 +/- 1.1	350	21 (22)	183.31 +/- 1.8 (183.31 +/- 1)	18	183.31 ± 1
S3	183.31 +/- 2.8	500	20	183.31 +/- 3	19	183.31 ± 3
S4	183.31 +/- 4.2	700	19	183.31 +/- 4.5		
S5	183.31 +/- 6.8	1200	18	183.31 +/- 7		
S6	183.31 +/- 11	2000				

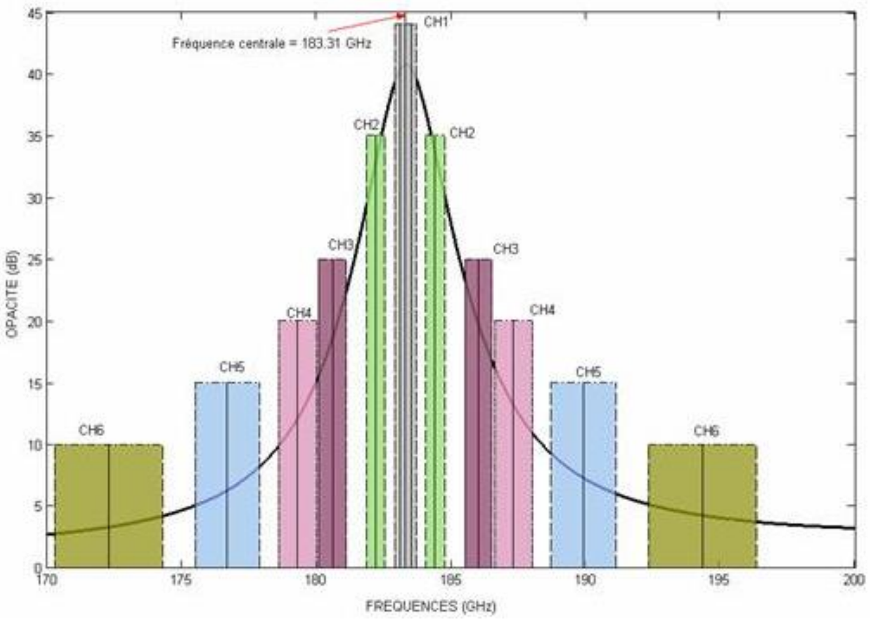

Figure 2: The 6 channels of SAPHIR positioned versus the water vapor absorption line at 183.31 GHz.

3. Met Office Data Assimilation System

The Met Office variational data assimilation system is based on incremental 4D-Var. The operational nonlinear forecast model has a resolution of 25 km in mid-latitudes and 70 levels from the surface to 80 km. The UM VAR is a simple extension of the 3D-VAR using a Perturbation Forecast (PF) Model and its adjoint. 4D-VAR implicitly uses a complete four dimensional PDF, with time evolution as accurate as PF model. 4D-VAR can make good use of time-distributed high-density observations such as satellite observations. For the data assimilation experiments with SAPHIR, used a reduced resolution of 40 km. The operational analysis makes use of data from a range of conventional observations, including surface, sonde and aircraft observations as well as data from satellite instruments including five ATOVS instruments (from NOAA-15, NOAA-18, NOAA-19, MetOp-A, and MetOp-B), infrared sounder data from Atmospheric Infrared Sounder (AIRS), the Infrared Atmospheric Sounding Interferometer (IASI), and Cross track Infrared Souder (CrIS), data from Advanced Technology Microwave sounder (ATMS), global positioning system (GPS) radio occultation (GPSRO) data, ground based GPS, atmospheric motion vectors, geostationary radiances, and scatterometer data.

4. Data Quality

In order to monitor the biases in the observations, measured satellite radiances are compared with their equivalents computed from a short-term forecasts or analysis estimate of the atmospheric state using a radiative transfer (RT) model. The assumptions made in this type of bias correction are: the observed satellite radiances are free from calibration errors, the radiative transfer model is accurate, and the short-term forecast provided by NWP model is free from systematic errors. However, these assumptions are not always valid. Biases vary (Bell et al. (2008) , Lu et al. (2011), and Doherty et al. (2015))with time (both diurnal and seasonal), geography or airmass, scan position of satellite instrument, and the position of the satellite around its orbit.

In this study, the model equivalents of the observed Brightness Temperatures (Tbs) are computed using a fast RTM (RTTOV-9). Model fields from short range forecasts are interpolated in space and time to the location of the observation using forecast fields at T +3, +6, and +9 hours from the previous analysis and the Tbs are simulated using the RTM. Innovations, the differences between the observations (O) and simulations (B), are used to diagnose the errors in the observation. In variational data assimilation, both the observation and background errors are assumed to normally distributed or unbiased. Histograms of innovations before and after the bias correction are indicative of how well the bias correction works. A non-zero mean of the innovation (O-B) distribution indicates the presence of bias, and the bias correction is not perfect. The bias correction works perfectly if the mean of the innovation distribution shifts towards zero (very close to zero) after bias correction.

Figure 3 shows the departures of observations from the simulations with and without applying bias correction for the respective 6 SAPHIR channels. Applying bias correction (dotted curve) shifted the mean of the O-B distribution towards zero, ensuring that the bias correction is working effectively. Large amplitude latitudinal and cross-track biases are clearly visible in the fields before bias correction and largely absent in those after the bias correction indicating that the bias correction scheme is effective.

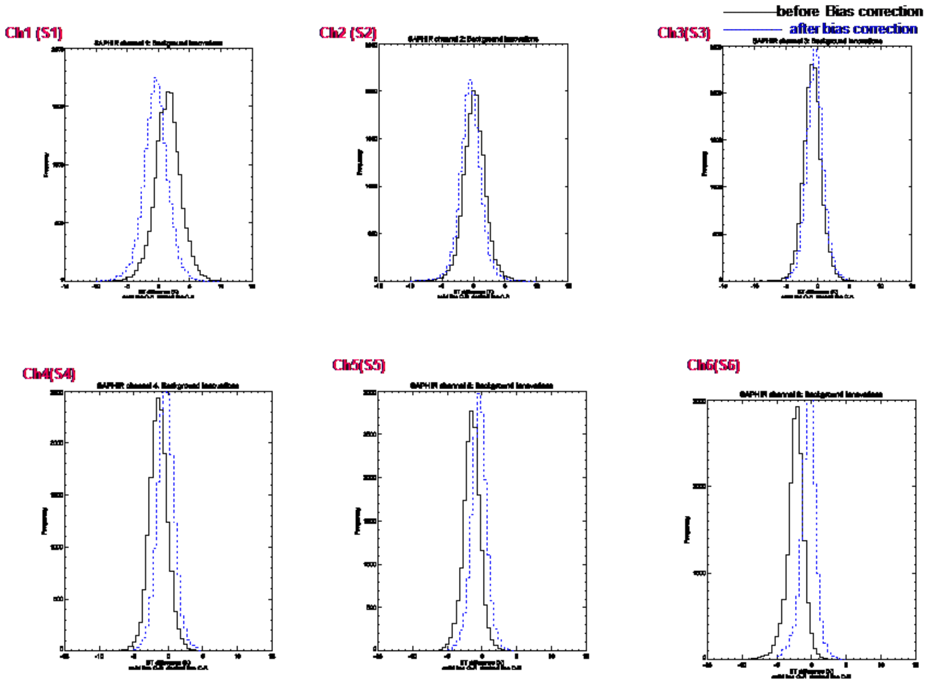

Figure 3: Guassian distribution of SAPHIR 6 channels bias. Black curve shows without bias correction and blue curve after bias correction.

5. Assimilation Experiments

The impact of the SAPHIR data on the global analyzes and forecasts was tested by adding SAPHIR data to a full Met Office observing system. Results from 10th September 2014 to 9th October 2014 are presented here. The low resolution version of the operational configuration described in section 3 was used for the experiments and the corresponding controls. Observations are thinned prior to assimilation to reduce data volume and avoid spatial correlations. Bias correction was calculated using 18 days data from September 2014. Figure 4 shows the verification over the Tropics of SAPHIR assimilation experiment with respect to the observations. SAPHIR assimilation increased the NWP index by approximately 1.82%. The improvements are clearly visible in the meteorological fields like relative humidity, temperature wind speed and geopotential height.

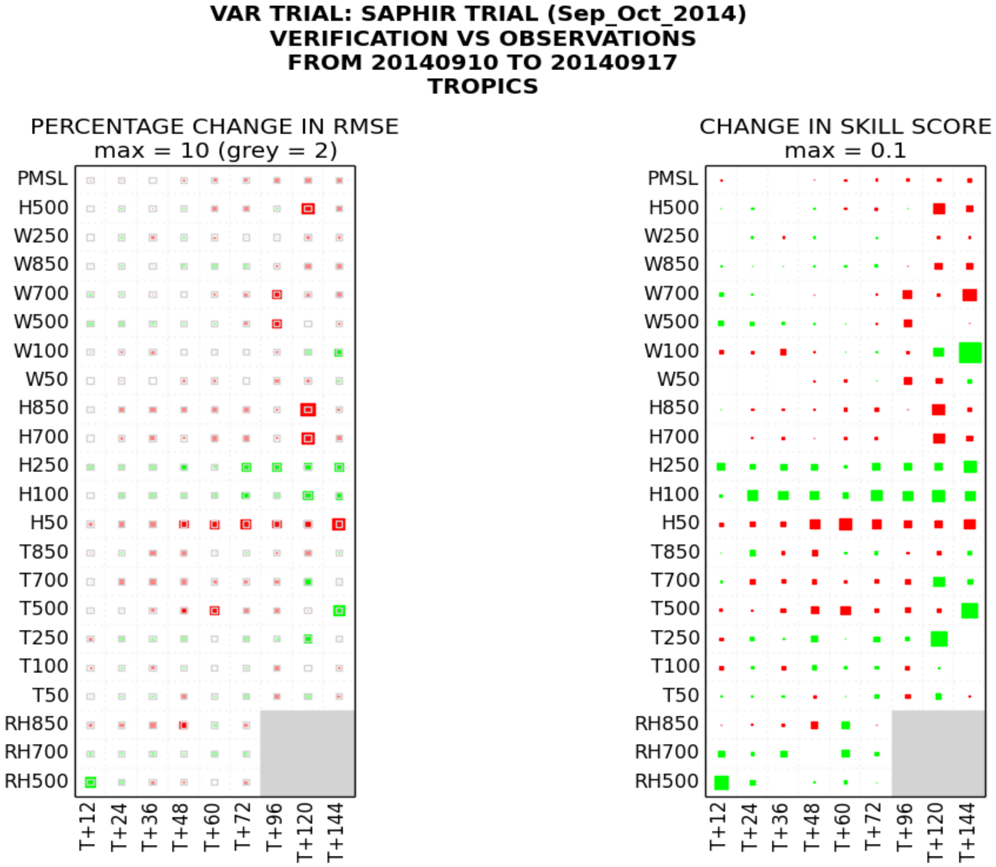

Figure 4: Verification of SAPHIR assimilation experiment over the Tropics with respect to observations.

6. Impact on other MW radiances

UM 4D-VAR assimilates the MW radiances from AMSU-B and ATMS. This section describes the impact of SAPHIR radiances on the MW radiances from these instruments in the assimilation system. Figure 5 a and b show the standard deviation and the number of observations of ATMS radiances with respect to the control run. In Figure 5 negative values indicate positive impact. Standard deviations in the similar channels of ATMS decreased due to the assimilation of SAPHIR radiances. Similarly the number of ATMS radiances assimilated in the similar channels also increased (Figure 5 b). Similar impact can also be seen in other MW radiances like AMSU-B on different platforms.

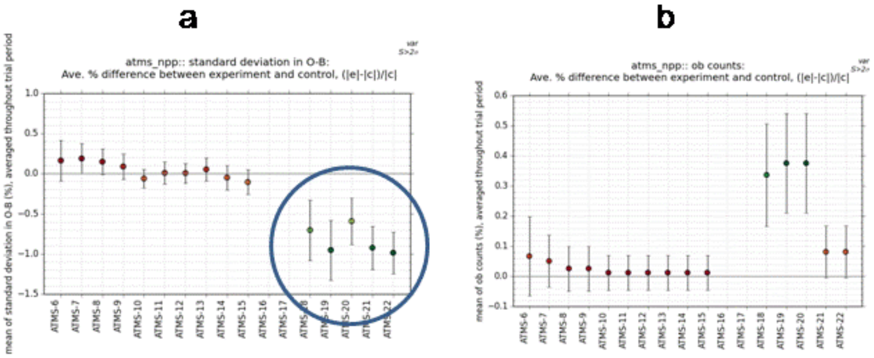

Figure 5: Standard deviation and the number of ATMS radiances assimilated in the assimilation system due to SAPHIR experiment with respect to the control.

7. Discussion and Conclusions

Assimilation of SAPHIR radiances increases the number of assimilated humidity sensitive MW and IR radiances from instruments on-board other satellites, especially over the Tropics. The standard deviations of the innovations of the overlapping channels of other instruments such as ATMS and AMSU-B/MHS are reduced by ~2% and the average number of observations assimilated from these instruments increased by ~1.5% with respect to the control experiment. Similar behavior has been noticed in the in the IR channel radiances from other instruments such as AMSU-A as well as in the hyperspectral radiances like IASI, AIRS, and CrIS.

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