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TECNICAL REPORT

Radiance Data Monitoring in Global Data Assimilation System for NGFS (NGFS-GDAS) at NCMRWF

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National Centre for Medium Range Weather Forecasting
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10	Abstract	With the advancement of satellite remote sensing of Earth's Atmosphere, the understanding on the atmospheric parameters on a global scale and its emerging effect towards the natural and anthropogenic processes are comprehensible. At the same time the monitoring of the observing system is useful to provide detailed statistical information on the quality and availability of the different components of the observing system. The National Centre for Medium Range Weather Forecasting (NCMRWF) plays a lead role in the data reception from different observational platforms and to prepare the analysis for the operational forecast. The monitoring of the observational data is requisite in improving the usage of observations within the data assimilation system. Present study encompasses the monitoring of satellite radiances received at NCMRWF. This procedure aids in identifying the observations which might be detrimental to the model analysis and forecast. Removal of these atrocious observations from the assimilation system helps in optimizing the performance of the operational data assimilation and forecasting system.
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Abstract

With the advancement of satellite remote sensing of Earth's atmosphere, the understanding on the atmospheric parameters on a global scale and its emerging effect towards the natural and anthropogenic processes are comprehensible. At the same time the monitoring of the observing system is useful to provide detailed statistical information on the quality and availability of the different components of the observing system. The National Centre for Medium Range Weather Forecasting (NCMRWF) plays a lead role in the data reception from different observational platforms and to prepare the analysis for the operational forecast. The monitoring of the observational data is requisite in improving the usage of observations within the data assimilation system.

Present study encompasses the monitoring of satellite radiances received at NCMRWF. This procedure aids in identifying the observations which might be detrimental to the model analysis and forecast. Removal of these atrocious observations from the assimilation system helps in optimizing the performance of the operational data assimilation and forecasting system.

1. Introduction

The advancement of atmospheric observation network is one of the imperative aspects of weather and climate forecasting system. In Earth observation, we have access to a huge amount of conventional and remote sensed observations. The conventional observations includes TEMP, PILOT balloons, profiler, SYNOP, SHIP, BUOY, METAR, AWS, Aircraft observations, satellite winds, etc, are communicated swiftly via the Global Telecommunication System (GTS) to the various national forecasting centers. However; the quantity and distribution of these conventional observation types are not sufficient to describe the state of the atmosphere in adequate detail for NWP purposes. Over land these observations are mainly concentrated over the densely populated and more developed areas. Over the oceans much less observations are present, and are restricted to the vicinity of the busiest sea channels. This leaves broad swathes of data sparse regions over the oceans. The problem of inadequate global observation coverage is especially acute for upper-air data. Therefore, over the past three decades, substantial effort has been devoted to the development of complementary space-based systems that can provide meteorological information in these otherwise data sparse regions. Since their potential was first recognized in the nineteen-sixties, the increasing flow of data from the growing constellation of meteorological satellites has reached a point today where their influence on NWP forecasts just about outweighs that from more conventional sources.

Moreover, an improvement in satellite technology along with increase in the number of meteorological satellites simplifies the monitoring and prediction of weather phenomena (Rani and Das Gupta, 2013). These observations play an important role in improving the numerical weather prediction (NWP) (Le Marshall and Leslie, 1998; Velden et al., 1988; Bouttier and Kelly, 2001; Cardinali, 2009). However, usage of these datasets for accurate weather prediction is one of the major challenges for all the NWP centers. Current observationalrequirements for global NWP are met, to varying degrees, by arrange of terrestrial and space-based observing systems.

With the advancement in remote sensing technologies and the increasing availability of satellite observations have recently led to the publication of several key reports describing the need for global data assimilation system that can optimally combine the diverse observational data streams to monitor and predict the changes in atmospheric condition and its socio-economic impact (Hollingsworth et al, 2008).

National Centre for Medium Range Weather Forecasting (NCMRWF) undertook a lead role in reception and processing of observations from different sources ranging from conventional in-situ observations to remote-sensing measurements to generate analysis for the operational numerical forecasts. An accurate analysis of the atmospheric state is a vital ingredient for skillful numerical weather predictions. For this purpose, the Global Data Assimilation and Forecasting system, based on National Centers for Environmental Prediction (NCEP) Global Forecasting System (GFS) i.e. NGFS-GDAS, is operated in real-time at NCMRWF since 1994.This report focuses on satellite observations received, monitored and assimilated in the NGFS-GDAS at NCMRWF. The main purpose of this data monitoring is to provide detailed statistical information on the quality and availability of the different components of the observing system used/monitored in each data assimilation cycle. Section 2 briefly describes about the NGFS-GDAS system. Section 3 describes the satellite observation received at NCMRWF. The data monitoring statistics is presented in section 4, and summary in section 5.

2. Global Data Assimilation System (NGFS-GDAS)

The journey of Global Forecasting System (GFS) at NCMRWF has started nearly three decades ago. The T80L18 was the first end-to-end NWP system implemented at NCMRWF, on CRAY X-MP supercomputer. Several research and operational applications were developed based on this system. The T80L18 Global Data Assimilation and Forecast system was replaced with newer updated version with horizontal resolution of T254 at par with operational version of NCEP GFS in January 2007. This new T254L64 system included all the changes that NCEP implemented in its GFS during the period 1995- 2006 (Rajagopal et. al 2007). The newer version with updated skill was implemented subsequently at par with NCEP GFS operational suite and the journey is continuing till date. Until 2007, Spectral Statistical Interpolation (SSI) analysis scheme was used along with GFS framework. The SSI has been replaced with Grid point Statistical Interpolation (GSI) in January 2008. GSI was developed at the Environmental Modeling Center (EMC) of NCEP as part of an effort to create a more unified, robust, and efficient analysis scheme. The key aspect of GSI is that it computes the analysis on model grid space, which allows more flexibility in the application of the background error co-variances and makes it straightforward for a single analysis system to be used across wide range of applications, including both global and regional modeling systems and domains. The improved features in GSI includes; observation selection, quality control, minimization algorithm, dynamic balance constraint, and assimilation of new observation types. The detailed salient features of NGFS-GDAS analysis system can be found at Prasad et al (2011) and subsequent up gradation are elaborated in Prasad et al (2014).

The assimilations cycles are carried out in six hourly intermittent time period. In each assimilation cycle, a new estimate of the atmospheric state (analysis) is prepared at every 6 hr to initialize a new 9 hr global model forecast. Although the background used for each analysis is the previous 6 hr forecast, a 9hr forecast is necessary to allow for time interpolation of synoptic observations that fall within the 6 hr analysis time window (i.e., time interpolation of the background is done between the 3-, 6-, and 9-h forecasts that covers the 6-h data window centered on the analysis time). The analyses so obtained are then used as the initial condition for subsequent forecasts and the cycle continues. The complete details of the GSI system can be found in Kleist et al. (2009).The NGFS-GDAS analysis has wide range of applications starting from preparation of re-analysis (Prasad et al., 2017), initialize the NWP model forecast (Johny et al., 2020) etc. The verification of NGFS-GDAS analysis in daily to monthly scale over global to regional sub-domains quantifies its performance across the globe (Pattanayak et al, 2020).

3. Observational Data

The Global Observing System (GOS)consists of a network of synoptic surface-based observations made at over 11000 land stations, by about 7000 ships and 750drifting buoys at sea and around 900 upper-air stations, together with reports from aircraft and remotely sensed data from geostationary and polar orbiting satellites. Weather forecasts have always relied on accurate observations of the current weather. Modern NWP has been changed numerously and makes an extensive use of conventional and satellite observations.

NCMRWF has made an extensive arrangements, to receive atmospheric and ocean observations from conventional and remote sensing platforms, with Global data centers. A majority of conventional observations are received via GTS network of World Meteorological Organisation (WMO), through its Regional Telecommunication Hub (RTH) at India Meteorological Department (IMD), New Delhi. Most of these GTS bulletins are decoded from their native format and encoded into NCEP BUFR format using various decoders. The details of data retrieval, processing and archival of conventional data received through GTS can be found at Prasad et al (2020). NCMRWF has made numerous efforts to establish dedicated data links with Global satellite operators such as NOAA, EUMETSAT, CMA, KMA, and ISRO etc. to receive huge Global satellite observations. It routinely processes data from around 35 satellites, as part of its operational daily data assimilation and monitoring activities. In addition to this, the operational set up of NCMWF also benefits from observations available from non-satellite sources, including surface-based and aircraft data.

Figure 1 presents all those dedicated links used to receive remote sensing observations and the percentage contribution of different types of data assimilated at NCMRWF. These satellite observations are assimilated using GSI analysis scheme. Each individual observation has its own importance in NWP model analysis prepared through the data assimilation. It is worthwhile to mention that the satellite and remote sensing observations contributes ~90% and conventional share is ~10% of the total observations received at NCMRWF.

(a) **(b)**

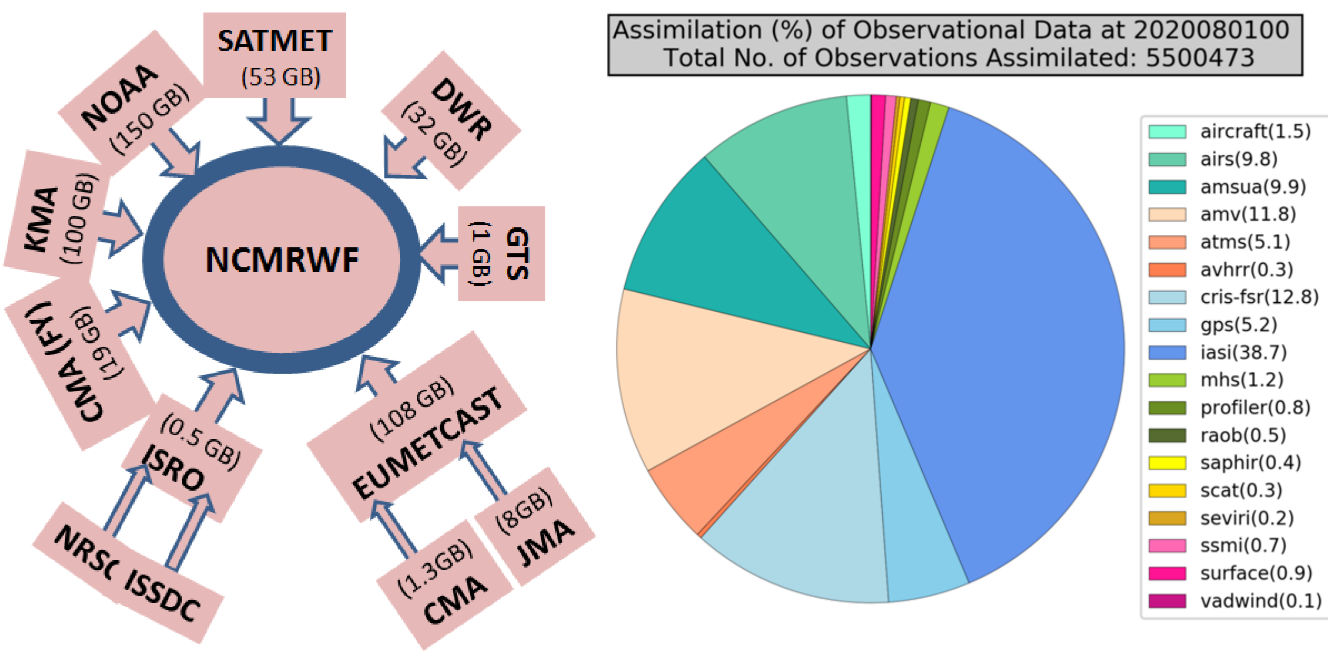

Figure 1 (a) Dedicated links used to receive remote sensing observations and (b) percentage contribution of different types of data assimilated in GDAS system at NCMRWF.

3.1 Satellite Radiance

The satellite data are extremely important in the assimilation system. Synoptic coverage provided by satellites is ideally suited to study weather related atmospheric processes on different scales. The recent advances in satellite technology in terms of high resolution, multi-spectral and hyper-spectral bands covering visible, infrared and microwave regions have made space data an inevitable component in weather monitoring and modeling. The impact of satellite data is phenomenal in many meteorological applications such as short-range forecasts, now-casting, aviation technology, extreme weather prediction etc. Much of the improvement in forecast skill can be attributed to the advanced data and their improved use in the assimilation procedures. With improving accuracy of satellite measurements, the numerical model forecasts are also improving.

Monitoring of satellite data used in operational NWP is a critical task. Monitoring activity is basically intended to obtain statistics indicative of the quality of the observations. This helps in providing necessary feedback to the data provider and warning to the data user. However, it should be noted that changes in the monitoring statistics may due to the following factors and not directly related to the observations itself.

- Departures are sensitive to variations in the accuracy of the atmospheric state that is used as a reference.
- Departures are also sensitive to the accuracy of the mapping of the reference model state variables to the parameters observed by the satellite.

The NCMRWF data hub receives millions of radiance observations through different satellites and monitoring of these data sets is routinely carried out. Figure 2 illustrate the spatial coverage of satellite radiances from various instruments received at 00Z 20200705.

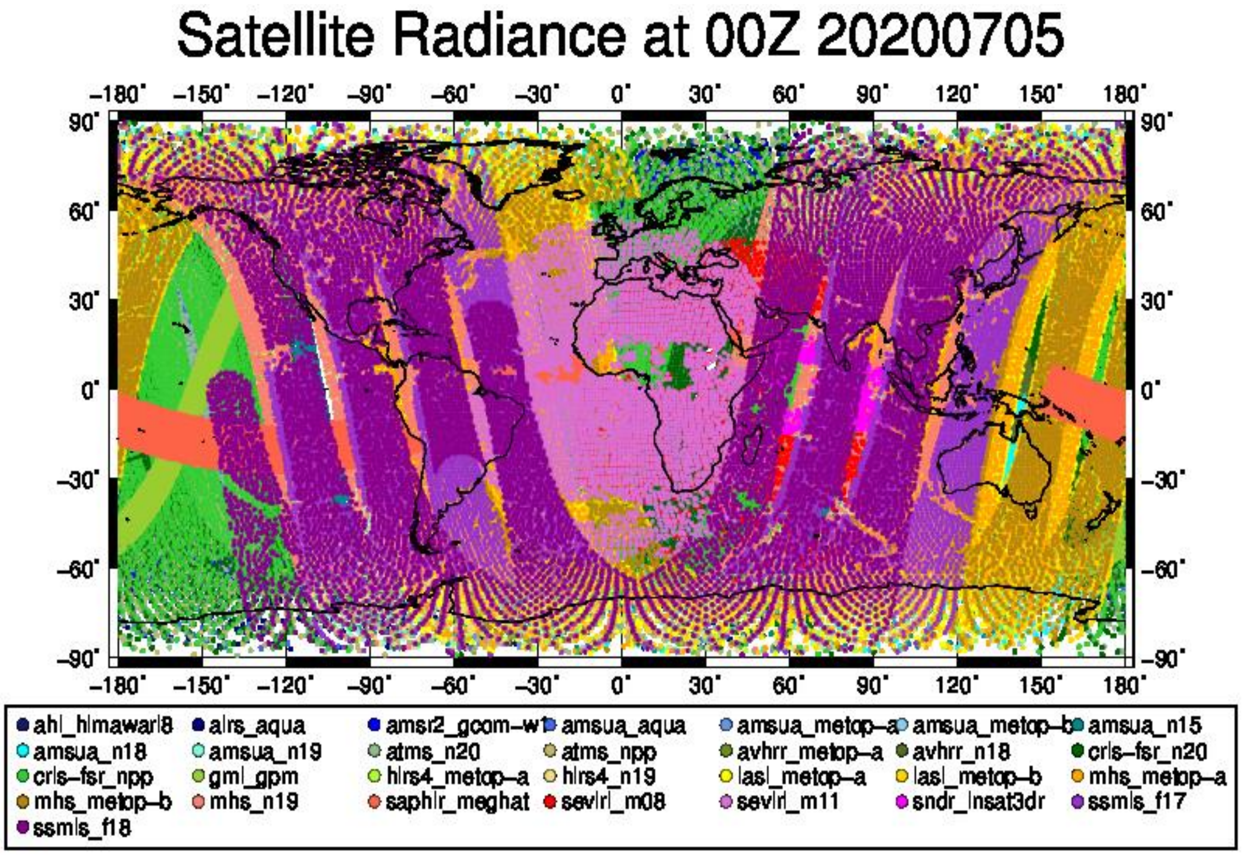

Figure 2 Spatial coverage of satellite observations received at NCMRWF (valid at 05 July 2020).

Figure 3 provides the spatial coverage of the satellite radiances having maximum contribution in the assimilation cycle. There are six data types like AIRS, AMSUA, ATMS, CRIS, IASI, and MHS contributes significantly.

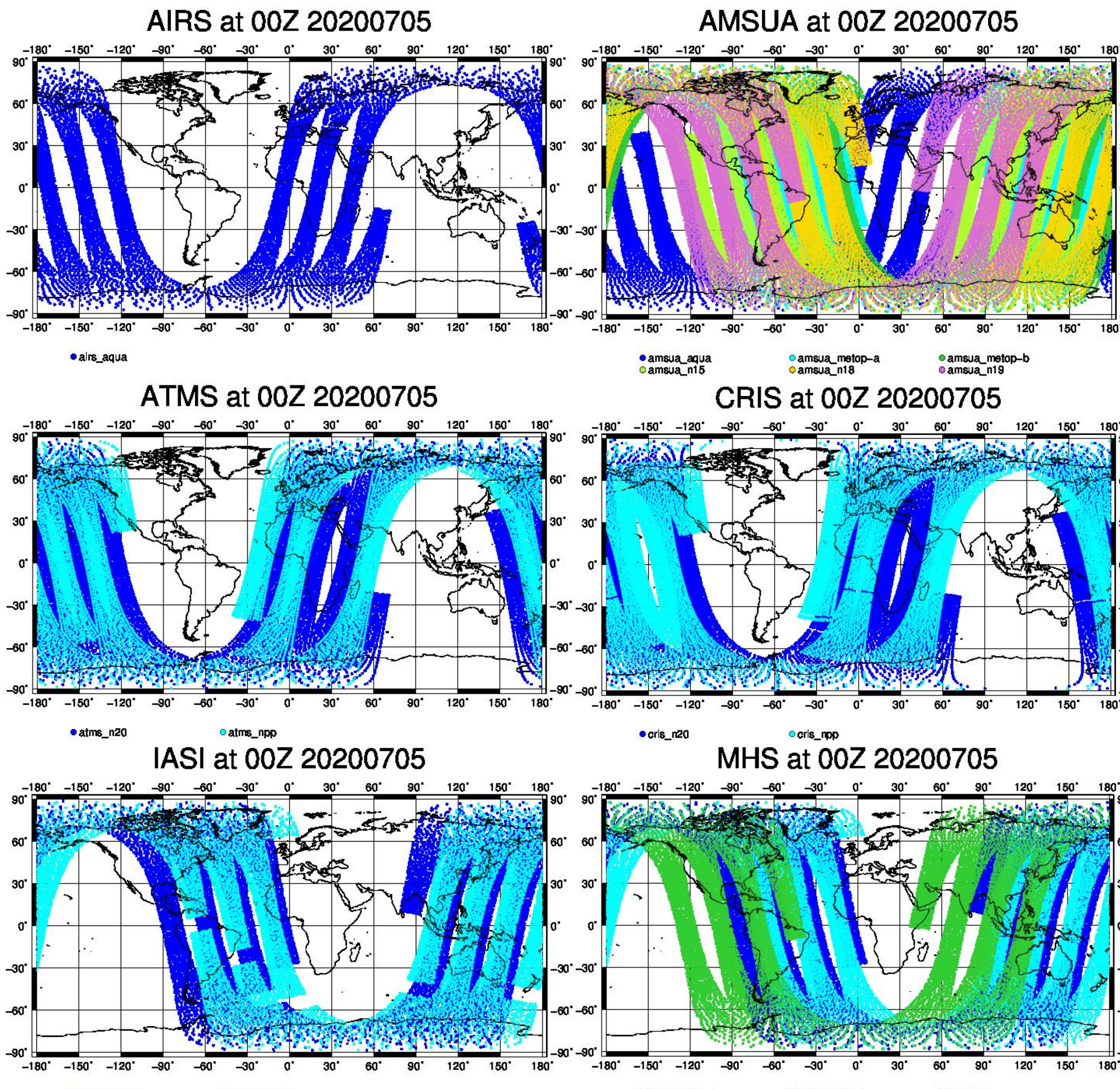

Figure 3 Spatial coverage of satellite observations which are having maximum contribution in the data assimilation.

Besides the global satellite observations from various International agencies, there are Indian satellites observations are also available which provide the temperature and humidity observations. Figure 4 represents the spatial coverage of Indian satellite observations from Megha-Tropiques SAPHIR and INSAT valid at 00Z 20200705.

INSAT-3D is a meteorological satellite of Indian Space Research Organisation (ISRO); an exclusive mission designed for enhanced meteorological observation and monitoring of land and Ocean surfaces for weather forecasting and disaster warning. The mission goals call for a significant technological improvement in sensor capabilities as compared to earlier INSAT missions. The meteorological payload features an imager and a sounder. The performances of the payloads are improved with the new additional features such as bi-annual rotation, image and mirror motion compensation. INSAT-3DR is very similar to INSAT-3D, configured as anadvanced meteorological satellite of India with an Imaging System and an Atmospheric Sounder. The major enhancements incorporated in INSAT-3DR are:

- Imaging in Mid Infrared band to provide night time pictures of low clouds and fog.
- Imaging in two Thermal Infrared bands for estimation of Sea Surface Temperature (SST) with better accuracy.
- Higher Spatial Resolution in the Visible and Thermal Infrared bands. Data Relay Transponder as well as a Search and Rescue Transponder.

Thus, INSAT-3DR is not only provide functional continuity to earlier meteorological missions of ISRO and further augment the capability to provide various meteorological observations using 6 imager and 19 sounder channels, it also aid in the search and rescue services.

Megha-Tropiques is a satellite mission aim to study the water cycle in the tropical atmosphere in the context of climate change. It is a joint venture of ISRO and French Centre National d'Etudes Spatiales (CNES) and was successfully setup into orbit in October 2011. SAPHIR on board Megha-Tropiques is a multi-channel passive microwave humidity sounder. Atmospheric humidity profiles can be obtained by measuring brightness temperatures in different channels close to 183.31 GHz water vapor absorption line. There are a number of studies (Singh et al, 2013; Singh and Prasad, 2017; Sumit Kumar et al, 2018, etc) on the performance of SAPHIR observations in NWP.

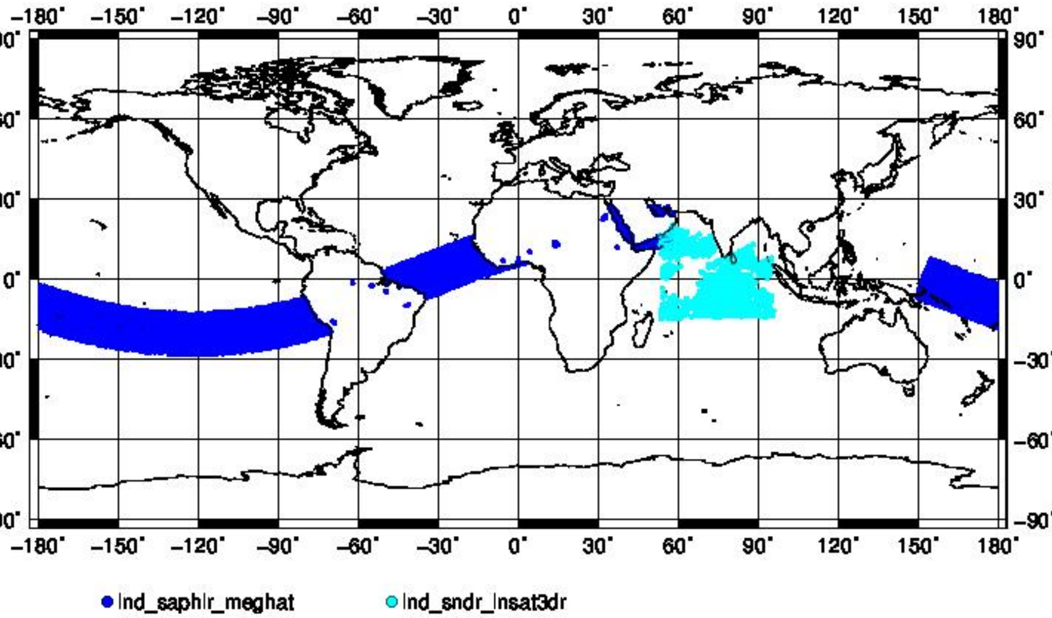

Figure 4 Spatial coverage of Indian satellites observations from Megha-Tropiques and INSAT valid at 00Z 20200705.

4. Data Monitoring

The radiance observations received at NCMRWF are monitored on daily basis for all the four cycles 00, 06, 12 and 18 UTC. Also computed the cycle wise statistics of the received, assimilated and monitored satellite observations for NGFS-GDAS system.

Figure 5 demonstrates the observation count of satellite radiances from all the sources received, kept and assimilated/monitored in the NGFS-GDAS analysis valid at 00 UTC 05 July 2020. It contains both hyper-spectral and multi-spectral sources of observations. There are millions of observations received from all the sources and the hyper-spectral observations are large in number. The total number of observations received at NCMRWF from various sources are marked as 'Obs_Received' and presented in 'purple' colour in the figure. All the observations which are passed through the quality check are marked as 'Obs_KeepGSI' and presented in 'blue' colour. The number of observations assimilated from the quality controlled observations are marked as 'Obs_Assimilated' and presented in 'green' color and the observations which are only monitored in the assimilation cycles are denoted in orange colour. The observations currently not assimilated but being monitored are marked as 'Obs_Monitored' and are shown in 'orange' colour.

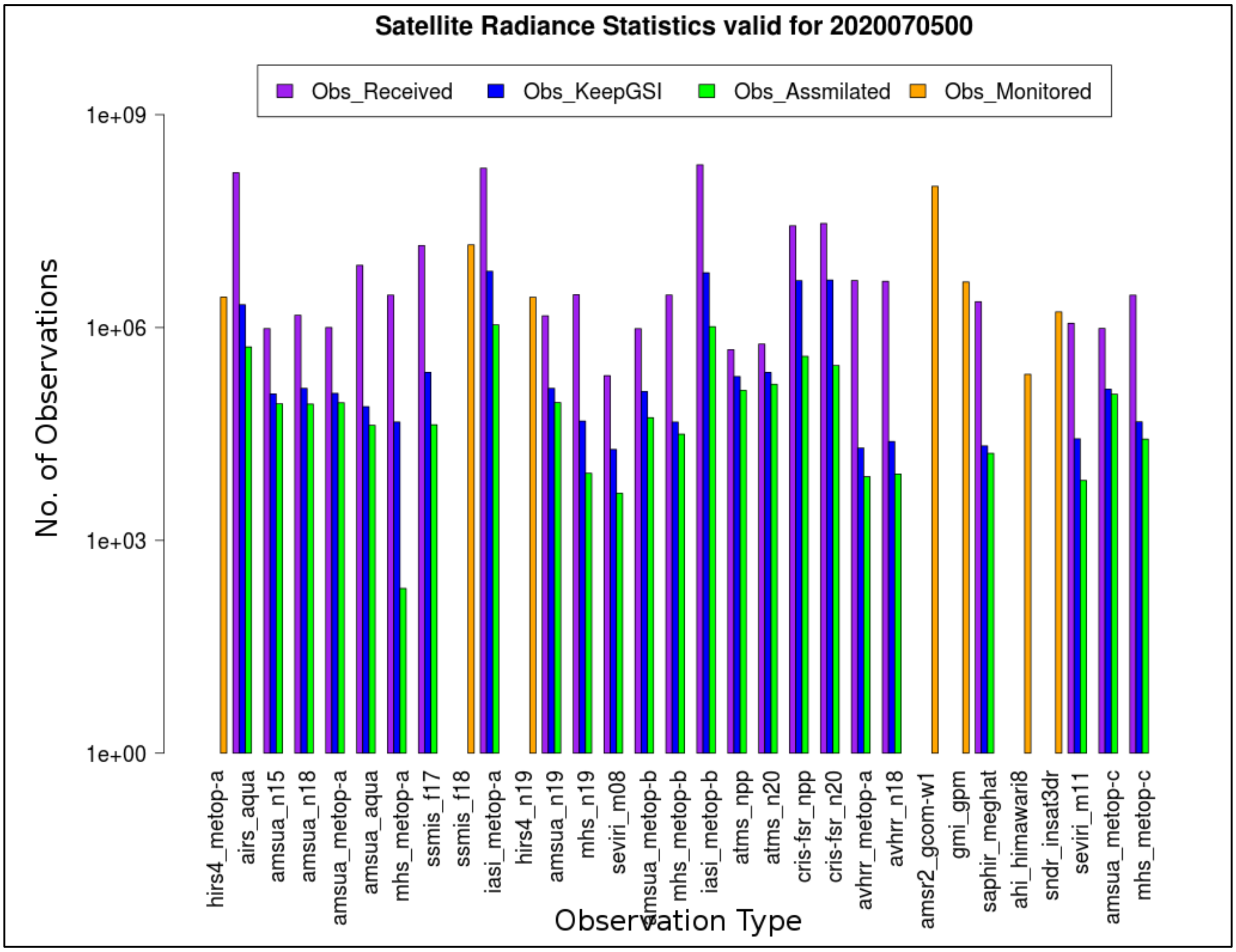

Figure 5 The total number of observations received, kept, assimilated and monitored valid at 00Z 20200705.

The contribution of each type of satellite observations w.r.t. the total number of observations is also evaluated routinely (on daily basis for all the 4 data assimilation cycles). Figure 6 presents contribution of each type of observation with respect to total no. of observations received, kept and assimilated in the NGFS-GDAS system. It may be noticed that a very few observation type contributes more than 10% (of its total) in the assimilation and a large group are under 1 % of the total data received/ assimilated. Furthermore, the contribution of each ‘kept’ type w. r. t. the total number of observations ‘received’ and the % of assimilated observation w. r. t. the ‘kept’ observations(which is the quality controlled observations passed through assimilation procedure) are estimated and presented in Figure 7.

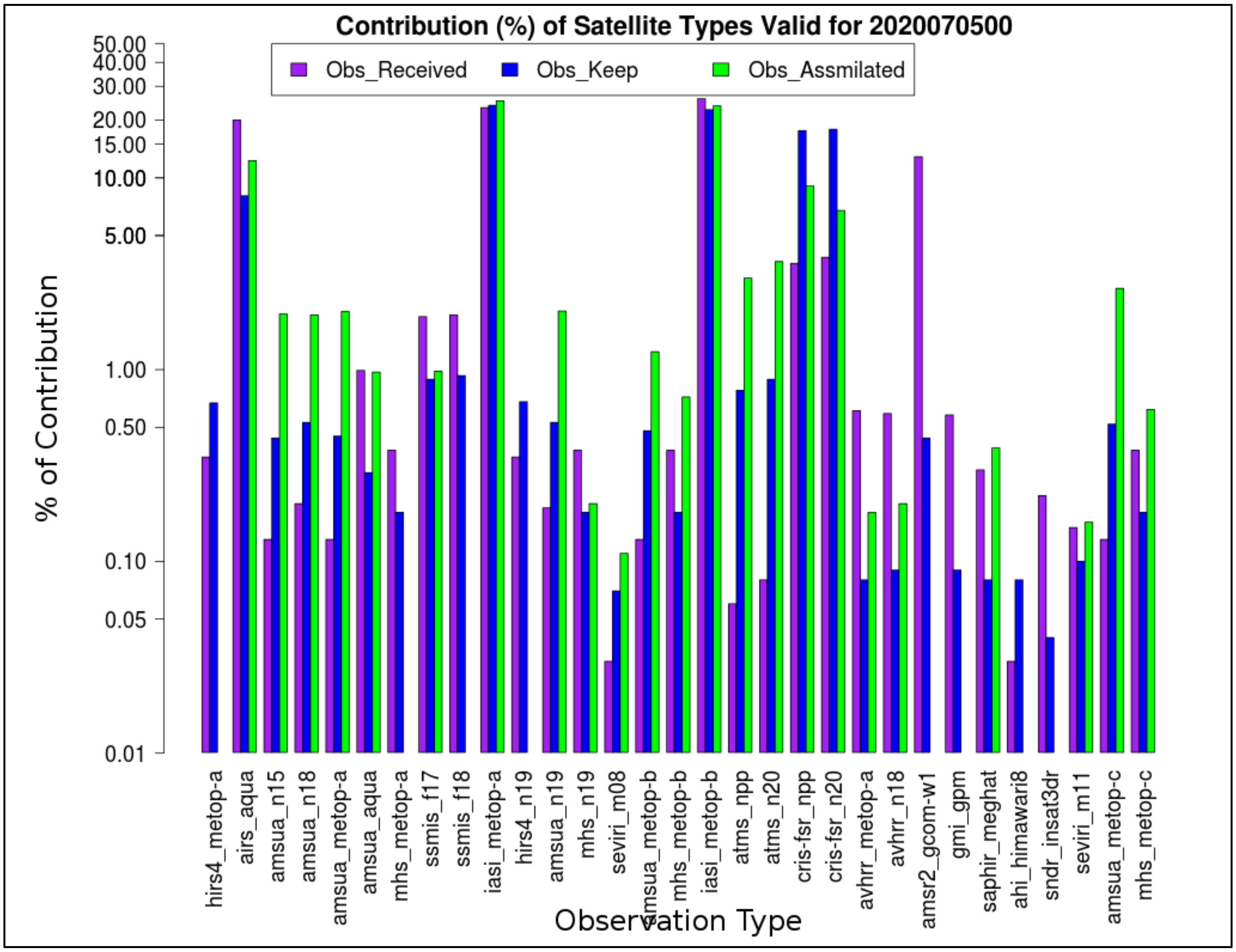

Figure 6 The contribution (%) of satellite observations (type wise) w. r. t. the total received, kept, and assimilated in NGFS-GDAS (analysis valid at 00Z 20200705).

It may be noticed that though the percentage of observation ‘kept’ w.r.t. the total number of observation received is less but the percentage of quality controlled observations passed through GSI analysis is high (with respect to the ‘kept’ observation) and is clearly shown in green color. In case of SAPHIR, though a very less data (0.93 %) could able to passed through the quality check, a large percentage (78.53 %) of the “kept” (quality controlled) observations are getting assimilated in the analysis. Similarly, 70 % of the kept observations are assimilated in case of AMSU. Hence, it worth to mention chances of quality controlled observations passes through the assimilation system are high.

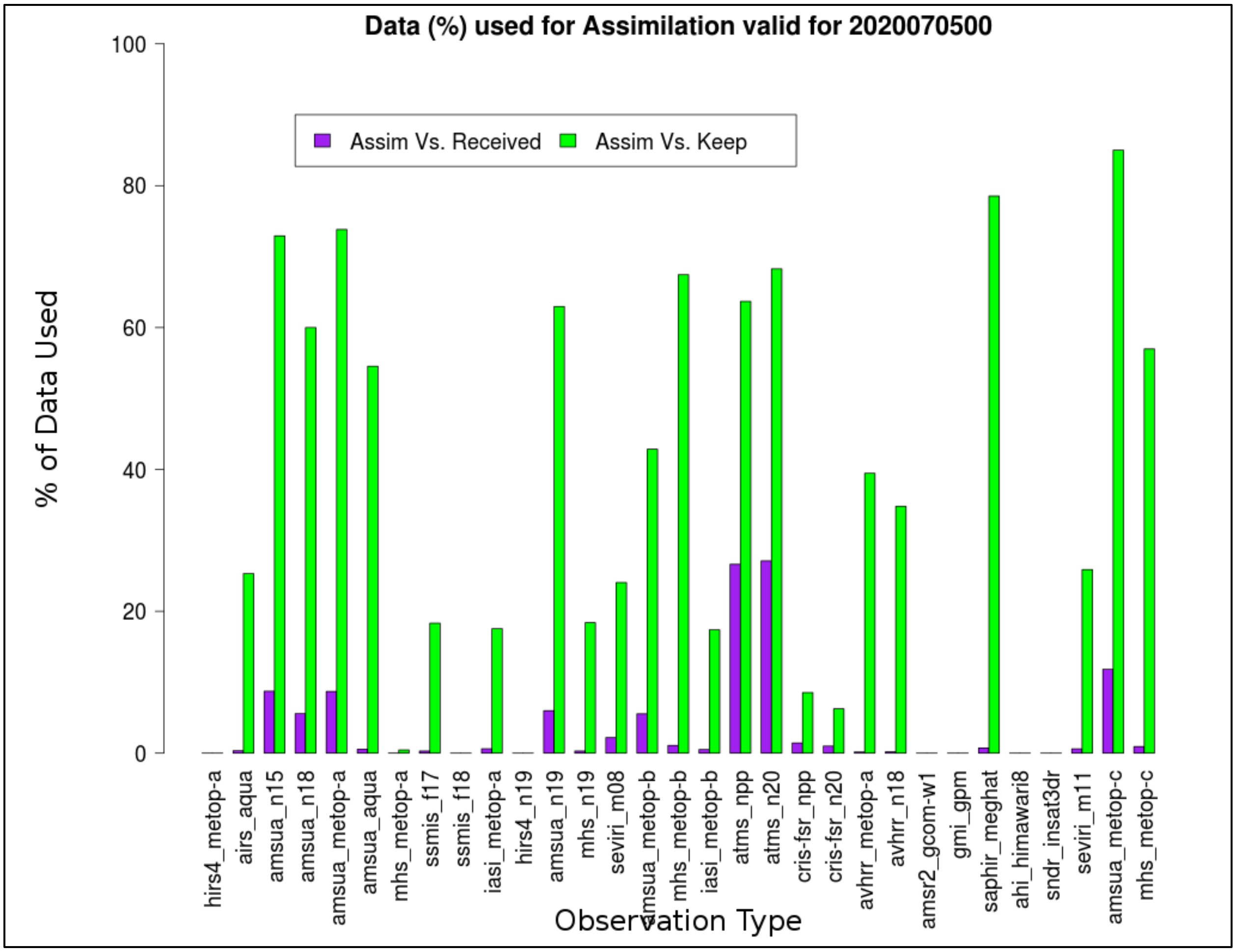

Figure 7 Percentage of satellite types Assimilated w. r. t. the total received for a particular type (Purple colored bar) and assimilated w. r. t. kept (Green colored bar) observations in NGFS-GDAS analysis valid at 00Z 20200705.

Further, the statistics on the total observations received and assimilated, regardless of satellite observations types, are investigated. Thus, the observations received and assimilated for different instrument types are grouped together and % of observations received and assimilated for different instrument types are calculated. Figure 8 (a) represents the % of observations received for all the instrument types valid at 00 Z 20200705. It may be noticed that the IASI contributes to a major portion (49 %) of the total satellite observations received at NCMRWF. Apart from IASI, AIRS, AMSR2 and CRIS contribute 20%, 13%, and 7%, respectively. Figure 8 (b) represents the % of observations assimilated for all the instrument types valid at 00Z 20200705. IASI, CRIS, AMSUA, AIRS and ATMS contributes 49%, 16%, 13%, 12% and 7%, respectively, in the assimilation cycle of 00Z of 20200705.

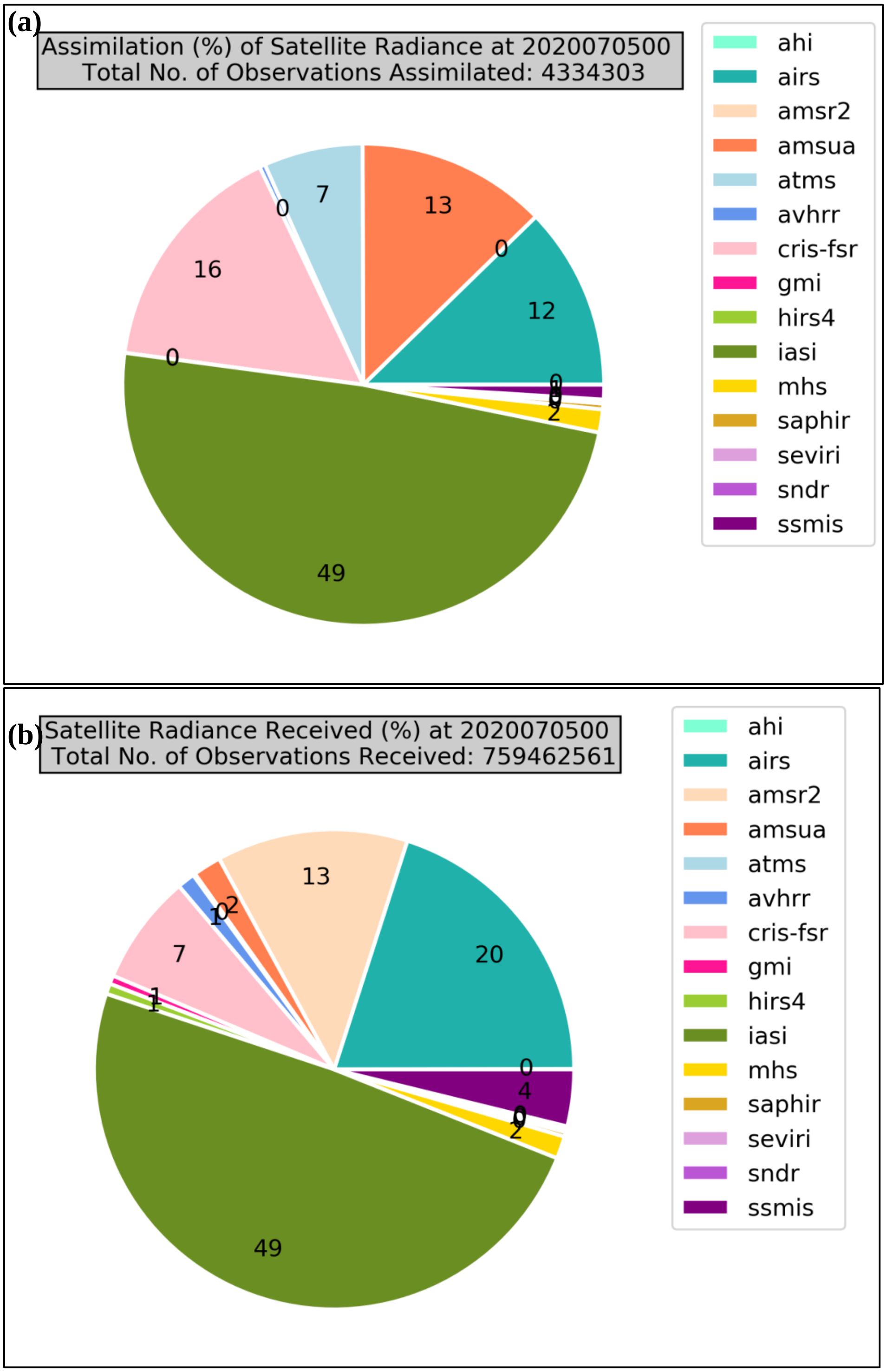

Figure 8 Percentage of radiance observations for different instrument types (a) received and (b) assimilated valid at 00Z 20200705.

As mentioned above, the radiance observations from Indian satellites INSAT-3D, INSAT-3DR and SAPHIR are continuously monitored at NCMRWF and among them INSAT-3D sounder and SAPHIR observations are assimilated in to the NGFS-GDAS. However, currently INSAT-3D sounder is not received due to some technical issues. Thus, the statistics based on the SAPHIR data is only presented.

The summary statistics for all the six channels of SAPHIR valid at 00Z 20200705 is presented in Figure 9. It shows the number of observations passing quality control during 6-hourly assimilation cycles, total bias correction, the difference (Guess with Bias Correction – Observation) and contribution to penalty. The statistical parameters like bias and standard deviation of the difference between Observation and background (O-B) are calculated for each spectral channels. The contribution of each instrument to penalty (or cost) function, which measures the misfit between the current estimate and the available information, is also derived.

The monthly monitoring statistics such as total number of observations received, bias, and bias corrections etc. are also computed along with the daily statistics for all satellite observations received at NCMRWF. Figures 10 represents the total number of observations from all the six channels of SAPHIR assimilated each day for one month period. Figure 11 presents the global bias in the SAPHIR observation for 1 month period from 05 June 2020 to 05 July 2020.SAPHIR contribution to the total penalty (or cost) function, J is presented in Figure 12. Figure 13 presents the statistics of the “bias corrected” in SAPHIR observations. The average correction and its standard deviation is also presented for all the channels. There is a reduction in the bias, in the monthly scale, is noticed, though it is minimal. Channel 1 and 6 show slightly higher bias than other channels and channel 3 shows less bias with minimum standard deviation.

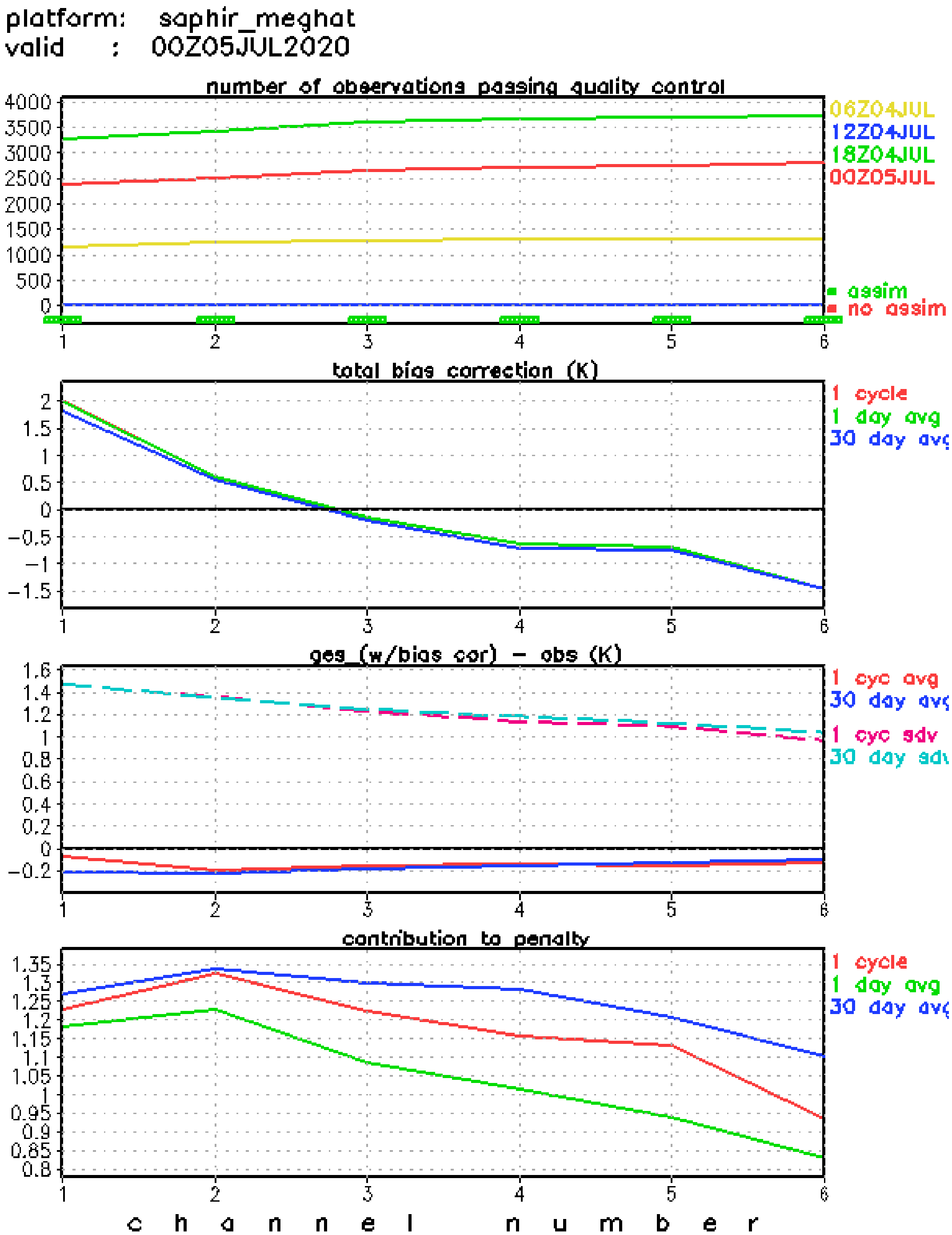

Figure 9 Statistical measures of all the six channels of SAPHIR valid at 00Z 20200705.

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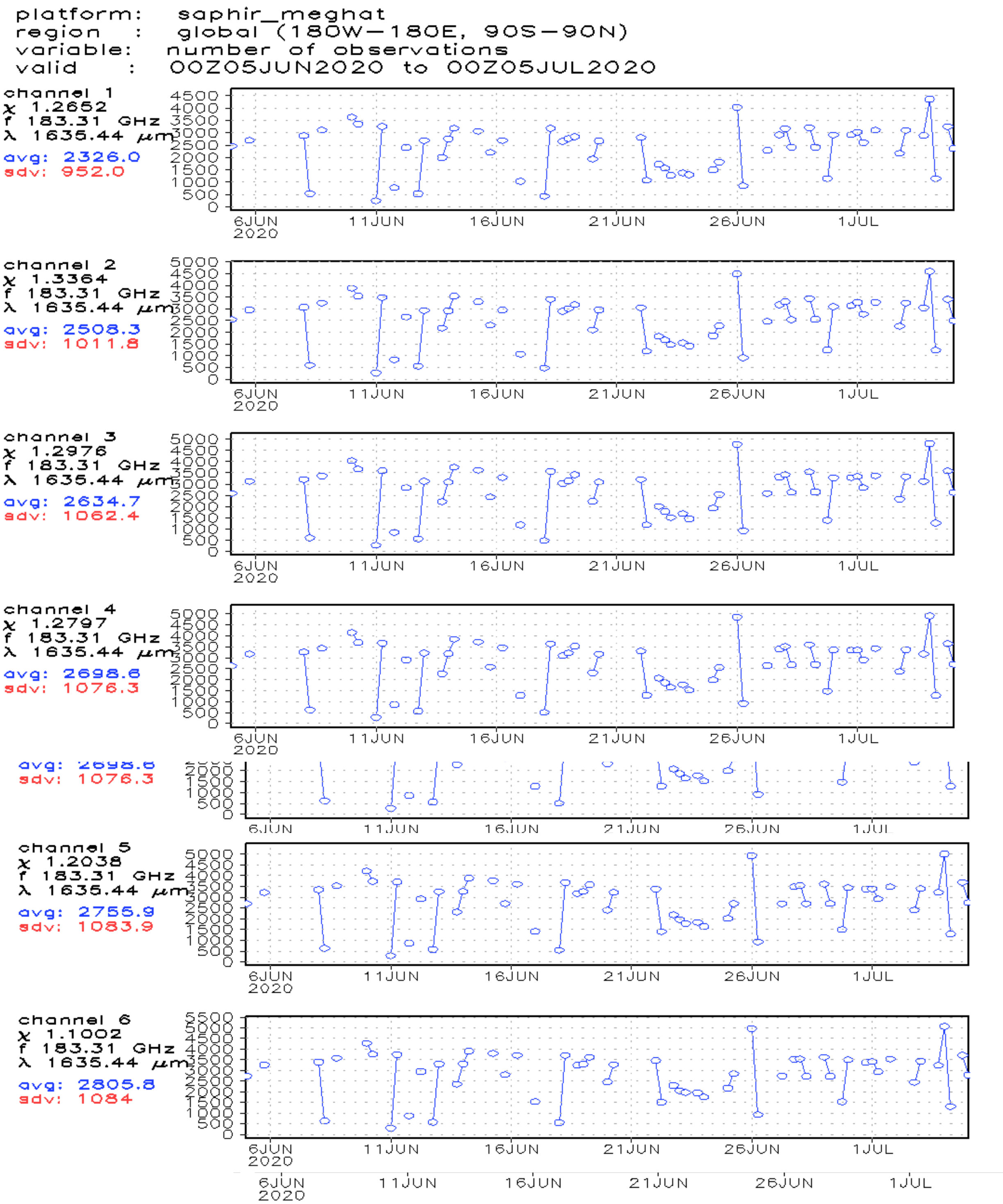

Figure 10: Time series of number of SAPHIR observations for all the channels assimilated for a month

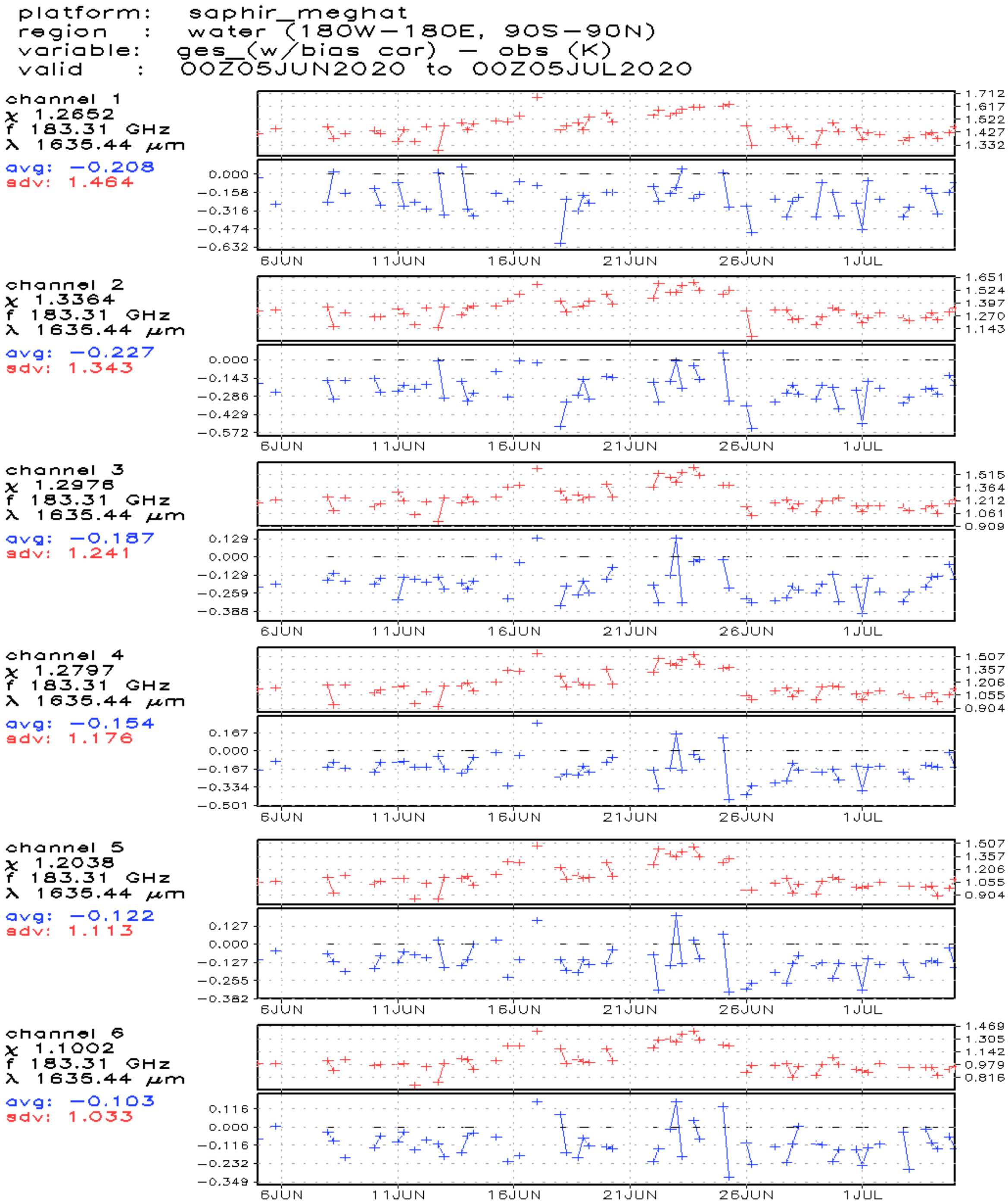

Figure 11: Same as figure 10 but for biases.

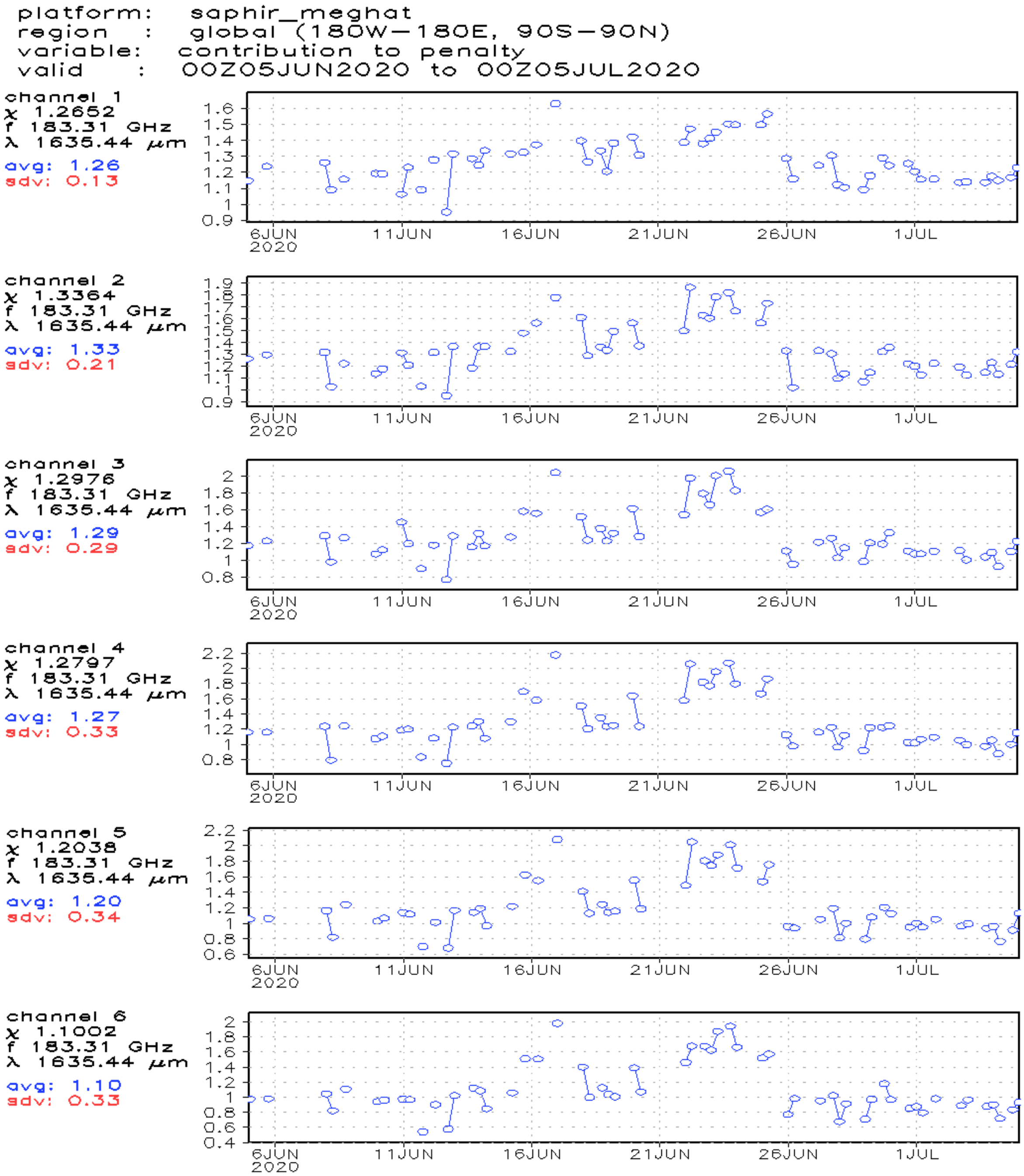

Figure 12 : Same as figure 10 but for “the contribution to the penalty”.

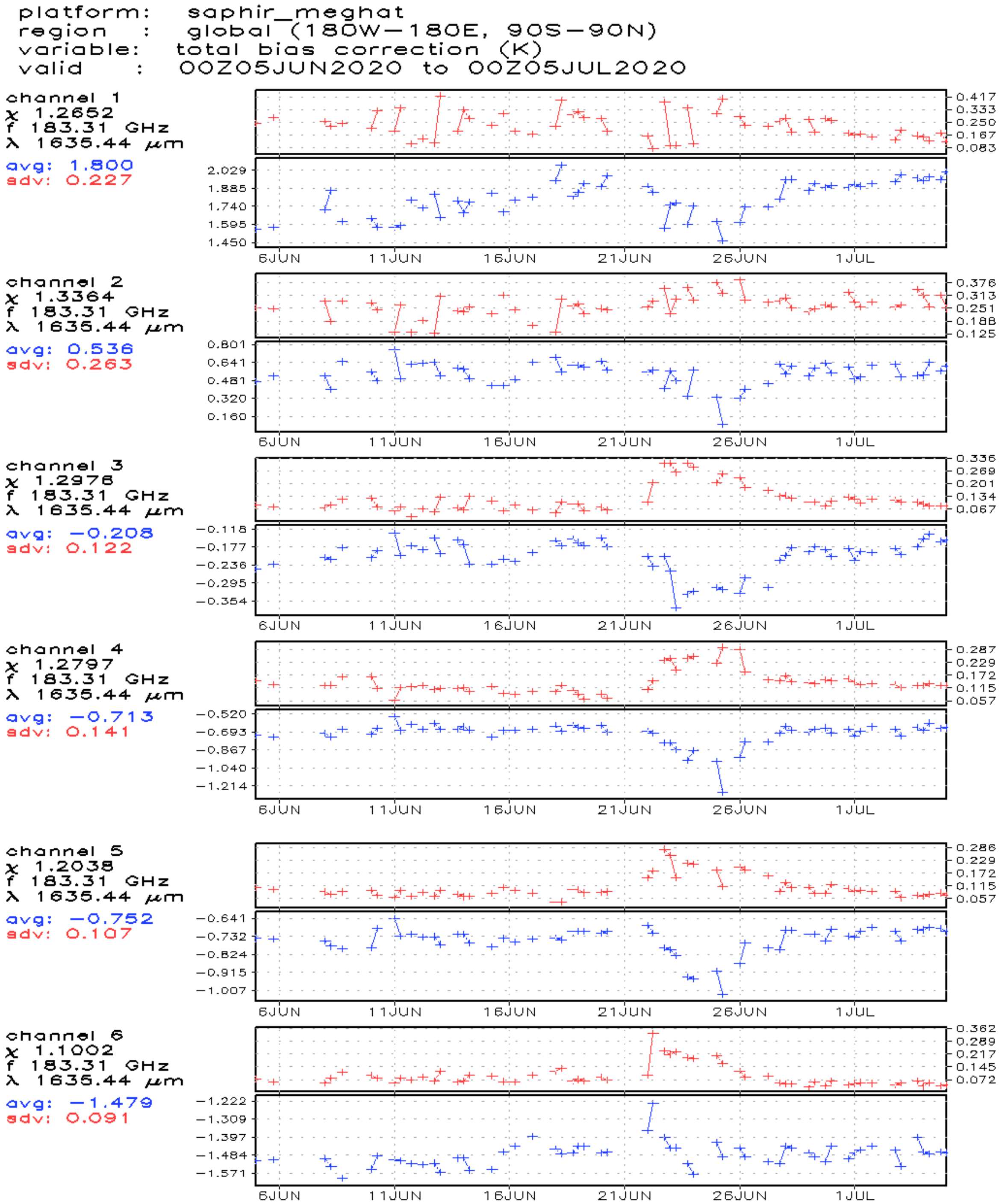

Figure 13 : Same as figure 10 but for the “bias correction”.

5 Summary

The monitoring of satellite observation is crucial for optimizing the performance of NWP models. Thus, the observation monitoring system has been developed for NGFS-GDAS at NCMRWF.

The radiance observations play a crucial role over the data sparse oceanic regions. The radiance data is being monitored at reception, after quality control and assimilation. The monitoring procedure gives the total number of observation actually getting assimilated after quality control. As part of the monitoring the statistical parameters such as bias and, standard deviation are computed on daily, weekly and monthly time scale. Observation monitoring helps decision making on its use in the data assimilation system for NWP and ensures its optimum performance

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