Monitoring the Satellite Observations Assimilated at NCMRWF

Priti Sharma, S. Indira Rani, and M. Das Gupta
National Centre for Medium Range Weather Forecasting (NCMRWF)
A-50, Sector-62, Noida
Email:priti@ncmrwf.gov.in

ABSTRACT

Reception of Global Meteorological Observations at NCMRWF has increased significantly in the recent years. Significant amount of satellite radiance observations are currently available for assimilation at NCMRWF. NCMRWF regularly assimilates various radiance observations in its global data assimilation systems viz. NCUM and NGFS. About 50% of total observations assimilated in these systems are satellite radiance observations. Due to the differences in observation pre-processing, thinning, quality control and channels selection, number of radiance observations assimilated in NCUM and NGFS are different. The percentage of satellite radiance observations assimilated in both NCUM and NGFS are a small fraction of the same received at NCMWF. The number of radiance observations from infrared based satellite sensors assimilated in NCUM and NGFS are 3% and 2% respectively. The percentage of Microwave radiance observations assimilated from instruments onboard polar satellites is slightly larger than the same from the IR instruments, 6% and 5% respectively in NCUM and NGFS. The percentage of geostationary radiance observations assimilated in NCUM and NGFS are approximately ~3% and 2%.

Keywords*: Radiance observations, Observation monitoring, Reception and Thinning.*

1. Introduction

With the advancements in measurement techniques, Satellite Observations have become one of the most important components of the Numerical Weather Prediction (NWP) system since last few decades. Satellite data provides excellent coverage over data sparse region otherwise poorly sampled by the conventional observing network. Satellite observations viz. Radiances measured by various spectral channels, Atmospheric Motion Vectors (AMVs), Scatterometer Ocean Surface wind vectors, GPS radio-Occultation, Ozone Profiles etc., are assimilated in real time in global data assimilation system of various leading operational NWP centres. Many of these observations viz. radiance, AMVs, scatterometer winds have shown significant improvement in NWP forecasts globally. However satellite radiance observations have maximum impact on NWP analyses and forecast compared to any other observations (*Eyre et al*., 1993; *Andersson et al*., 1994). In context of satellite radiance observation assimilation, data thinning, quality control and bias corrections are important issues. Though very high volume of satellite radiance

Table 1. NWP centres and their website for real time satellite radiance monitori*ng*

NWP centres	Web-sites
NCEP	https://www.emc.ncep.noaa.gov/gmb/gdas
ECMWF	https://www.ecmwf.int/en/forecasts/charts/obstat
METOFFICE	http://research.metoffice.gov.uk/research/nwp/satellite

observations are received by various leading NWP centres in real time, after thinning and quality control, only a fraction of that are used in actual assimilation system (Rahul et al. 2015, Bauer, P., 2009). Real time satellite radiance monitoring statistics generated by some of the leading global NWP centres of the world are provided in Table 1.

National Centre for Medium Range Weather Forecasting (NCMRWF) receives various geostationary and polar satellite observations through GTS as well as via internet. As the volume and type of observations assimilated in NWP system has direct impact on the analysis and hence subsequent prediction, monitoring of these observations are of great importance for underpinning the limitations associated with these data sets and data assimilation systems. The amount of satellite observations received at NCMRWF is being regularly monitored before its utilization in the assimilation systems. In this paper an attempt has been made to quantify the amount of various satellite radiance observations received and assimilated at NCMRWF's global data assimilation systems (GDAS) during September 2017. The two different GDAS's operationally running at NCMRWF is described in section 2. Section 3 describes the details of the monitoring of satellite observations at NCMRWF.

2. Global Data Assimilation Systems at NCMRWF

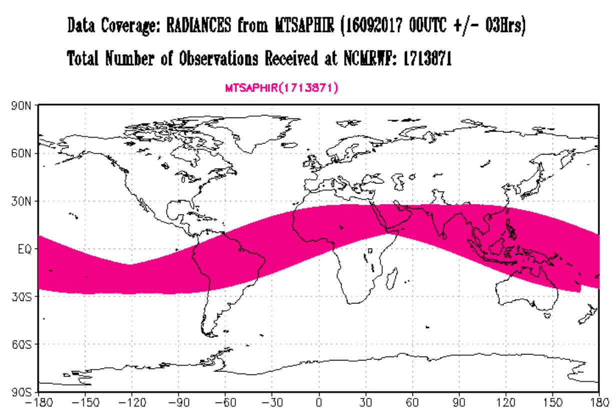
NCMRWF operationally runs two global data assimilation systems compatible for (i) NGFS, Global Forecast System, adopted from NCEP, USA (Prasad, et al, 2011) and (ii) NCUM unified modeling system adopted from UK Met Office (Rajagopal et al., 2012) . Both the systems are six-hourly intermittent systems, run four times a day viz. 00, 06, 12 and 18 UTC (assimilation cycle) with ± 3 hrs data window.

The configuration of these two data assimilation systems along with observations used during the study period i.e. September 2017 are described below.

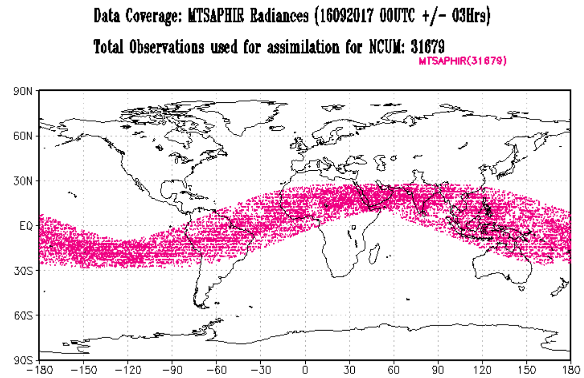
GDAS for NGFS was based on a hybrid data assimilation system combining 80 members Ensemble Kalman Filter at T574L64 resolution with 3D VAR at T1534L64 resolution during the study period. In hybrid method, data assimilation is done in the variational framework by effective incorporation of ensemble covariances in estimating background error covariance (Hu, et al., 2016, GSI User's Guide Version 3.5). For radiance assimilation, Radiative transfer Model CRTM V2.2.3 (Chen et al., 2008) was used. GDAS for NCUM was based on Hybrid-4DVAR. The Hybrid 4D-Var combines the advantages of traditional 4D-Var and the ensemble data assimilation. NCUM Hybrid 4D-Var system uses the ensemble forecasts from the NCMRWF ensemble prediction system (NEPS) which uses Ensemble Transform Kalman Filter (ETKF) method for perturbation generation. The model resolution is 17km, while the assimilation is done in dual resolution, first 40 iterations in 90 km and the next 30 iterations in 40 km. The radiative transfer model used in NCUM GDAS during the study period was RTTOV-9.

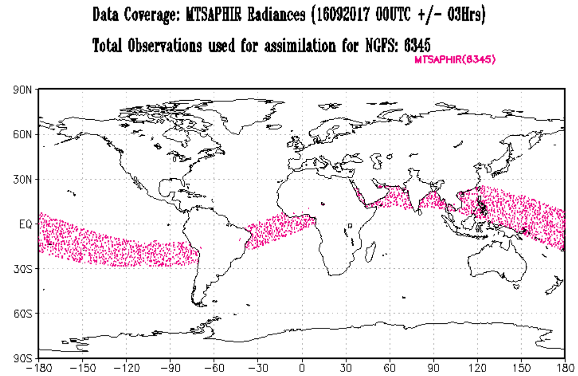
NCMRWF was receiving global radiance observations via different communication channels. Mainly the polar satellite radiance observations viz. HIRS, AMSU, MHS (onboard NOAA, METOP), AIRS (onboard AQUA), CRIS, ATMS (onboard NPP), SSMI/S (onboard DMSP) during the study period were being received at NCMRWF from NESDIS server via ftp. Geostationary radiances of GOES satellite is also downloading from NESDIS server. Himawari-8 radiances were being received through GTS and INSAT-3D radiances are downloading from IMD server. SEVIRI radiances from METEOSAT were received through EUMETCAST. IASI radiances were available via both through NESDIS and EUMETCAST; however the number of channels in these two datasets was different. IASI data received from EUMETCAST were being assimilated in NCUM and the same received from NESDIS were being used in NGFS.

Apart from satellite radiances discussed above, other global observations assimilated in both the systems mainly comprise of land surface observations, marine surface observations (ship and buoy), upper-air sonde observations, aircraft observations, atmospheric motion vectors and bending angle radio occultation observations etc.



(A)





(B) **(C)**

Figure 1: SAPHIR Observations Received (a) and assimilated after Thinning & Quality Control in NCUM (b) and NGFS (c).

3. Monitoring of Satellite Observations

Satellite radiance observations received at NCMRWF through GTS and other ftp sources during the month of September 2017 are used for the current study. Number of satellite observations received at NCMRWF and the number of satellite observations assimilated in the NCMRWF GDAS's are generated. Files created after observation pre-processing along with statistics files generated after assimilation for NCUM and NGFS are being used for this study. Monthly mean count of radiance observations received from various satellites and assimilated in each assimilation system has been generated.

The radiance observations discussed in previous section passed through observation pre-processing modules of both GDAS's before their actual assimilation into the systems. After pre-processing, these observations are passed through various steps such as thinning, quality control and channel selection. Satellite observations are very high in density, thus thinning is required to avoid high computational cost and violation of the assumption of independent measurement errors. Thinning criteria is different for NCUM and NGFS data assimilation system. For NCUM each observation is selected within a grid box of 80.0×80.0 km for polar satellite and 120.0×120.0 km for geostationary satellite radiances, whereas in the case of NGFS, each observation is selected within a grid box of size 145.0×145.0 km for both polar as well as geostationary satellite radiances. Radiance observations over sea-ice, high land and for some channels over land with significant surface contribution are rejected in both NGFS and NCUM assimilation systems.

As the observation pre-processing, thinning, quality control and channel selection criteria are different for NGFS and NCUM, accordingly the number of radiance observations for a particular type and satellite, available for assimilation in both the systems are also different. The effect of observation pre-processing, thinning, channel selection etc. on the observations available for assimilation in NGFS and NCUM are shown in Figure 1. Radiance observations from SAPHIR microwave sounder onboard Megha-Tropiques received at NCMRWF on 00UTC of 16th Sep, 2017 (a typical day) are shown in (Figure 1a) along with the same available after pre-processing, thinning and channel selection for NCUM (Figure 1b) and NGFS (Figure1c).

The lowest channel of SAPHIR peaks high in the atmosphere, at around 700 hPa, compared to the other microwave sounders and imagers and influence of surface property is minimal. Hence all the SAPHIR channels are assimilated both over land and ocean in the NCUM system. However in the NGFS system, microwave radiance observations from various satellite instruments are assimilated only over the ocean, and the same criteria adapted for SAPHIR too.

Table 2 shows the count of different type of conventional as well as satellite radiances observations (per assimilation cycle) after the pre-processing module and the observations assimilated in NCUM for September 2017. After observation pre-processing, 70% of the available observations for assimilation are satellite radiance observations. However due to thinning, channel selection and quality control criteria only a nominal part of it is used in the assimilation purpose. Still, 50% of total observations assimilated in the system are satellite radiance observations. NGFS also shows similar type of results, for brevity the same is not included here.

As 50% of the observations assimilated in NCMRWF GDAS system are satellite radiances, the monitoring of the same is important to ensure its proper reception and assimilation. Satellite radiance observations received at

Table 2. Count of Pre-Processed and Assimilated Observation (NCUM) Sept.2017

Observation type	Pre-processed	Assimilated
AIRCRAFT	1,50,000	20,000
SONDE	3,000	1,000
SURFACE	30,000	20,000
SCATWIND	6,00,000	25,000
SATWIND	3,00,000	25,000
Satellite Radiance Observations		
AIRS	40,000	6,000
ATMS	40,000	9,000
ATOVS	5,00,000	30,000
CRIS	40,000	6,000
GOES	50,000	1,500
GPSRO	28,000	25,000
IASI	7,000	1,200
INS3DS	15,000	1,000
MTSAPHIR	10,00,000	2,000
SEVIRICLEAR	5,00,000	10,000

NCMRWF in real time, during the study period, are mainly from (i) operational polar orbiting satellites viz. NOAA-15, 18 & 19, NPP, AQUA, & METOP-A & B (ii) geostationary satellites viz. GOES-15, Himawari-8, METEOSAT, INSAT-3D and (iii) low inclination research satellite Megha-Tropiques. Polar and low-inclination satellite measures global radiances

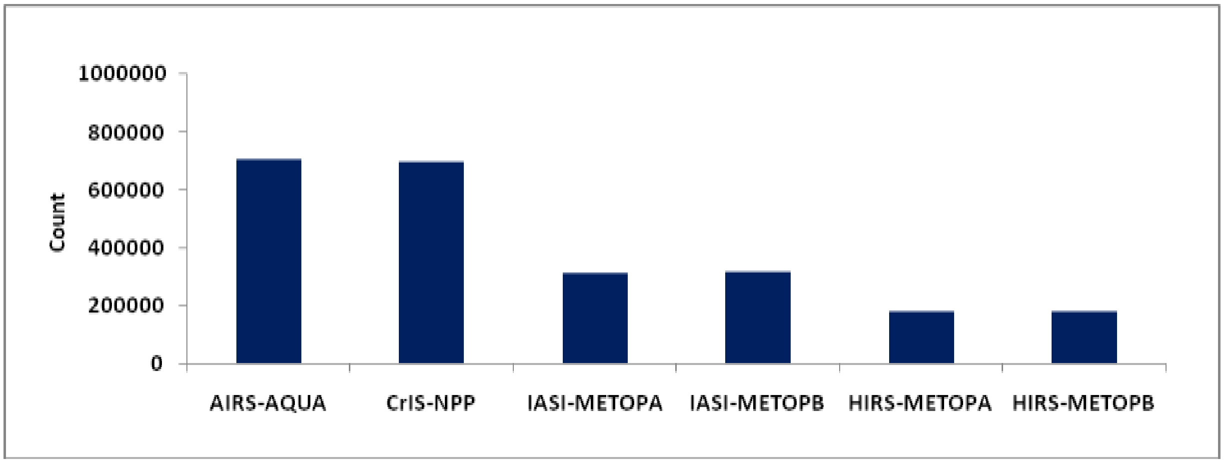


Figure 2: Observation count (per assimilation cycle) for IR Radiances (Monthly Average September 2017.

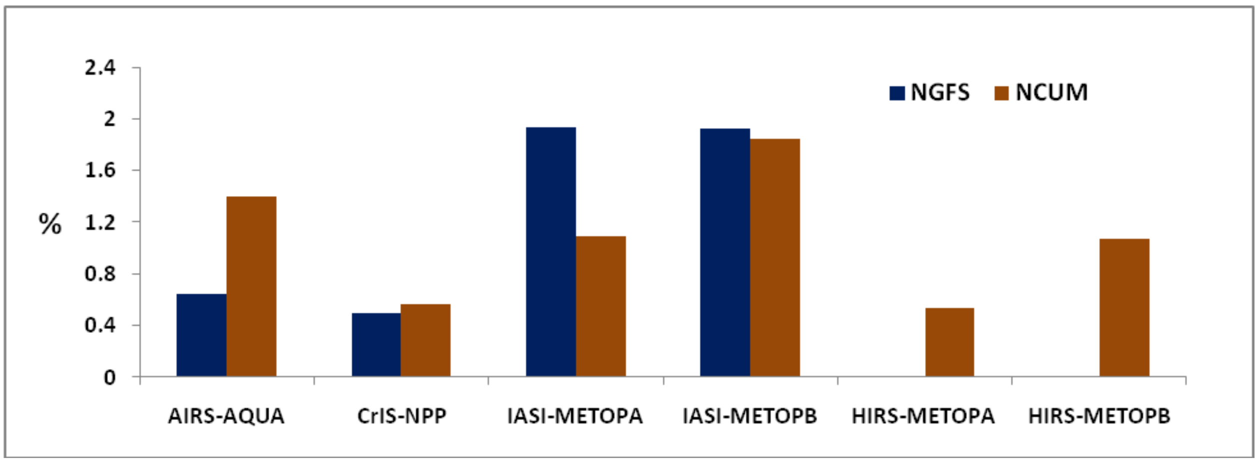


Figure 3: Percentage (%) of assimilated IR Radiances (Monthly Average September-2017).

using both infrared (IR) and microwave (MW) channels whereas geostationary satellites use only IR channels to measure the radiances. Monthly monitoring statistics for polar IR, MW and geo-stationary radiances are presented in the following sections.

3.1 Infrared radiance observations from Polar Orbiting Satellites

Infrared sounders onboard polar satellites are further classified as multispectral sounders and hyperspectral sounders. Multispectral sounders provide information about the vertical atmospheric structure and composition in multiple bands of electromagnetic spectrum; while hyperspectral remote sensing involves data collection in thousands of bands. High Resolution Infrared Radiation Sounder (HIRS) is a multispectral sounders whereas AIRS (Atmospheric Infrared Sounder), IASI (Infrared Atmospheric Sounding Interferometer) and CrIS (Cross-track Infrared Sounder) are the hyperspectral infrared sounders, measure the top-of-atmosphere radiance emitted by the Earth system with very high spectral resolution using thousands of channels, which are regularly used in NWP systems in real time.

Multispectral HIRS are from polar orbiting NOAA-18/19 and METOP-A/B satellites. HIRS performs atmospheric sounding with 19 infrared channels (3.8-15 µm) and one visible channel. HIRS Level 1 data at 10 km resolution are used for pre-processing modules in NCUM and NGFS. AIRS onboard AQUA is a high resolution spectrometer with 2378 channels in the thermal infrared spectral region (3.74 - 15.4 µm) and 4 bands in the visible spectral region (0.4 - 1.0 µm). CrIS onboard NPP satellite is a Fourier transform spectrometer with 1305 spectral channels (3.92 - 15.38 µm). IASI onboard METOP-A & B measures the radiance emitted from the Earth in 8641 channels, covering the spectral interval 645-2760 cm^{-1}. Level 1 data from AIRS at 13.5km, CrIS at 16km and IASI at 25 km resolution are used for pre-processing modules in NCUM and NGFS.

Mean monthly statistics for the reception of IR radiances (per assimilation cycle) viz. HIRS, CrIS, AIRS and IASI from different polar orbiting satellites for September, 2017 are shown in Figure 2. ~8,00,000 received from hyperspectral sounders AIRS & CrIS and 4,00,000 from IASI for each assimilation cycle. Though the resolution of HIRS is higher, due to significant scan separation of 42.15 km along track only ~2,00,000 of data from HIRS received per assimilation cycle. Figure 3 represents mean number of polar IR radiances assimilated in each assimilation cycle in NCUM and NGFS

It is observed that maximum number of observations assimilated is ~ 2% for IASI onboard METOP-B per assimilation cycle in both the GDAS. Due to the quality issue of observations, HIRS radiance onboard METOP-A and B was only being assimilated in NCUM (0.5% and 1%) and HIRS onboard NOAA satellite is not used for assimilation in NCUM. However HIRS from both METOP and NOAA are not assimilated in GDAS.

3.2 Polar microwave radiance observations

Microwave radiance observations from polar orbiting satellites are less affected by the presence of clouds compared to infrared observations and therefore providing important information over the cloudy region also. Unlike IR instruments, microwave (MW) instruments onboard polar satellites are only multispectral.

AMSU-A (Advanced Microwave Sounding Unit-A) is a multi-channel microwave radiometer which measures radiances in 15 discrete frequency channels (23-90 GHz) and MHS (Microwave Humidity Sounding) is a microwave radiometer measures radiances in five microwave channels between 89 and 183.3 GHz. ATMS (Advanced Technology Microwave Sounder) is a cross-track scanning microwave radiometer measures at 22 frequency bands in the range from 23 GHz through 183 GHz. SAPHIR onboard Megha-Tropiques (MT) satellite is a sounding instrument with 6 channels near the absorption band of water vapor at 183 GHz. AMSU-A Level 1 data at 48km, MHS at 16 km and SAPHIR at 10km are used for pre-processing modules. ATMS Level 1 data at 16 km for channels 165-183 GHz, 32 Km for channels 50-90 GHz and 75 km for channels 23-32 are used for pre-processing modules in NCUM and NGFS.

One month average of reception of microwave radiances for September, 2017 is shown in Figure 4. Due to low inclination orbit and more temporal frequency of MT satellite the observation received from SAPHIR onboard MT satellite is higher than other Microwave satellite radiances. Maximum observation received (16,00,000) is from Megha-Tropiques SAPHIR and ~8,00,000 of radiance observations received is from MHS and ATMS for each assimilation cycle. Least observation received is from AMSU-A (~2,00,000) per assimilation cycle.

Figure 5 represents percentage of microwave radiances assimilated after thinning and quality control in both NCUM and NGFS for September, 2017. Maximum radiances assimilated is from AMSU-A onboard METOP-B, ~ 18% in NCUM and 12% in NGFS. It is noticed that though large volume of observations received for SAPHIR but after thinning and quality control very less observation (~2%) is assimilated in the system.

3.3 Geostationary radiance observations

Geostationary satellites provide radiances in lower spectral resolution however due to high temporal resolution these observations are very crucial for predictions of

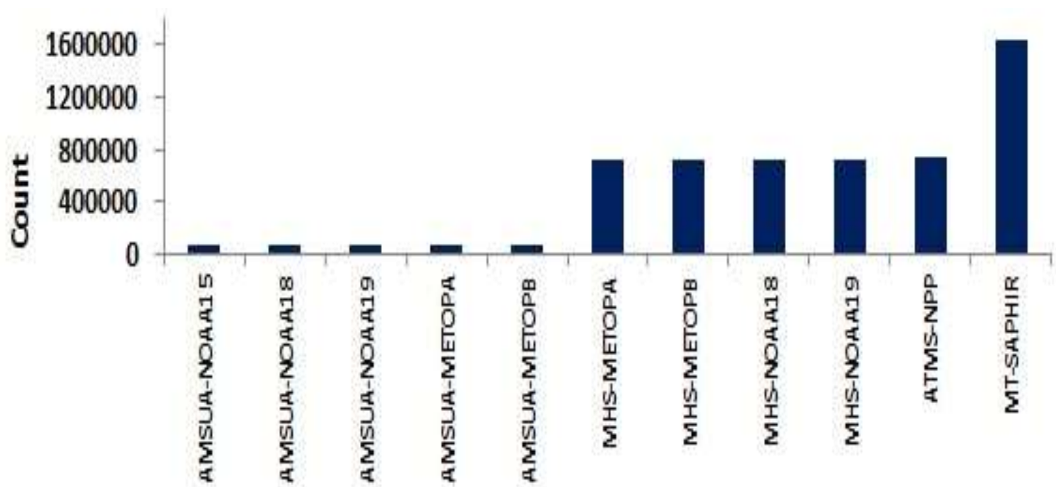


Figure 4: Observation count (per assimilation cycle) for Microwave Radiances (Monthly Average September 2017.

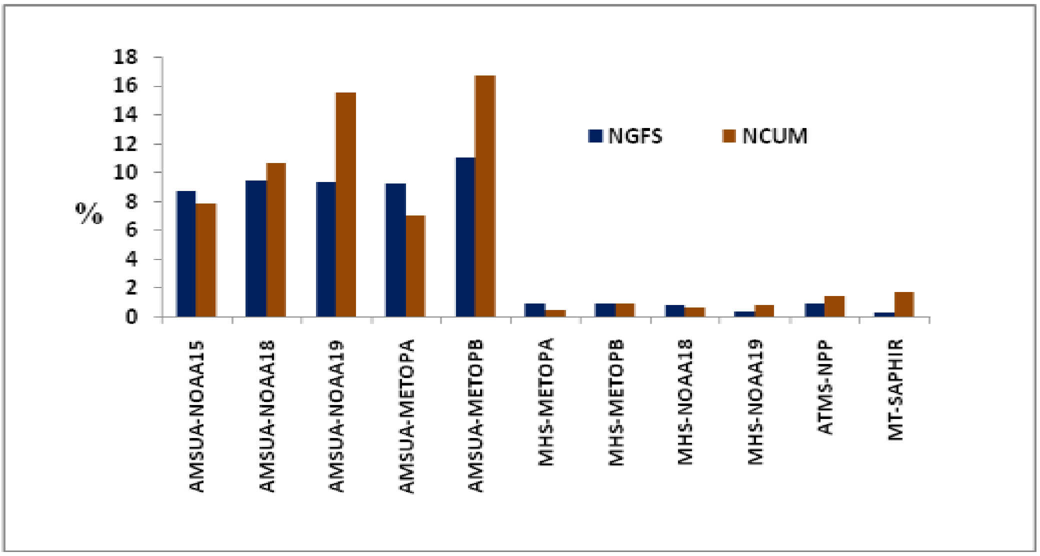


Figure 5: Percentage (%) of assimilated Microwave Radiances (Monthly Average September-2017).

fast-evolving weather systems at the mesoscale to the convective scale (Stengel et al. 2009).

Presently, NCMRWF assimilates Clear Sky Radiances (CSRs) mainly from the water vapor channels. This observation improves the assimilation of relative humidity (RH) in the upper troposphere (Peubey, C. and McNally, A.P. (2009)). Geostationary radiances during the study period were available from geostationary imagers viz. GOES onboard GOES-13/15, SEVIRI onboard METEOSAT-10, AHI onboard HIMAWARI-8 and geostationary sounders onboard INSAT-3D. GOES-13/15 imagers measures radiances in 5 channels, one visible and four IR with resolution of 1.0 km for visible channels and 4.0 km for IR channels. SEVIRI (Spinning Enhanced Visible and Infrared Imager) onboard Meteosat-10 has the capacity to observe the Earth in 12 spectral channels (4 visible/NIR channel and 8 IR channels). Resolution is 1 km for the high-resolution visible channel and 3 km for the infra-red and the 3 other visible channels.

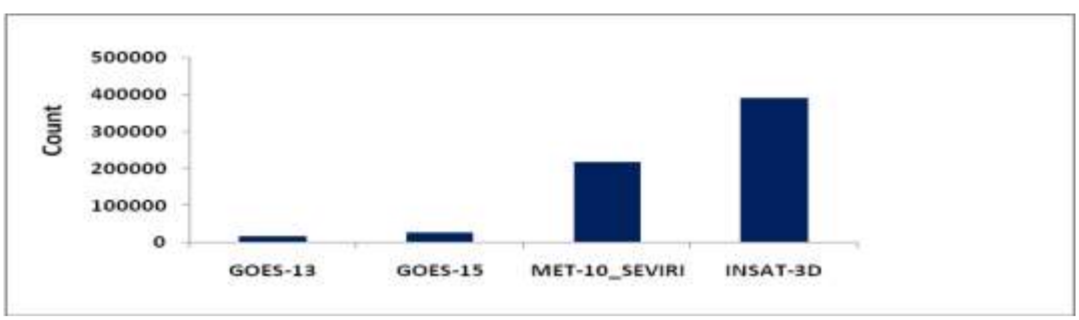


Figure 6: Observation count (per assimilation cycle) for Geostationary Radiances (Monthly Average September 2017.

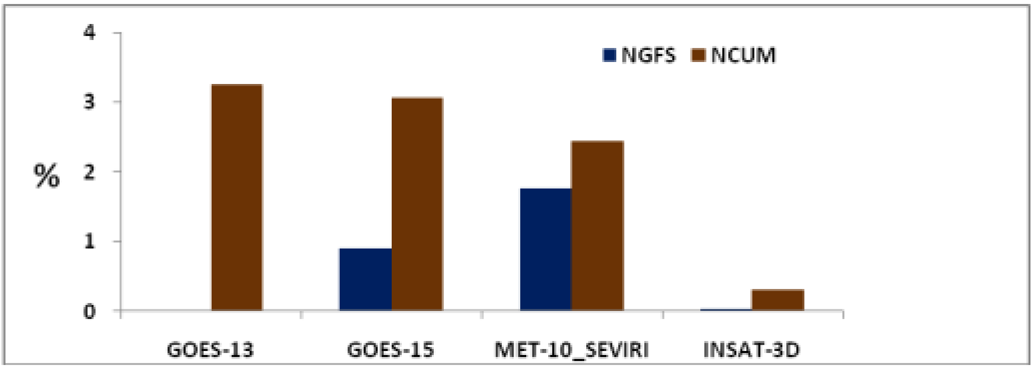


Figure 7: Percentage (%) of assimilated Geostationary Radiances (Monthly Average September-2017).

The Sounder onboard Indian satellite INSAT-3D carries a 6 channel imager and 19 channel sounder payload. The Sounder measures radiance in eighteen IR and one visible channel simultaneously over an area of 10 km x 10 km. One month average of reception of geostationary radiances for September, 2017 is shown in Figure 6.

About 4,00,000 radiance observations received from sounder onboard INSAT-3D and 2,50,000 observations received from SEVIRI onboard METEOSAT-10 satellites. Due to the technical issues reception of GOES radiances was less (~30,000 observations per assimilation cycle).

Figure 7 represents percentage of geostationary radiances assimilated after thinning and quality control in both NCUM and NGFS for September, 2017. For each assimilation cycle, 2% of SEVIRI radiances were assimilated in NCUM and 3% in NGFS, whereas for INSAT-3D, only 0.2% and 0.5 % of radiance observations were assimilated in NGFS and NCUM respectively. In case of GOES-15, ~3% and ~1 % of observation were assimilated in NCUM and NGFS respectively.

4. Summary

Satellite radiances are one of the crucial input for NCMRWF'S NGFS and NCUM GDAS. But due to the difference in the observation pre-processing, thinning criteria and quality control number of radiance observations assimilated in both NGFS and NCUM are different. Based on the statistics of data received and assimilated in NCMRWF GDAS, it is seen that for Polar IR and Geostationary radiances only ~3 % and ~2 % of the total received observations are assimilated in NCUM and NGFS respectively. For Microwave only ~6% assimilated in NCUM and ~5 % in NGFS. This result is in line with the amount of satellite observations assimilated in other leading NWP centres of the world.

Acknowledgements

The Authors are grateful to Secretary MoES and Head, NCMRWF for the encouragement during this work. The Authors also like to thank NCMRWF scientists, Dr. V. S. Parsad and Dr. John P. George for many valuable discussions during the study.

References

Andersson E, Pailleux J, Thépaut JN, Eyre JR, McNally AP, Kelly GA, Courtier P. 1994. Use of cloud-cleared radiances in three/four-dimensional variational data assimilation. Q. J. R. Meteorol. Soc. 120: 627–653.

Bauer, P., 2009: ECMWF Seminar on Diagnosis of Forecasting and Assimilation System. (available at https://www.ecmwf.int/en/learning/workshops-and-seminars/past-workshops/2009-annual-seminar)

Chen Y, F. Weng, Y. Han, and Q. Liu, 2008: Validation of the community radiative transfer model (CRTM) by using CloudSat Data. J. Geophys.Res., 113(D8), 2156-2202.

Dahoui M., Bormann N, Isaken L., 2014: ECMWF Newsletter No. 140-summer 2014, pp 21-24

Eresmaa, R., 2014: Imager-assisted cloud detection for assimilation of infrared atmospheric sounding interferometer radiances. Q. J. R. Meteorol. Soc., 140, 2342–2352. doi: 10.1002/qj.2304

Eyre JR, Kelly G, McNally AP, Andersson E, Persson A. 1993: Assimilation of TOVS radiance information through one-dimensional variational analysis. Q. J. R. Meteorol. Soc. 119: 1427–1463.

Hu,M., H. Shao, D. Stark, K. Newman, C. Zhou, and X. Zhang, 2016: Grid-point statistical Interpolation(GSI, User's Guide Version 3.5. Developmental Testbed Center.

Mcnally, A. P., Watts, P. D., A. Smith, J., Engelen, R., Kelly, G. A., Thépaut, J. N. and Matricardi, M., 2006: The assimilation of AIRS radiance data at ECMWF. Q.J.R. Meteorol. Soc., 132: 935–957. doi:10.1256/qj.04.171

Peubey, C. and McNally, A.P., 2009; Characterization of the impact of geostationary clear-sky radiances on wind analyses in a 4D-Var context. Q.J.R. Meteorol. Soc., 135: 1863–1876.

Prasad, V. S., S. Mohandas, M. Das Gupta, E. N. Rajagopal and S. K. Dutta, 2011: Implementation of Upgraded Global Forecasting Systems (T382L64 and T574L64) at NCMRWF. NCMRWF/TR/5/2011. NCMRWF, A-50, Sector-62, Noida, (UP)-201307, India.

Rahul M., Collard A., 2015: DTC GSI Tutorial (available at https://dtcenter.org/com-GSI/users/docs/presentations/2015_tutorial)

Rajagopal, E.N., Iyengar,G.R., George, J.P., Gupta, M. D., Mohandas, S.,Siddharth, R.,Anjari, G., Manjusha, C., Prasad,V.S., Aditi, Kuldeep, S., and Amit, A.,"Implementation of Unified Model based Analysis-Forecast System at NCMRWF," Internal Report, NMRF/TR/2/2012, National Centre for Medium Range Weather Forecasting, Ministry of Earth Sciences, Gov. of India. p 1-45 (2012). doi:10.1002/qj.500

Stengel., M.P.Unden, M. Lindskog, P. Dahlgren, N.Gustafsson, and R.Bennartz, 2009: Assimilation of SEVIRI infrared radiances with HIRLAM 4D-var. Quart. J. Roy. Meteor. Soc., 135, 2100-2109