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Validation and Assimilation of ABI GOES-18 Radiance Data in the NCMRWF Global Data Assimilation System

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National Centre for Medium Range Weather Forecasting
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10	Abstract	The advancement and deployment of next-generation geostationary and polar-orbiting satellites in Earth's orbit provide a significant opportunity to enhance the understanding of the atmospheric parameters on a global scale and their plausible application to improve the assimilation suite. The U.S. Geostationary Operational Environmental Satellite R-series (GOES-R) launched its third satellite, GOES-18, on 01 March 2022 and placed it in geostationary orbit on 14 March 2022, GOES-18 was designated as GOES West in early January 2023. The Advanced Baseline Imager (ABI) is the primary instrument on both GOES-16 and GOES-18, used for imaging Earth's surface and atmosphere to significantly improve the detection and observation of severe environmental phenomena. The National Centre for Medium Range Weather Forecasting (NCMRWF) receives GOES-16 and GOES-18 data from the Production Distribution and Access (PDA) server of the National Oceanic and Atmospheric Administration (NOAA). While ABI GOES-16 data is operational at NCMRWF, it is essential to analyse GOES-18 data for its potential use in the Global Data Assimilation System (GDAS) of NCMRWF. The objective of this study is to evaluate the consistency of GOES-18 ABI data and incorporate it into 06-hourly intermittent assimilation cycles. The analysis employs the Model Evaluation Tool (MET), Python and NCL for diagnostic verification and statistical analysis. Analysis suggests that GOES-18 provides a comparatively higher number of observations than GOES-16, with a larger number of these observations being accepted in the assimilation cycle. The analysis reveals substantial improvements in spread of error, standard deviation and Root Mean Square Error (RMSE) in the analysis, indicating the potential of GOES-18 data to enhance the performance of the GDAS in the NGFS system.
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सारांश

पृथ्वी की कक्षा में अगली पीढ़ी के भूस्थैतिक और ध्रुवीय-परिक्रमा उपग्रहों की उन्नति और तैनाती वैश्विक स्तर पर वायुमंडलीय मापदंडों की समझ को बढ़ाने और एसिमिलेशन सिस्टम में सुधार के लिए उनके प्रशंसनीय अनुप्रयोग को बढ़ाने का एक महत्वपूर्ण अवसर प्रदान करती है। यूएस जियोस्टेशनरी ऑपरेशनल एनवायरनमेंटल सैटेलाइट R-Series (GOES-R) ने 01 मार्च 2022 को अपना तीसरा उपग्रह, GOES-18 लॉन्च किया और इसे 14 मार्च 2022 को भूस्थैतिक कक्षा में रखा, GOES-18 को जनवरी 2023 की शुरुआत में जीओईएस- वेस्ट के रूप में नामित किया गया था। एडवांस्ड बेसलाइन इमेजर (ABI) जीओईएस -16 और जीओईएस -18 दोनों पर प्राथमिक उपकरण है, जिसका उपयोग पृथ्वी की सतह और वायुमंडल की इमेजिंग के लिए किया जाता है ताकि गंभीर पर्यावरणीय घटनाओं का पता लगाने और अवलोकन में काफी सुधार किया जा सके। राष्ट्रीय मध्यम अवधि मौसम पूर्वानुमान केंद्र (NCMRWF) राष्ट्रीय महासागरीय और वायुमंडलीय प्रशासन (NOAA) के उत्पादन वितरण और पहुंच (PDA) सर्वर से जीओईएस -16 और जीओईएस -18 डेटा प्राप्त करता है। जबकि एबीआई जीओईएस-16 डेटा एनसीएमआरडब्ल्यूएफ में चालू है, एनसीएमआरडब्ल्यूएफ के ग्लोबल डेटा एसिमिलेशन सिस्टम (जीडीएएस) में इसके संभावित उपयोग के लिए जीओईएस-18 डेटा का विश्लेषण करना आवश्यक है।

इस अध्ययन का उद्देश्य जीओईएस -18 ABI डेटा की स्थिरता का मूल्यांकन करना और इसे 06-घंटे के आंतरायिक आत्मसात चक्रों में शामिल करना है। विश्लेषण नैदानिक सत्यापन और सांख्यिकीय विश्लेषण के लिए मॉडल मूल्यांकन उपकरण (एमईटी), पायथन और एनसीएल को नियोजित करता है। विश्लेषण से पता चलता है कि जीओईएस -18, जीओईएस -16 की तुलना में तुलनात्मक रूप से अधिक संख्या में अवलोकन प्रदान करता है, जिसमें इन टिप्पणियों की एक बड़ी संख्या को एसिमिलेशन चक्र में स्वीकार किया जाता है। विश्लेषण में त्रुटि, मानक विचलन और रूट मीन स्क्वायर एरर (RMSE) के प्रसार में पर्याप्त सुधार का पता चलता है, जो एनजीएफएस प्रणाली में जीडीएएस के प्रदर्शन को बढ़ाने के लिए जीओईएस -18 डेटा की क्षमता को दर्शाता है।

Abstract

The advancement and deployment of next-generation geostationary and polar-orbiting satellites in Earth's orbit provide a significant opportunity to enhance the understanding of the atmospheric parameters on a global scale and their plausible application to improve the assimilation suite. The U.S. Geostationary Operational Environmental Satellite R-series (GOES-R) launched its third satellite, GOES-18, on 01 March 2022 and placed it in geostationary orbit on 14 March 2022, GOES-18 was designated as GOES West in early January 2023. The Advanced Baseline Imager (ABI) is the primary instrument on both GOES-16 and GOES-18, used for imaging Earth's surface and atmosphere to significantly improve the detection and observation of severe environmental phenomena. The National Centre for Medium Range Weather Forecasting (NCMRWF) receives GOES-16 and GOES-18 data from the Production Distribution and Access (PDA) server of the National Oceanic and Atmospheric Administration (NOAA). While ABI GOES-16 data is operational at NCMRWF, it is essential to analyse GOES-18 data for its potential use in the Global Data Assimilation System (GDAS) of NCMRWF.

The objective of this study is to evaluate the consistency of GOES-18 ABI data and incorporate it into 06-hourly intermittent assimilation cycles. The analysis employs the Model Evaluation Tool (MET), Python, and NCL for diagnostic verification and statistical analysis. Analysis suggests that GOES-18 provides a comparatively higher number of observations than GOES-16, with a larger number of these observations being accepted in the assimilation cycle. The analysis reveals substantial improvements in the spread of error, standard deviation, and Root Mean Square Error (RMSE) in the analysis, indicating the potential of GOES-18 data to enhance the performance of the GDAS in the NGFS system.

1. Introduction

The enhancement in the remote sensing observational network is one of the imperative aspects of the weather and climate forecasting systems. Moreover, the expansion of satellite technology and the increase in the number of meteorological satellites simplify the monitoring and prediction of weather phenomena (Rani and Das Gupta, 2013). These observations play a significant role in improving numerical weather prediction (NWP) (Le Marshall and Leslie, 1998; Velden et al., 1988; Bouttier and Kelly, 2001; Cardinali, 2009). The deployment of next-generation geostationary weather satellites provides a robust global network of geostationary data, greatly complementing the existing satellite data coverage.

The challenge lies in using these data, which can sometimes be conflicting, to find the best estimate of the state of the Earth system for diverse applications. It must be ensured that a time sequence of these estimated states is consistent with any known equations governing the evolution of the system (Mathieu and O'Neill, 2008). Thus, the quality of any newly adopted data plays a crucial role in the global/regional data assimilation suite proposed for use in the NWP system to improve the initial state of the atmosphere and, in turn, the weather forecast (Pattanayak and Prasad, 2020). Thus, the operational use of any observation needs to be scrutinized based on certain quality assessment criteria. These include the real-time availability of observations in an acceptable format, the source of the data needs to be ascertained, and ensuring that the data pass several quality checks (Purser et al., 2000).

The National Centre for Medium Range Weather Forecasting (NCMRWF) has undertaken a leading role in the reception and processing of observations from various sources, ranging from conventional in-situ observations to remote-sensing profilers and satellite measurements, to generate analysis for the operational forecasts. An accurate analysis of the atmospheric state is vital for skillful numerical weather predictions. The centre also aims to expand its Global Data Assimilation System (GDAS) to verify and assimilate data from any new observational platform available worldwide. This report focuses on the assimilation of ABI radiances from the Geostationary Operational Environmental Satellite (GOES-18) by NOAA, received through the NOAA, Production Distribution and Access (PDA) service. A brief overview of the global data assimilation system is provided in section 2, followed by the data reception in section 3. The details about GOES-R satellite retrievals are presented in section 4. The ABI data assimilation procedure, data analysis and discussion are presented in section 5, followed by the conclusions in section 6.

2. Global Data Assimilation System

The journey of the Global Forecasting System (GFS) at NCMRWF began over two decades ago. The initial version, T80L18, was implemented on the CRAY supercomputer. Several research and operational applications were developed based on this system. In January 2007, the T80L18 Global Data Assimilation and Forecast system was replaced with an updated version with a horizontal resolution of T254, at par with the operational version of NCEP GFS. This new system, T254L64, included all the changes that NCEP implemented in its GFS during 1995- 2006 (Rajagopal et. al., 2007). The newer version, with improved skills, was implemented subsequently at par with the NCEP GFS operational suite and the journey is continuing to date. Since 2007, the Spectral Statistical Interpolation (SSI) analysis scheme was used along with the GFS framework. However, in January 2008, SSI was replaced with Gridpoint Statistical Interpolation (GSI). 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, allowing more flexibility in applying background error co-variances and making it straightforward for a single analysis system to be used across a wide range of applications, including both global and regional modeling systems and domains. The improved features in GSI include observation selection, quality control, minimization algorithm, dynamic balance constraint, and assimilation of new observation types. The detailed salient features of the GDAS analysis system can be found in Prasad et al (2011) and subsequent up-gradations are elaborated in Prasad et al (2014).

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

3. Data Reception

NCMRWF collaborates with several international agencies to receive continuous and reception of satellite data and has made numerous efforts to establish dedicated data links with global satellite operators such as IMD, NOAA, EUMETSAT, CMA, KMA, and ISRO etc., to receive huge amounts of global satellite observations. This advanced data reception infrastructure is essential for maintaining a high-quality data assimilation. NCMRWF routinely processes data from around 35 satellites as part of its operational daily data assimilation and monitoring activities. In addition to satellite data, the operational setup of NCMRWF also benefits from observations available from non-satellite sources, including surface-based stations, aircraft data, and marine buoys.

The infrastructure for data reception at NCMRWF includes high-speed data links and dedicated servers to ensure timely and efficient data transfer. To handle the large volume of data, NCMRWF has implemented various data processing systems that can manage and process terabytes of data daily.

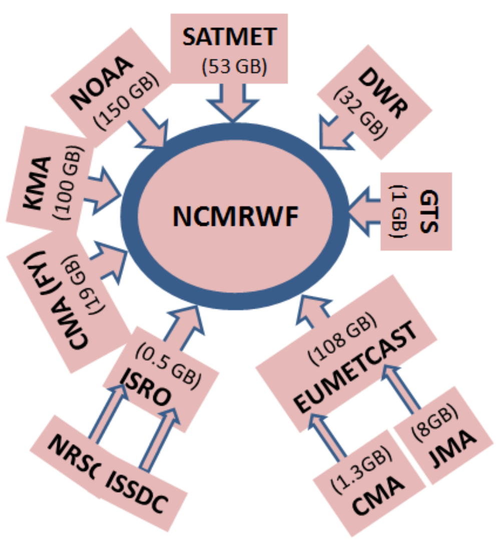

Figure 1: Meteorological and Oceanographic data reception at NCMRWF from various data providers

Figure 1 illustrates the dedicated agencies/institutes through which NCMRWF receives remote sensing observations. These satellite observations are assimilated using the GSI hybrid 4DEnvar analysis scheme (Ashu et al, 2018; Bushair et al, 2019). Each individual observation has its own importance in improving the NWP model analysis through the assimilation cycle. It is worthwhile to mention that the satellite and remote sensing observations contribute ~90% of the total observations received at NCMRWF.

4.GOES-R Satellite Retrievals

The GOES-R Series is the current generation of NOAA geostationary weather satellites**.** These satellites have significantly improved the capacity to detect and observe environmental phenomena, resulting in improved public safety, more accurate forecasts, and better protection of property. The GOES-R Series Program is a four-satellite mission that includes GOES-R (GOES-16, launched on 19 November 2016), GOES-S (GOES-17, launched on 01 March 2018), GOES-T (GOES-18, launched on 01 March 2022), and GOES-U, which is scheduled to launch in 2024. GOES-U is the last of the series and is expected to extend the operational lifespan of the GOES satellite system through 2036. The GOES-R series program is a collaborative effort between NOAA and NASA. NASA is responsible for building and launching the satellites, while NOAA operates them and distributes their data to users worldwide. The Advanced Baseline Imager (ABI) is the primary instrument on the GOES-R series for imaging Earth's surface and atmosphere to significantly improve the detection and observation of severe environmental phenomena. A team of scientists supporting the GOES-R Flight Project at NASA's Goddard Space Flight Center developed algorithms and software for independent verification of ABI Image Navigation and Registration (INR), which became known as the INR Performance Assessment Tool Set (IPATS). GOES-R is bringing new capabilities to address our changing planet and the evolving needs of NOAA's data users. The GOES-R Series provides advanced imagery and atmospheric measurements, real-time mapping of lightning activity, and monitoring of space weather. The details are described in the subsequent section.

4.1 ABI Instrument

ABI is a multi-channel passive imaging radiometer designed to observe the Western Hemisphere and provide variable area imagery and radiometric information of Earth's surface, atmosphere and cloud cover. The ABI operates in several scan modes to optimize data collection. In continuous full disk mode (Mode 4), the ABI captures a full disk image Western Hemisphere every five minutes. In flex mode (mode 3), the ABI captures a full disk every 15 minutes, a Continental United States (CONUS) image (resolution 3000 km by 5000 km) every five minutes, and two mesoscale images (resolution 1000 km by 1000 km at the satellite sub-point) every 60 seconds. Mode 6, the 10-minute flex mode, is the default operating mode for GOES-16 and GOES-

18, providing a full disk image every 10 minutes, a CONUS image every five minutes and mesoscale images every 30 seconds. The ABI has 16 different spectral bands significantly more than the previous generation of GOES satellites, which had only five. These bands include two visible channels, four near-infrared channels, and ten infrared channels. The spectral bands and their characteristics are detailed in Table 1.

Table 1: Spectral bands and characteristics of the ABI sensor on GOES-16 and GOES-18 satellites

Band	Wavelength Range (µm)	Spatial Resolution (km)	Descriptive name
1	0.45 to 0.49	1	Blue
2	0.59 to 0.69	0.5	Red
3	0.846 to 0.885	1	Vegetation
4	1.371 to 1.386	2	Cirrus
5	1.58 to 1.64	1	Snow
6	2.225 to 2.275	2	Cloud Particle Size
7	3.8 to 4	2	Shortwave Window
8	5.77 to 6.6	2	Upper-level water vapor
9	6.75 to 7.15	2	Mid-level water vapor
10	7.24 to 7.44	2	Lower-level water vapor
11	8.3 to 8.7	2	Cloud-top phase
12	9.42 to 9.8	2	Ozone
13	10.1 to 10.6	2	Clean longwave window
14	10.8 to 11.6	2	Longwave Window
15	11.8 to 12.8	2	Dirty longwave Window
16	13 to 13.6	2	CO_2

4.2 GOES-16 and GOES-18 Satellite

The GOES-16 satellite, launched on 19 November 2016, became the first in the new GOES-R ABI series to enter operations. After a period of calibration and post-launch verifications, GOES-16 replaced GOES-13 as the operational GOES-East satellite on 18 December 2017 and relocated to its designated operational location of 75.2 °W, occupying the East orbit of the two satellites constellation of the operational GOES observing system. The ABI on GOES-16 generates Level 1B (L1B) images (or frames) categorized into three types: Full Disk (FD), which spans the entire viewable hemisphere; Continental United States (CONUS), which covers the United States, and Mesoscale (MESO) which can be tasked to any local region. The FD is a circle of angular diameter 17.4 degrees as measured from the satellite's location with the center at satellite nadir and circumference at the Earth limb. The CONUS images are rectangular, spanning 5000 km in the East-West (EW) direction and 3000 km in the North-South (NS) direction. Similarly, MESO images are rectangular, covering 1000 km in both EW and NS directions. GOES-16 ABI provides a vantage observational point of much of the Americas, in addition to oblique views of the western tip of Africa.

NOAA's operational satellite fleet welcomed a new member, GOES-18, in the R-series as it entered the operations as GOES West on 04 January 2023 positioned in at 137.2 degrees west over the Pacific Ocean, GOES-18 replaced GOES-17 as GOES-West, located 22,236 miles above the equator over the Pacific Ocean. GOES-18 now serves as NOAA's primary geostationary satellite for detecting and monitoring Pacific hurricanes, thunderstorms, atmospheric rivers, coastal fog, wildfires, volcanic eruptions, and other environmental phenomena affecting the western contiguous United States, Alaska, Hawaii, Mexico, and Central America. The satellite delivers high-resolution visible and infrared imagery, atmospheric measurements, and real-time mapping of lightning activity. It is ideally located to monitor the northeastern Pacific Ocean, where many weather systems affecting the continental U.S. originate. GOES-18 also monitors the sun and detects approaching space weather hazards. GOES-18 joins GOES-16 (GOES East) in operational service and both satellites watch over more than half the globe, from the west coast of Africa to New Zealand and from near the Arctic Circle to the Antarctic Circle. Figure 2 demonstrates the geographical coverage of GOES-16 and GOES-18 satellites, showing their complementary roles in providing extensive observational data across the Western Hemisphere.

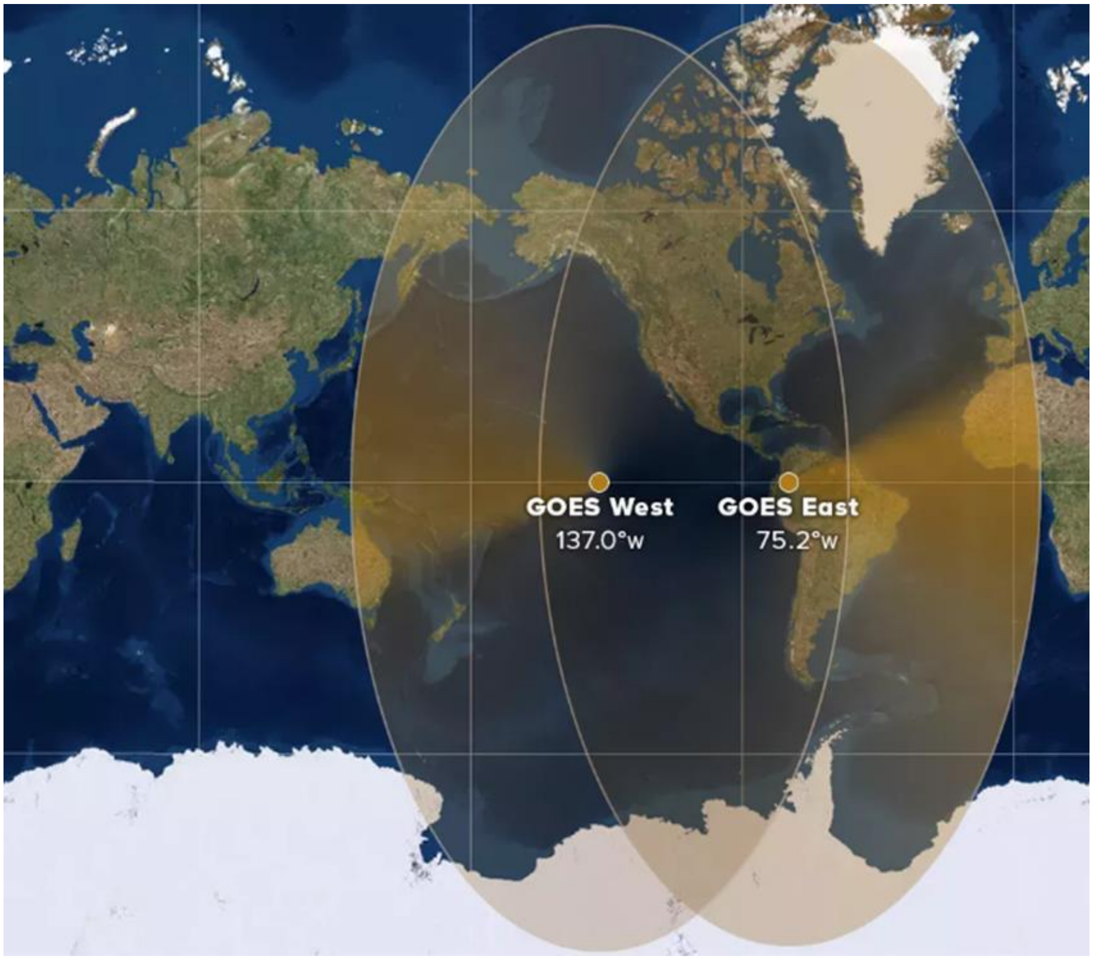

Figure 2: Geographical coverage of GOES East (GOES-16) and West (GOES-18) satellites. (*Courtesy: NOAA, USA)*

The datasets from these satellites assist a wide range of users, including weather forecasters, emergency managers, first responders, and the aviation and shipping industries. Both satellites are ideally located to monitor weather systems and hazards that most affect this region of the Western Hemisphere, including:

- Atmospheric Weather
- Environmental Hazard Monitoring
- Ocean Observations
- Space Weather

The ABI's 16 spectral bands have undergone rigorous testing; ultimately, channels 8, 9, and 10 were selected for use in NCMRWF's global data assimilation system. The spatial coverage of the ABI GOES-16 and GOES-18 radiance observations received at NCMRWF for 00 UTC 15 November 2023 is presented in Figure 3. It is seen that for each cycle, millions of observations are received at NCMRWF. Thus, there is a need to enhance the capability of the NWP system with the maximum utilization of satellite radiance observation.

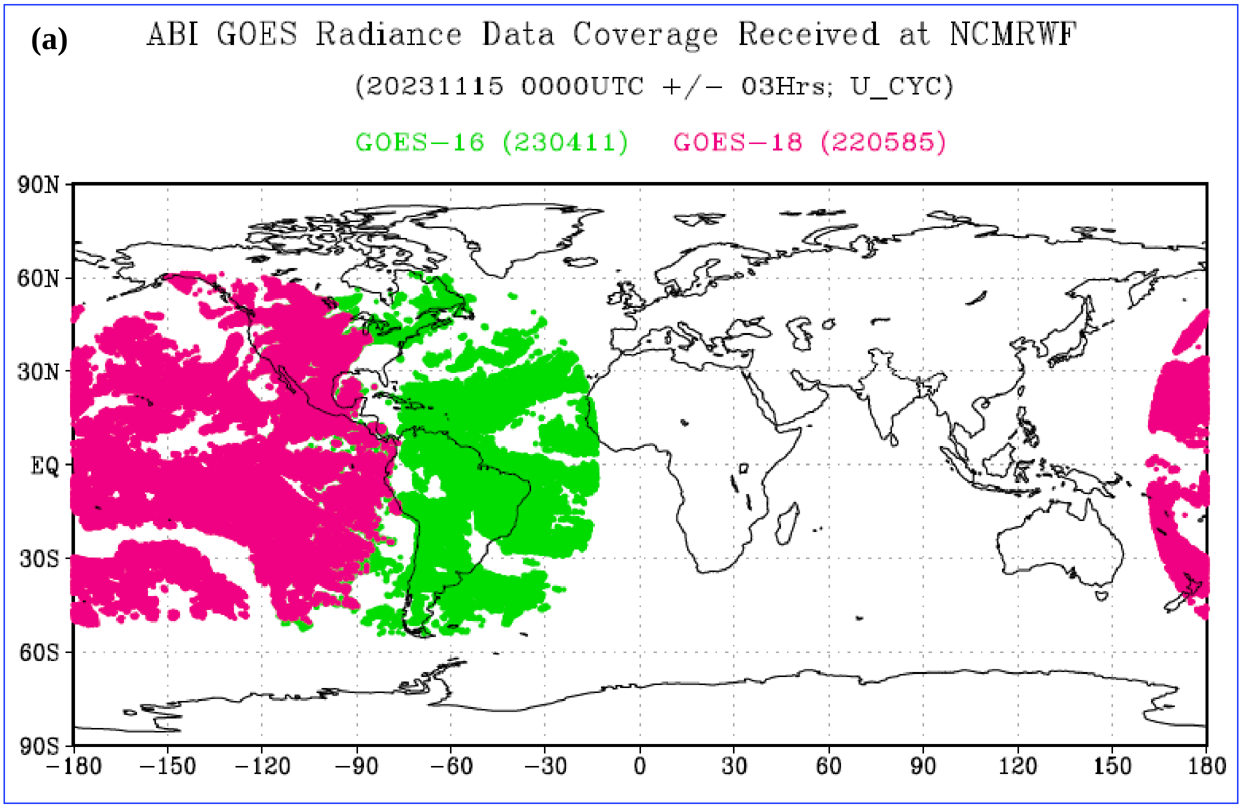

Figure 3: ABI GOES-16 and GOES-18 satellite radiance data coverage valid for 00 UTC 15 Nov 2023. The GOES-16 is presented as a green shade, and the GOES-18 a magenta shade.

5. Assimilation Procedure

The assimilation of new observational data, such as the ABI radiances from GOES-18, involves several critical steps to ensure that the data is accurately incorporated into the Global Data Assimilation System (GDAS). This section outlines the steps taken to integrate GOES-18 data into the GDAS at NCMRWF. The following steps are opted to assimilate the GOES-18 observations.

a. Update in GSI code to read the GOES-18 observations: The GSI code was modified to include the identification of GOES-18 data. This involved updating the "read_abi.f90" program to enable the system to recognize and process the radiance data from GOES-18.
b. Incorporation of GOES-18 satellite coefficient in CRTM fix data: The necessary radiative transfer coefficients for the GOES-18 satellite, such as "abi_g18.SpcCoeff.bin" and

"abi_g18.TauCoeff.bin," were incorporated into the Community Radiative Transfer Model (CRTM) fixed data. This ensures accurate simulation of satellite radiances during the assimilation process.

c. Modification in "global_satinfo.txt" and "global_satangbias.txt" as per GOES-18 observations: The files "global_satinfo.txt" and "global_satangbias.txt" were updated to include information specific to GOES-18 observations. This step is crucial for the correct handling and bias correction of the satellite data.

d. Incorporation of error coefficient in the bias file: Error coefficients specific to GOES-18 were introduced into the bias file to account for any systematic errors in the satellite radiance data. This step is essential for minimizing biases in the assimilation process.

On the successful upgradation in GSI code to utilize the GOES-18 data in NGFS global data assimilation, the Observation Sensitivity Experiment (OSE) is run for a one-month period to assess the performance of GOES-18 radiance observation in NGFS, as is illustrated subsequently.

6. Analysis, Validation and Discussion

This section aims to provide a comprehensive analysis and validation of the GOES-18 data, highlighting its assimilation into the NCMRWF Global Data Assimilation System (GDAS). The ABI data from both GOES-16 and GOES-18 is assimilated into the global GSI system at a 06-hour interval for the month of November 2023. The assimilation status is analysed and presented in this section, along with a detailed validation of the GOES-18 observations. Additionally, relevant topics such as data assimilation impacts, error analysis, and case studies are introduced to enrich the discussion.

6.1Analysis of GOES-16 and GOES-18

The total number of observations received from the ABI satellite instrument is analysed for November 2023. The analysis of the ABI data from both GOES-16 and GOES-18 (Figure 4a) suggests that NCMRWF receives nearly the same number of observations from both satellites. However, a large number of observations from GOES-18 are used in the assimilation system (Figure 4b).

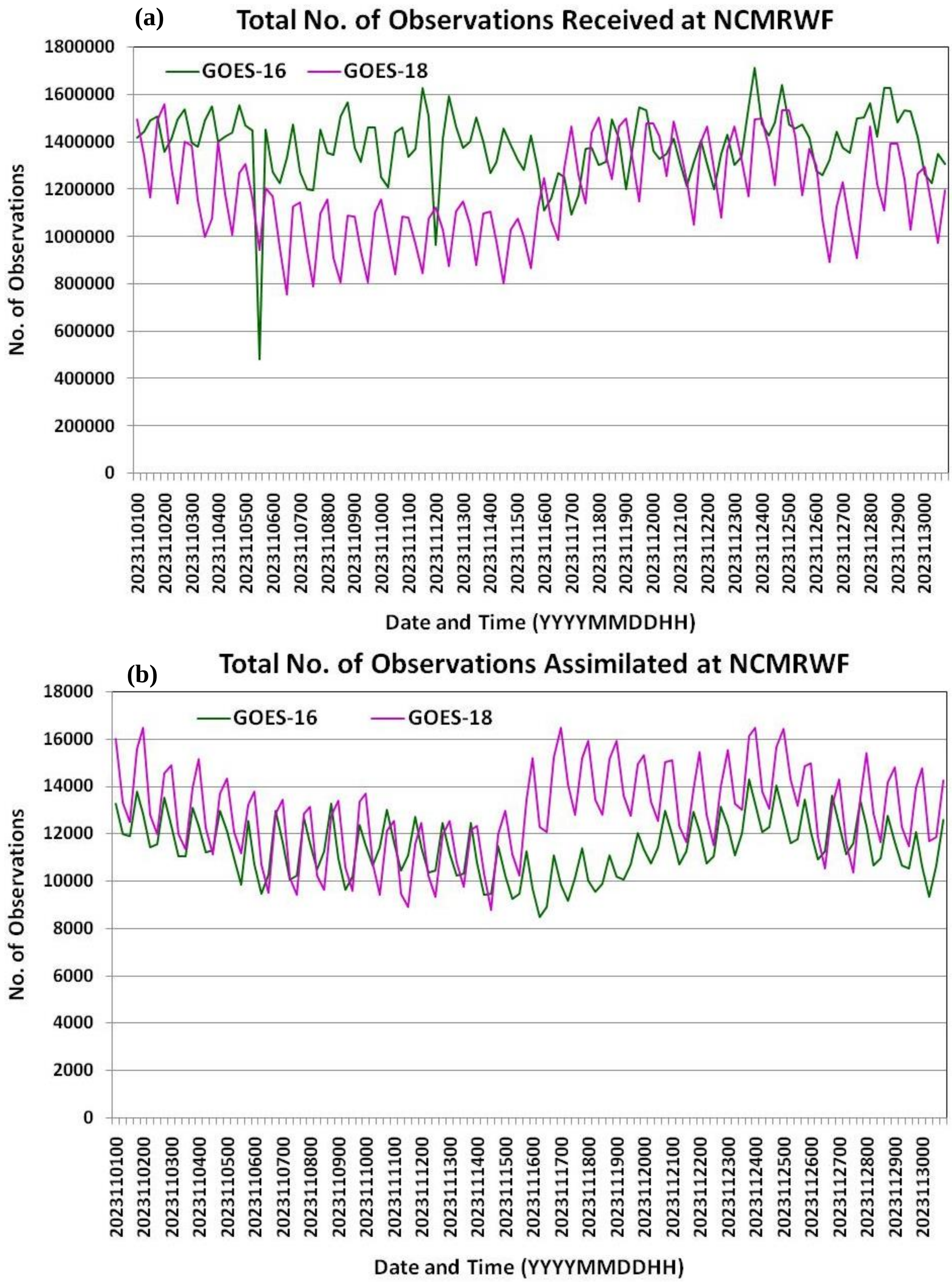

Figure 4: The number of GOES observations (a) received and (b) assimilated on a daily basis during 01-30 November 2023.

It is noticed that more radiance observations are assimilated from the GOES-18 satellite, even though a higher number of observations are received for GOES-16. A detailed analysis of GOES-18 radiance data is carried out before its use in the operational suite. The subsequent section focuses on GOES-18 radiance data.

6.2 Validation of GOES-18 Data

The successful up-gradation in the operational suite with the assimilation of new observations necessitates the validation of the product. The data assimilation system provides a powerful and systematic means for comparing the new remote measurements with all earlier and current in situ and remotely sensed measurements. Thus, the real-time operational assimilation system can provide quality assurance and validation of the new satellite observations.

The quality control (QC) is the most important aspect of satellite data assimilation. Unlike conventional observations from a prepbufr file, which includes the quality markers from the NCEP quality control process, the satellite radiance BUFR file does not include observation quality information. Instead, the quality control for radiance observations is inside the GSI. Many QC steps are employed to identify erroneous satellite data, which mainly come from the following four sources such as (i) Instrument problems, (ii) Clouds and precipitation simulation errors (iii) Surface emissivity simulation errors (iv) Processing errors (e.g., wrong height assignment, incorrect tracking, etc.).

Considering the importance of quality control, the radiance diagnostic code of the GSI system (da_rad_diags.f90) has been modified to generate a detailed observation quality check. It is seen that the threshold value of "0" and "3" are passed at the preliminary stage. However, GSI only accepts the quality controlled data with the "0" threshold value. Accordingly, the python based extraction script (extract_metdata_python.py) has been developed to extract the data generated through the radiance diagnostic package at the accepted location. The NCL based plotting package is developed to represent the data for visualization.

Among the 16 channels of ABI, the radiance observations from channels 8, 9, and 10 are used in the assimilation and the spatial illustrations of the brightness temperature from these channels are presented in Figures 5, 6 and 7. Figure 5 (a), and (b) represent the brightness temperature from observation and background for channel 8 valid at 00UTC 15 November 2023, which shows the total quality checked observation (with both '0' and '3' threshold values) locations in both observation and background. This does not reflect the number of observations actually assimilated from the channel itself. Using the updated diagnostic package, the number of observations assimilated in channel 8 (with threshold value ‘0’ only) and the corresponding model equivalent from the background field are shown in Figure 5 (c) and (d). It clearly shows that out of 4500 QCed observations, 3930 are assimilated in the GSI for that particular cycle. Similarly, Figure 6 (a), (b) represents the brightness temperature from observation and background for channel 9 and Figure (c), and (d) represents the updated plots with an improved diagnostic package. It is seen that out of 4500 QCed observation locations, only 4006 observations are assimilated for channel 9. Figures 7 (a), and (b) represent the brightness temperature from observation and background for channel 10 and Figures (c) and (d) represent the updated plots with an improved diagnostic package. It is seen that out of 4500 QCed observation locations, 4219 number of observations are assimilated for channel 10. Thus, it is concluded that the improved diagnostic package realistically represent the actual number of observation assimilated in each six hourly intermittent cycles.

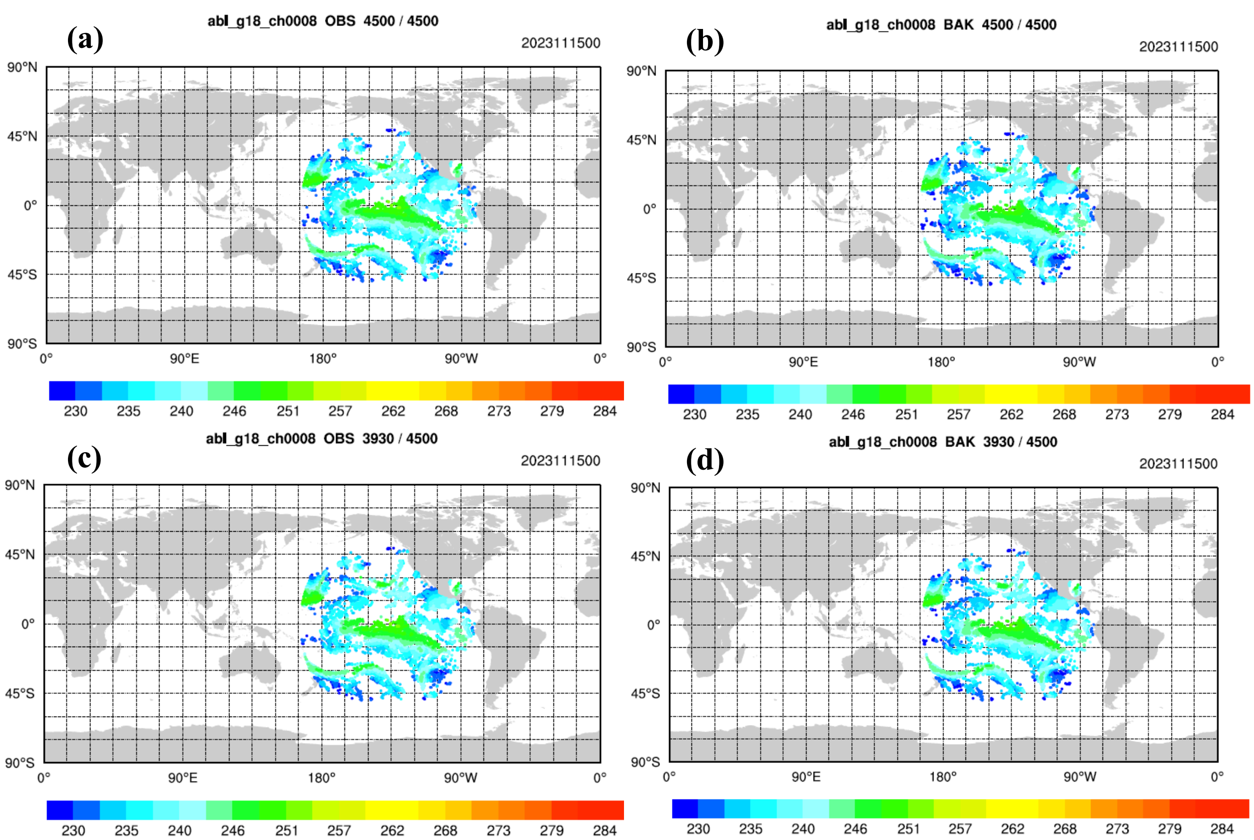

Figure 5: ABI GOES-18 brightness temperature from (a) observation and (b) background for Channel-8 valid for 00 UTC 15 November 2023. (c) and (d) are same as (a) and (b), but with updated threshold value.

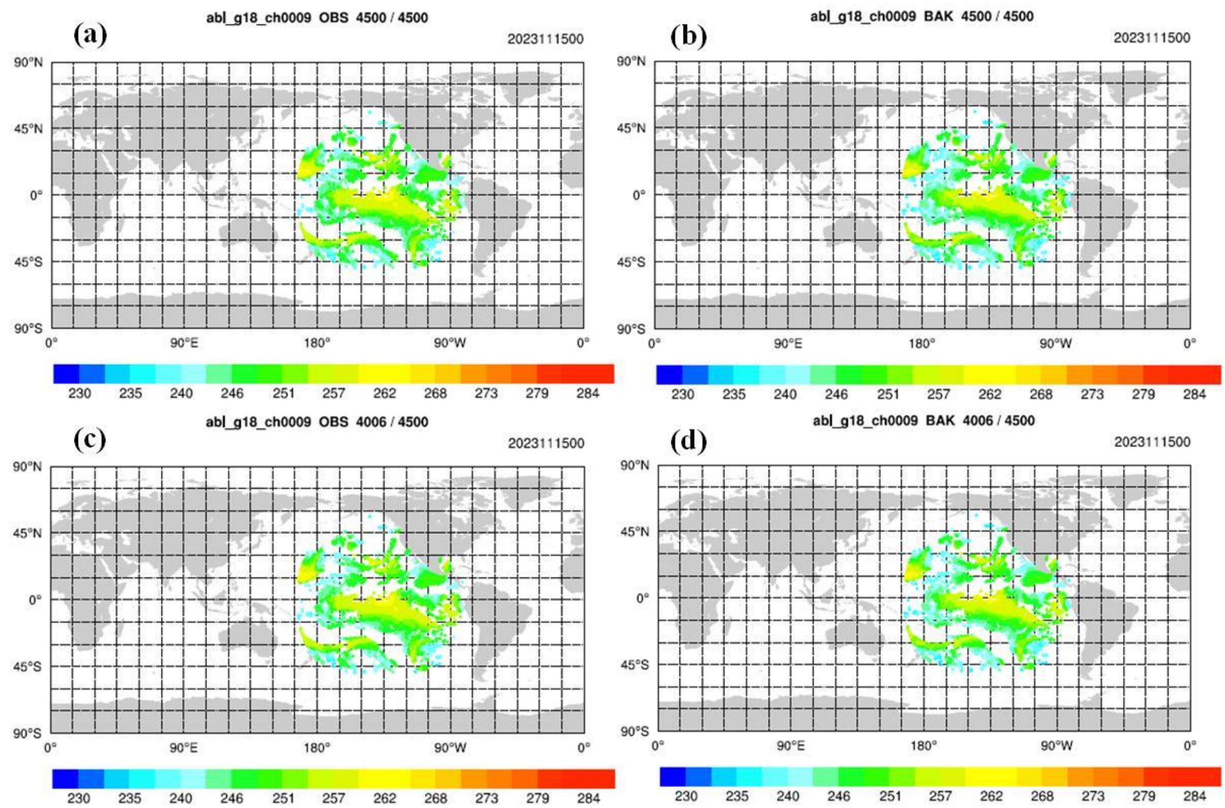

Figure 6: ABI GOES-18 brightness temperature from (a) observation and (b) background for Channel-9 valid for 00 UTC 15 November 2023. (c) and (d) are same as (a) and (b), but with updated threshold value.

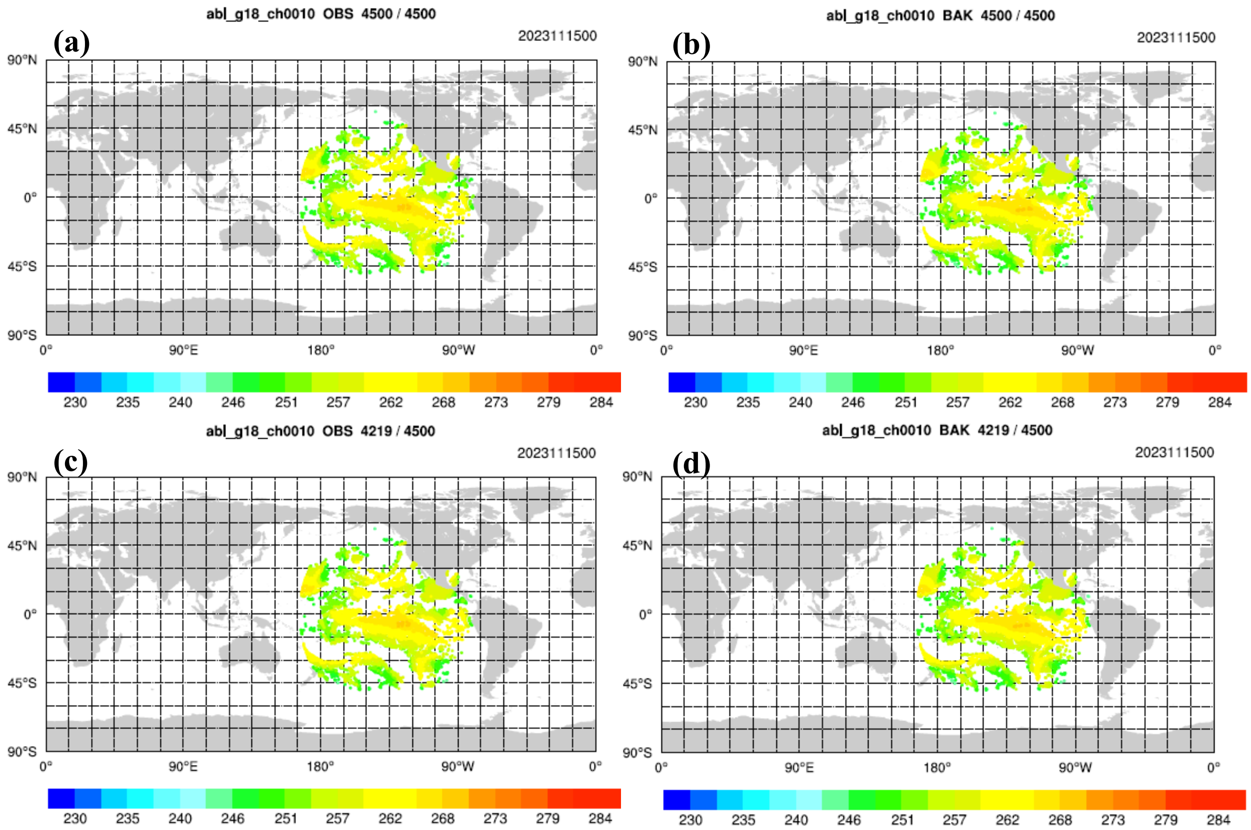

Figure 7: ABI GOES-18 brightness temperature from (a) observation and (b) background for Channel-10 valid for 00 UTC 15 November 2023. (c) and (d) are same as (a) and (b), but with updated threshold value.

The error in the background without bias correction (OMB no BC), with bias correction (OMB with BC), and error in analysis with bias correction (OMA with BC) are also computed for the assimilated channels. Figure 8 represents the error values associated with channel 8. The left panel (Fig. 8) shows the error field as generated in considering all the QCed observation locations and the right panel shows the error field as generated with the actual number of assimilated observations with the updated monitoring package. Nearly 40% of error reduction is noticed for the latter case with threshold value ‘0’. The reduction of error in the analysis will significantly impact the forecast model. Similarly, channels 9 and 10 also showed significant improvement in the upgraded diagnostics, as shown in Figures 9 and 10, respectively. When using the updated package, observation locations with threshold value ‘0’, an improvement of ~ 70-80 % is noticed in the analysis as compared to the background.

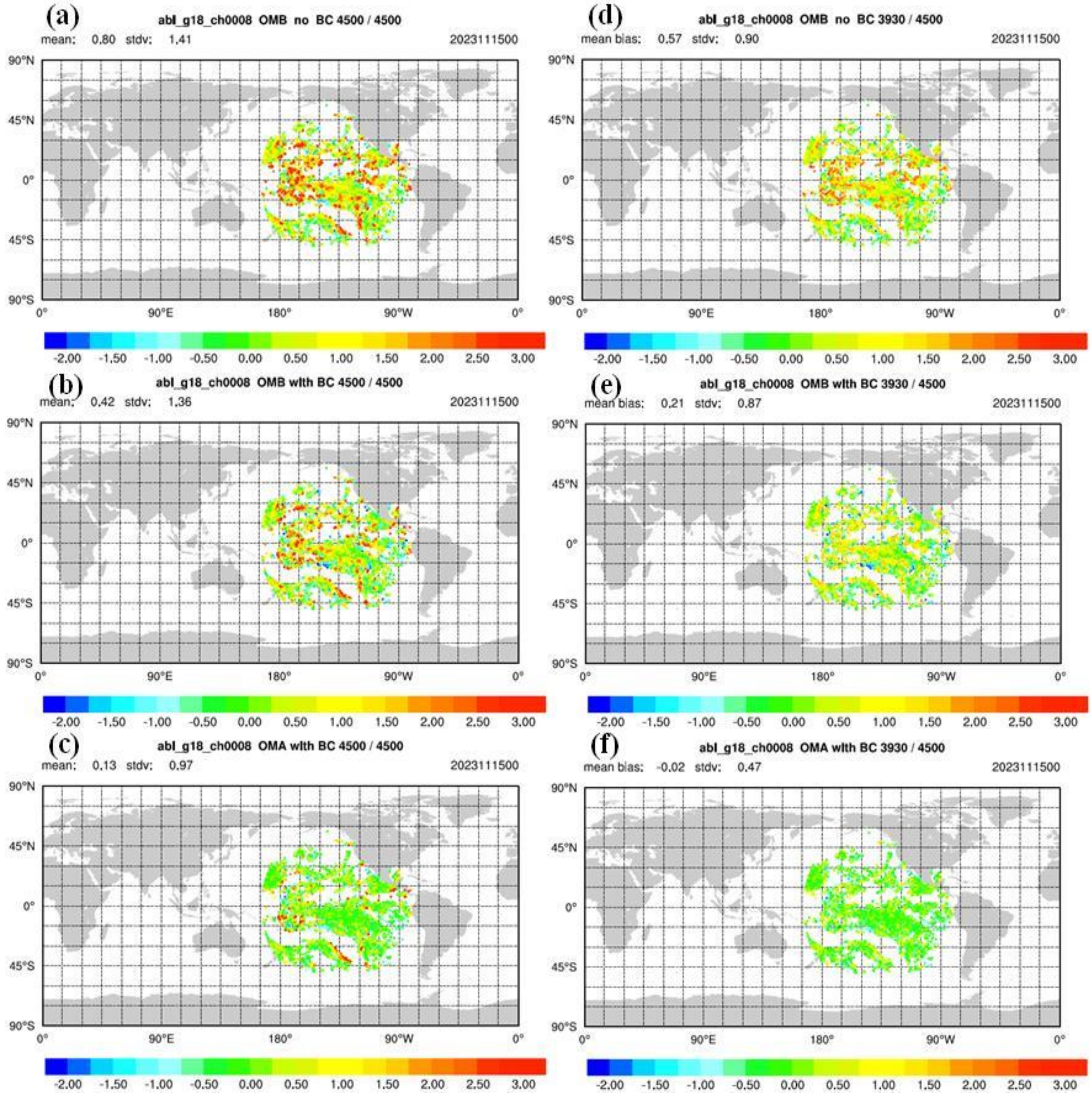

Figure 8: The error generated considering all the QCed observation locations for (a) background without bias correction, (b) background with bias correction and (c) analysis with bias correction for Channel-8 valid for 00 UTC 15 November 2023. (d-f) are same as (a-c), but with actual number of assimilated observations.

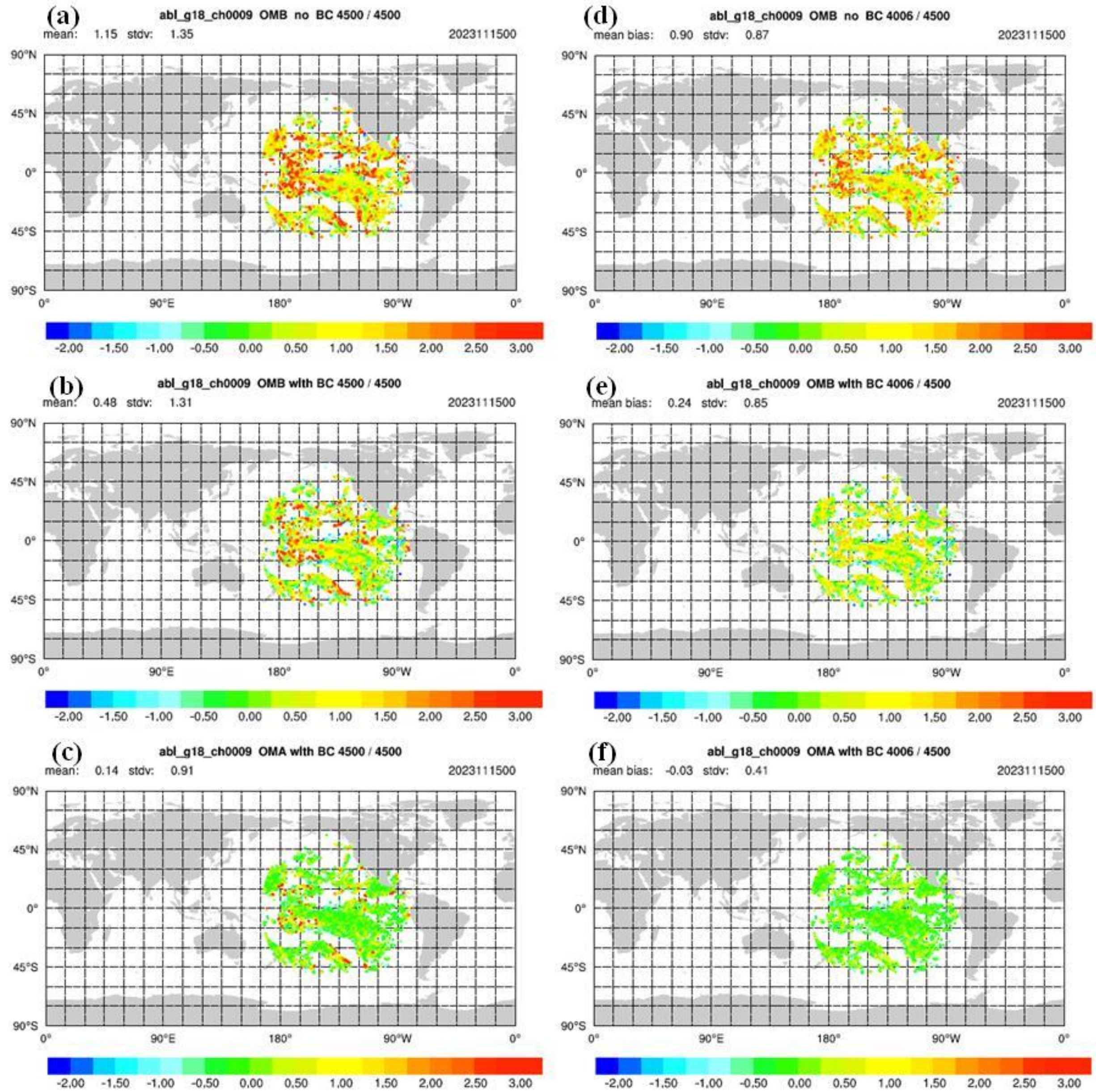

Figure 9: The error generated considering all the observation locations for (a) background without bias correction, (b) background with bias correction and (c) analysis with bias correction for Channel-9 valid for 00 UTC 15 November 2023. (d-f) is same as (a-c), but with actual number of assimilated observations.

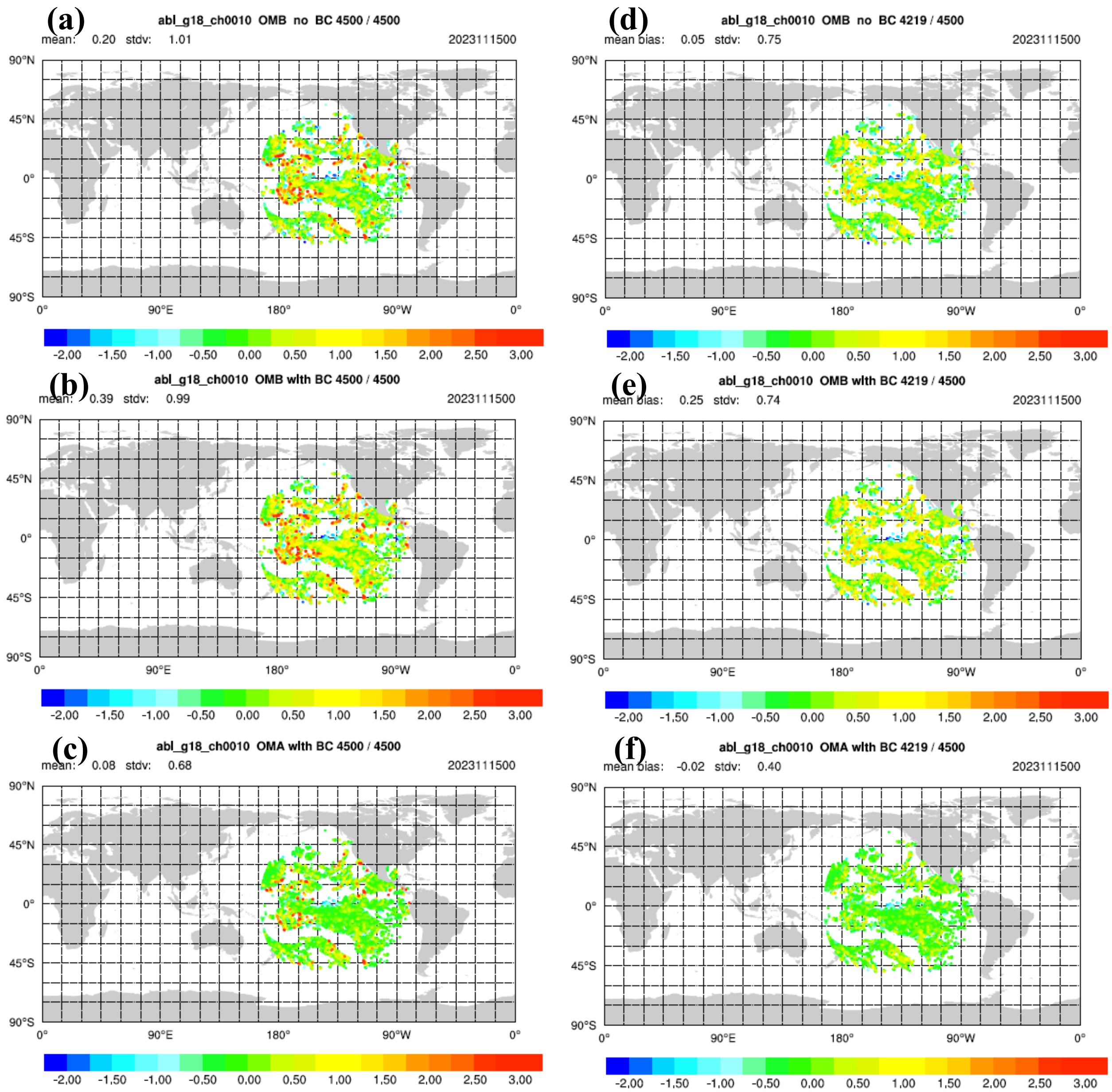

Figure 10: The error generated considering all the QCed observation locations for (a) background without bias correction, (b) background with bias correction and (c) analysis with bias correction for Channel-10 valid for 00 UTC 15 November 2023. (d-f) is same as (a-c), but with actual number of assimilated observations.

6.3 Daily Statistics

The statistics of the daily assimilated data are carried out based on the existing and upgraded diagnostic tool through scatter plots and the error distribution. The scatter plots are generated between observed and background brightness temperature without BC, and with BC and between observed and analysis with BC. The scatter plots are shown in Figures 11, 12 and 13 for channels 8, 9 and 10, respectively. The left panels for each of these plots are calculated considering all the observed locations and the right panel shows the statistics based on the data actually assimilated. The mean bias, root mean square error (RMSE), and standard deviations are calculated for each cycle during November 2023, however, the scatter plot valid for 00 UTC 15 November is shown here for channels 8, 9, and 10. In the case of channel-8 (Figure 11), the mean bias of 0.8°K is seen in the background without BC and it has been reduced to -0.024 with BC and with upgraded diagnostic tool. Here we can see 100% improvement in the analysis field with the upgraded diagnostic tool. Similarly, for channel-9, presented in Figure 12, the improvement in terms of mean bias is 100% with the upgraded diagnostic tool, though it is nearly 87 % in the previous diagnostic package. In the case of channel-10, the mean bias in the analysis reduced to less than half when used the upgraded diagnostic tool. It is presented in Figure 13. The error distribution for channels -8, 9, and 10 are presented in Figures 14, 15, and 16, respectively. It is seen that the analysis field with the upgraded diagnostic tool gives very little error and the error range is within ± 2° K. Thus, it may be concluded that the assimilation of GOES-18 data improves the analysis field, keeping errors (± 2° K) within an acceptable range.

6.4 Monthly Statistics

The statistics on a monthly scale are also evaluated to demonstrate the performance of the analysis. Figure 17 represents the time series of the mean bias for (a) channels-8, (b) channel-9 and (c) channel-10. It is noticed that for all the channels, the analysis improved significantly. With the bias correction, there is an improvement of ~70% seen in the background and the analysis is improved by about 90% for channels 8 and 9. In the case of channel 10, the bias is quite low in the background as well, and the analysis still improved over the background. Figure 18 (a), (b), and (c) represents the RMSE in the background and analysis field w.r.t. the observation for channels 8, 9, and 10, respectively. The analysis field with bias correction improves significantly over the background for all the channels. This suggests that the assimilation of GOES-18 observation will provide a positive impact on the global analysis field and, consequently, the forecast system.

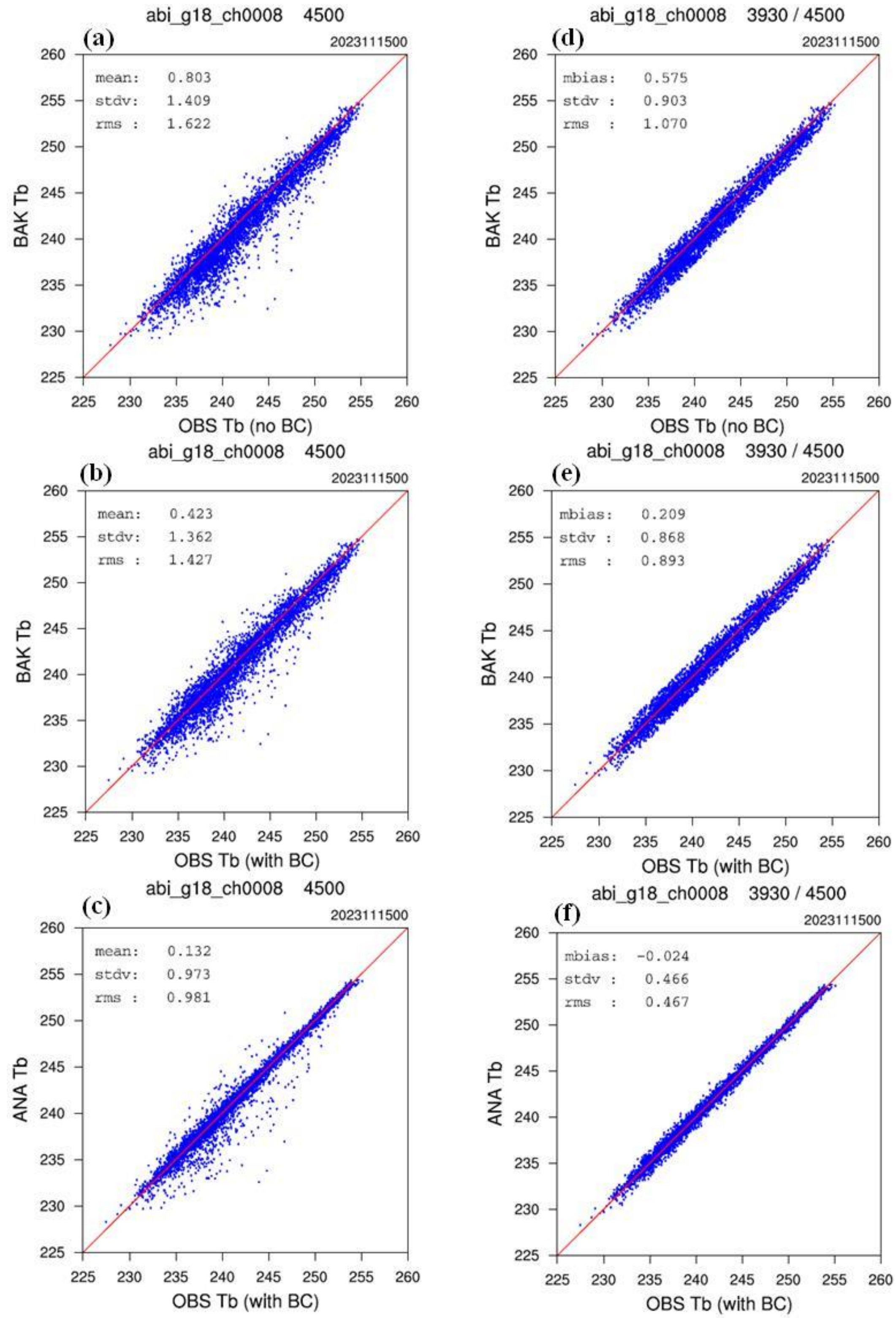

Figure 11: Scatter plot considering all the QCed observation locations for (a) background without bias correction, (b) background with bias correction and (c) analysis with bias correction for Channel-8 valid for 00 UTC 15 November 2023. (d-f) are same as (a-c), but with actual number of assimilated observations.

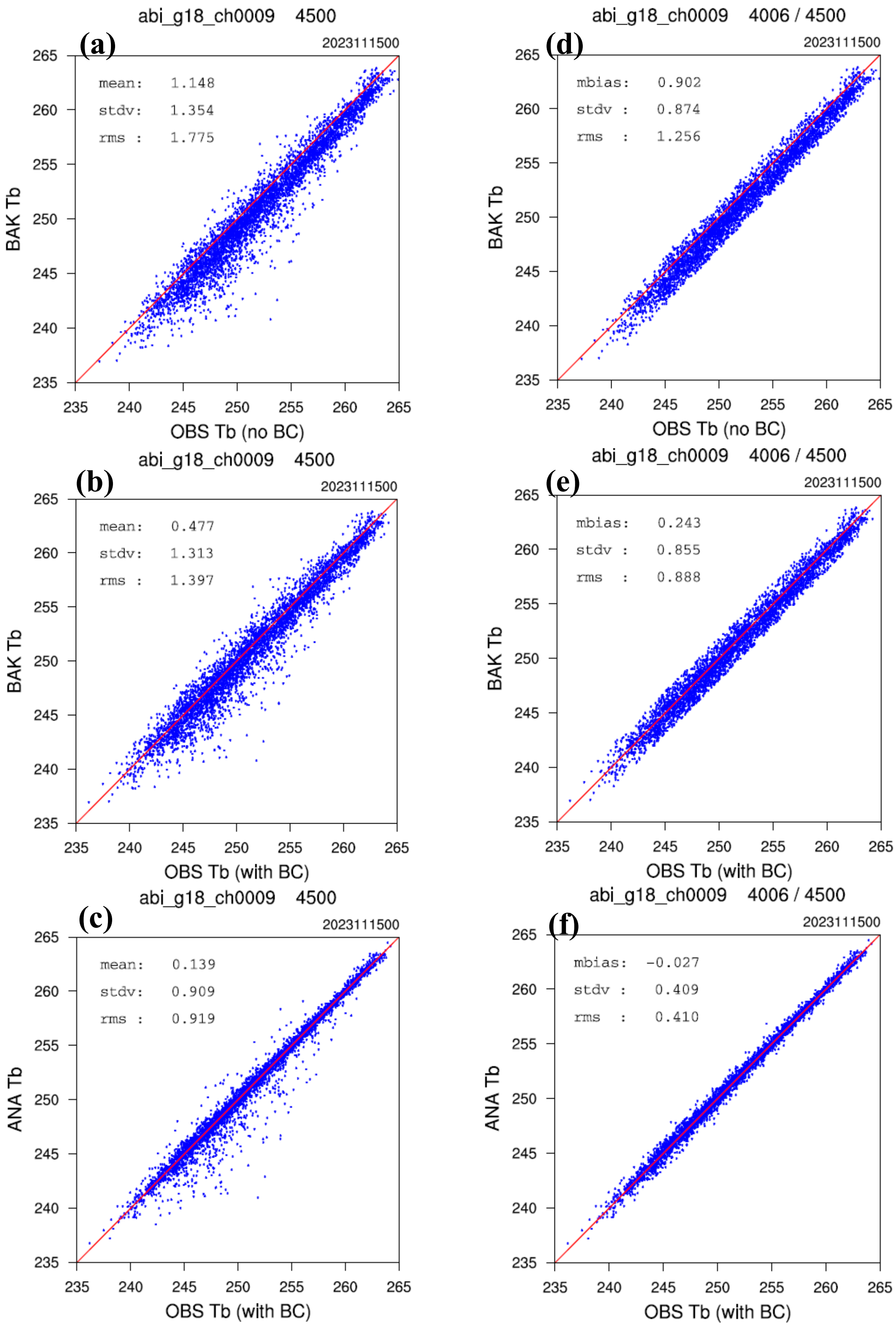

Figure 12: Scatter plot considering all the QCed observation locations for (a) background without bias correction, (b) background with bias correction and (c) analysis with bias correction for Channel-9 valid for 00 UTC 15 November 2023. (d-f) are same as (a-c), but with actual number of assimilated observations.

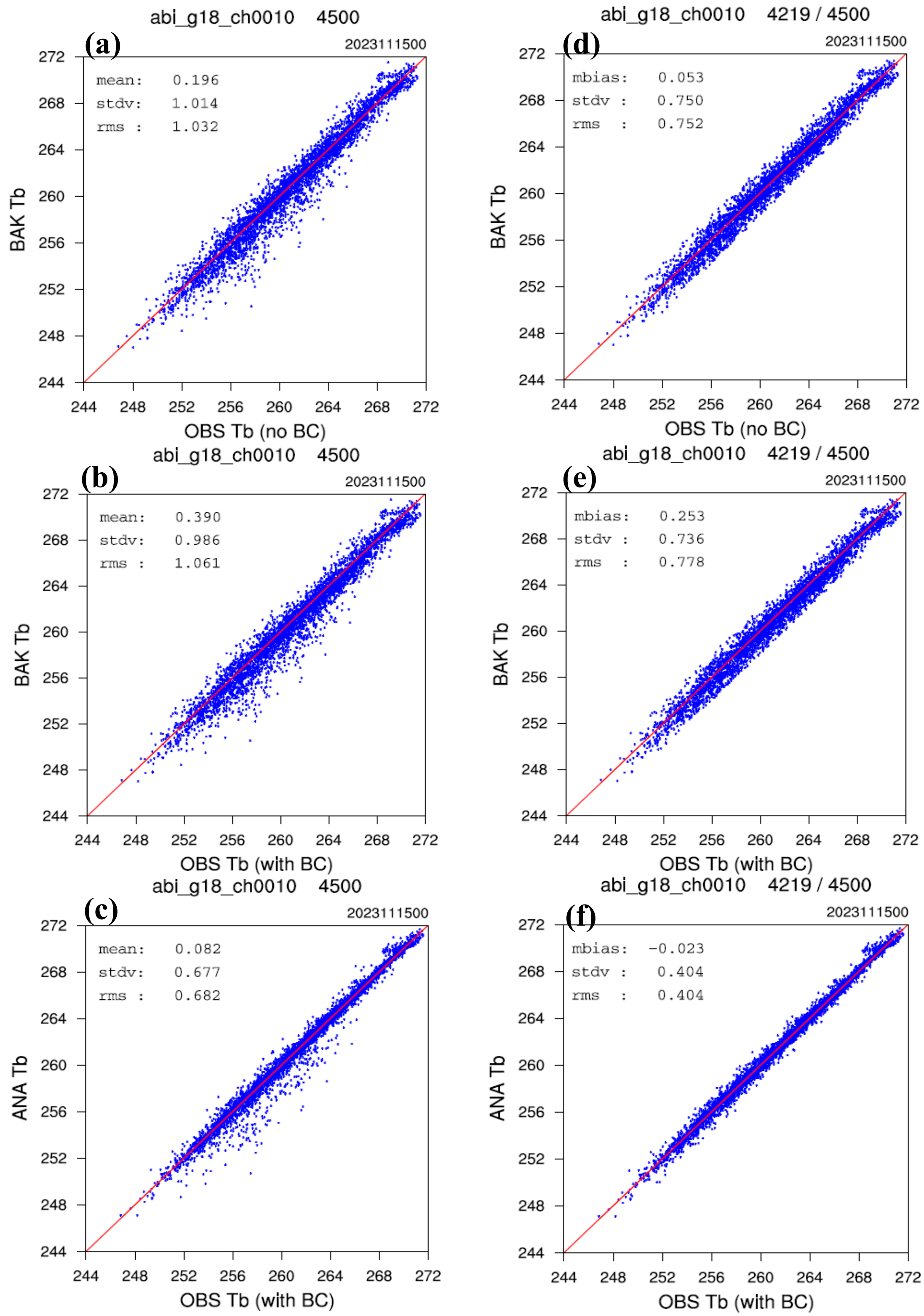

Figure 13: Scatter plot considering all the QCed observation locations for (a) background without bias correction, (b) background with bias correction and (c) analysis with bias correction for Channel-10 valid for 00 UTC 15 November 2023. (d-f) are same as (a-c), but with actual number of assimilated observations.

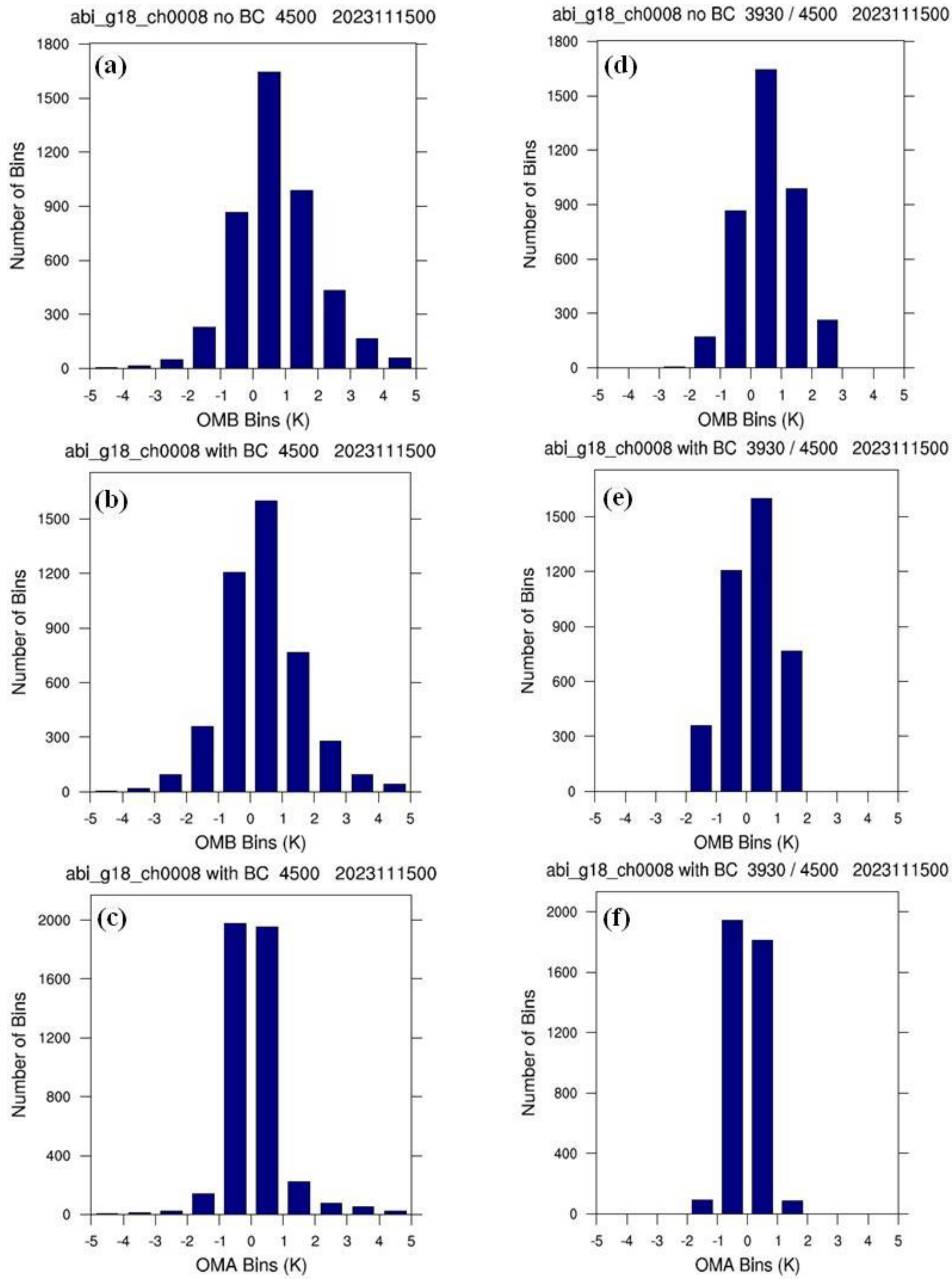

Figure 14: Error distribution while considering all the QCed observation locations for (a) background without bias correction, (b) background with bias correction and (c) analysis with bias correction for Channel-8 valid for 00 UTC 15 November 2023. (d-f) are same as (a-c), but with actual number of assimilated observations.

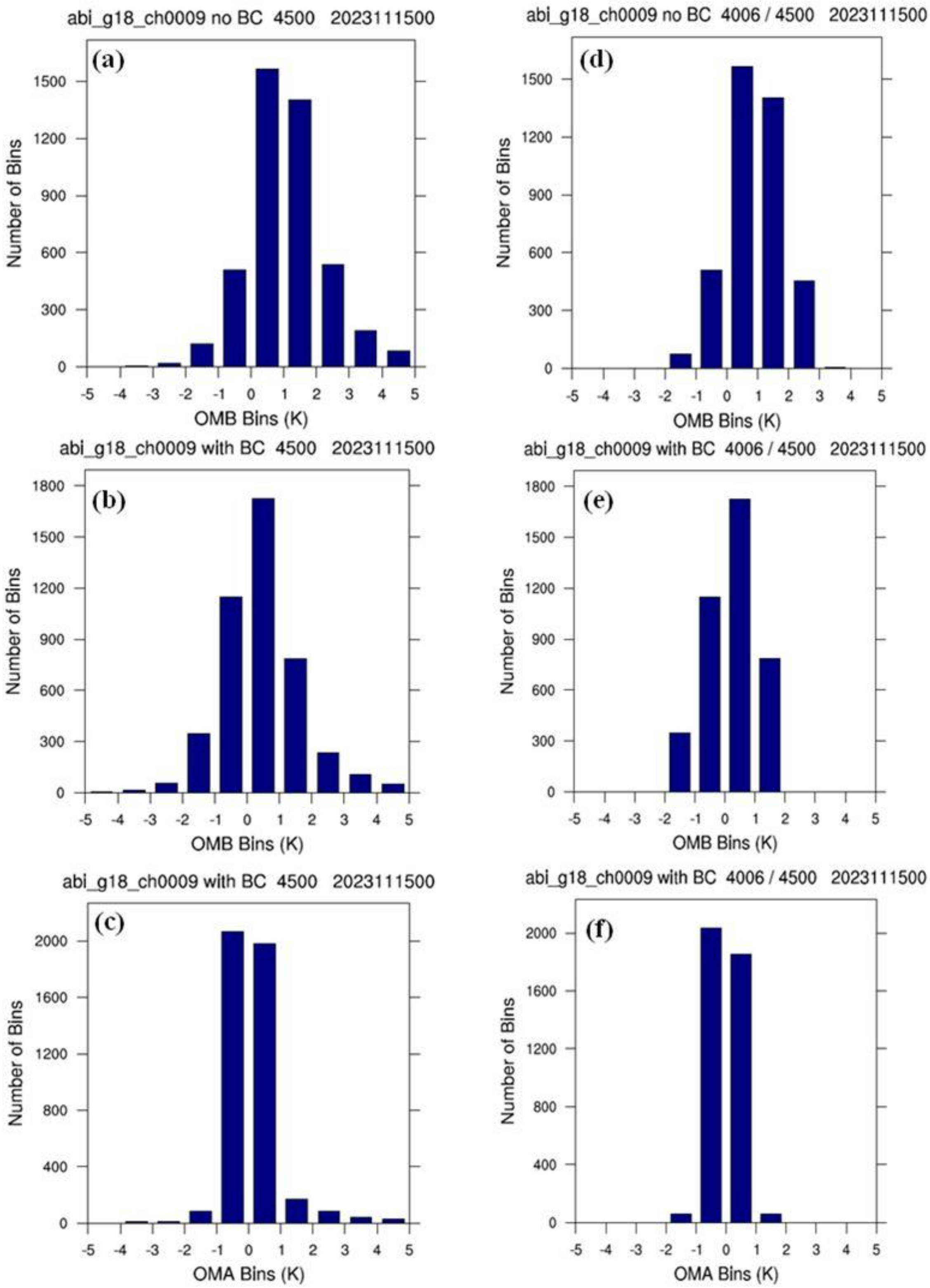

Figure 15: Error distribution while considering all the observation locations for (a) background without bias correction, (b) background with bias correction and (c) analysis with bias correction for Channel-8 valid for 00 UTC 15 November 2023. (d-f) are same as (a-c), but with actual number of assimilated observations.

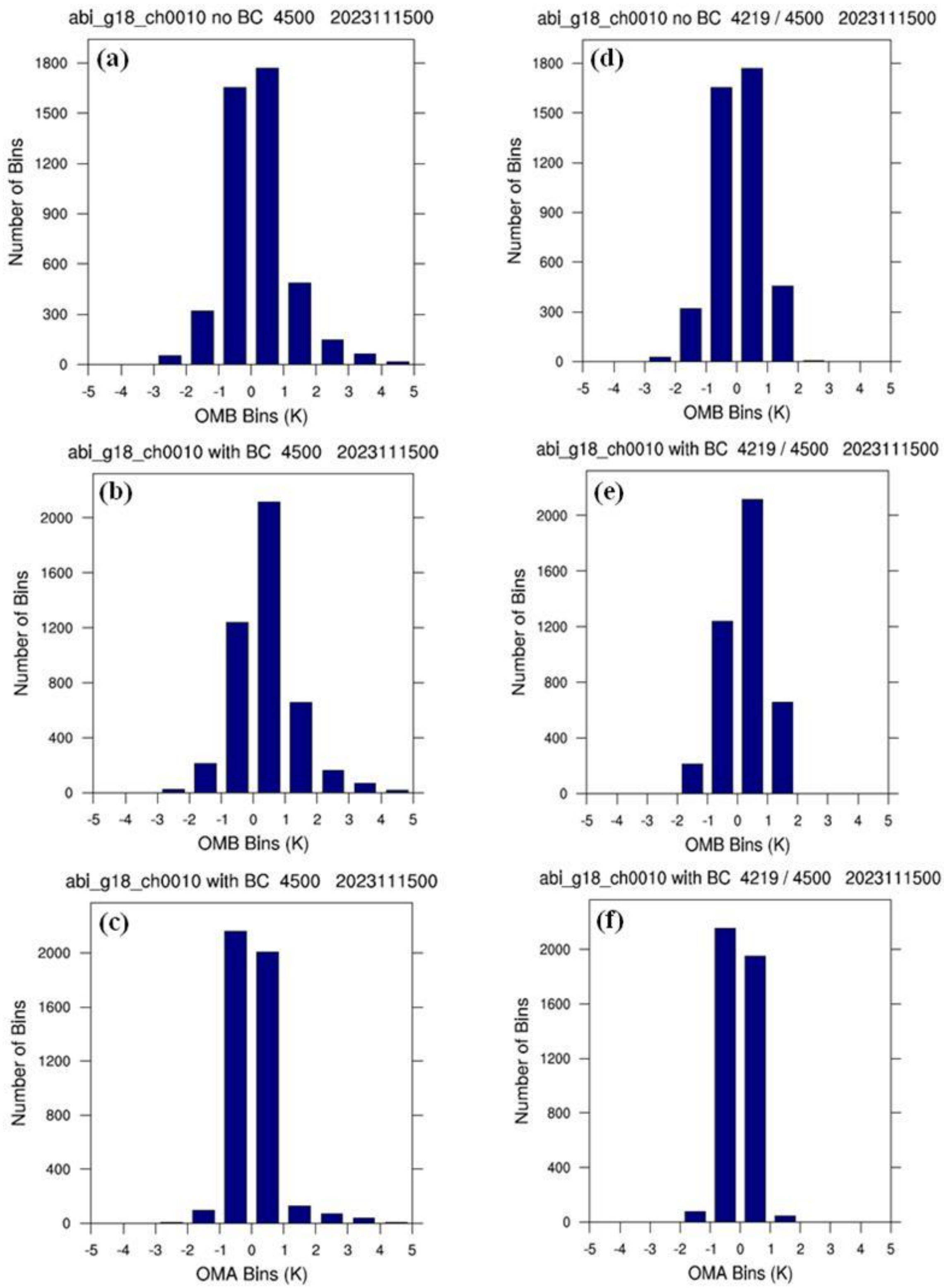

Figure 16: Error distribution while considering all the observation locations for (a) background without bias correction, (b) background with bias correction and (c) analysis with bias correction for Channel-8 valid for 00 UTC 15 November 2023. (d-f) are same as (a-c), but with actual number of assimilated observations.

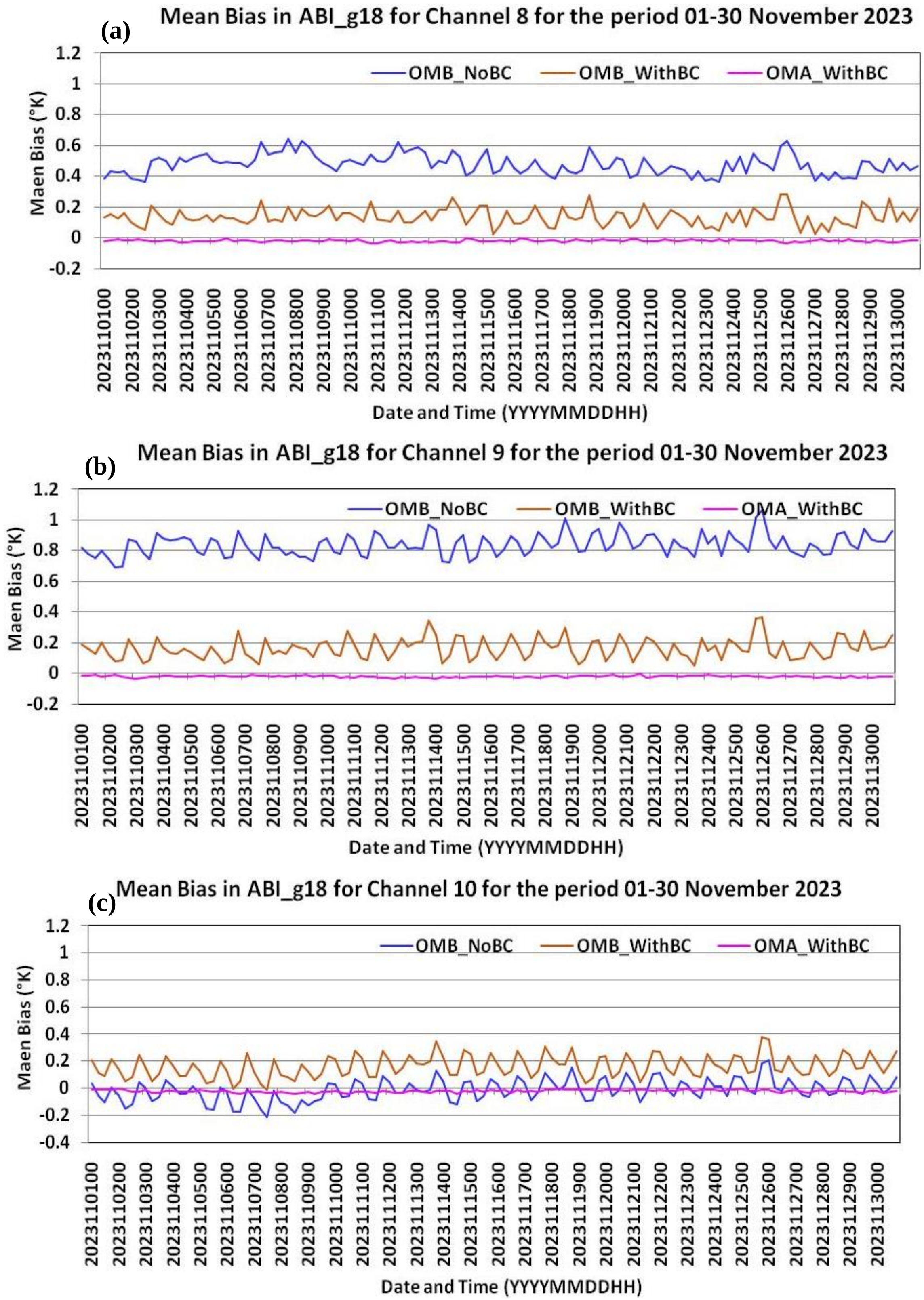

Figure 17: Background and analysis innovations in the observations from GOES-18 for (a) channel-8, (b) channel-9, and (c) channel-10 for the period 01-30 November 2023.

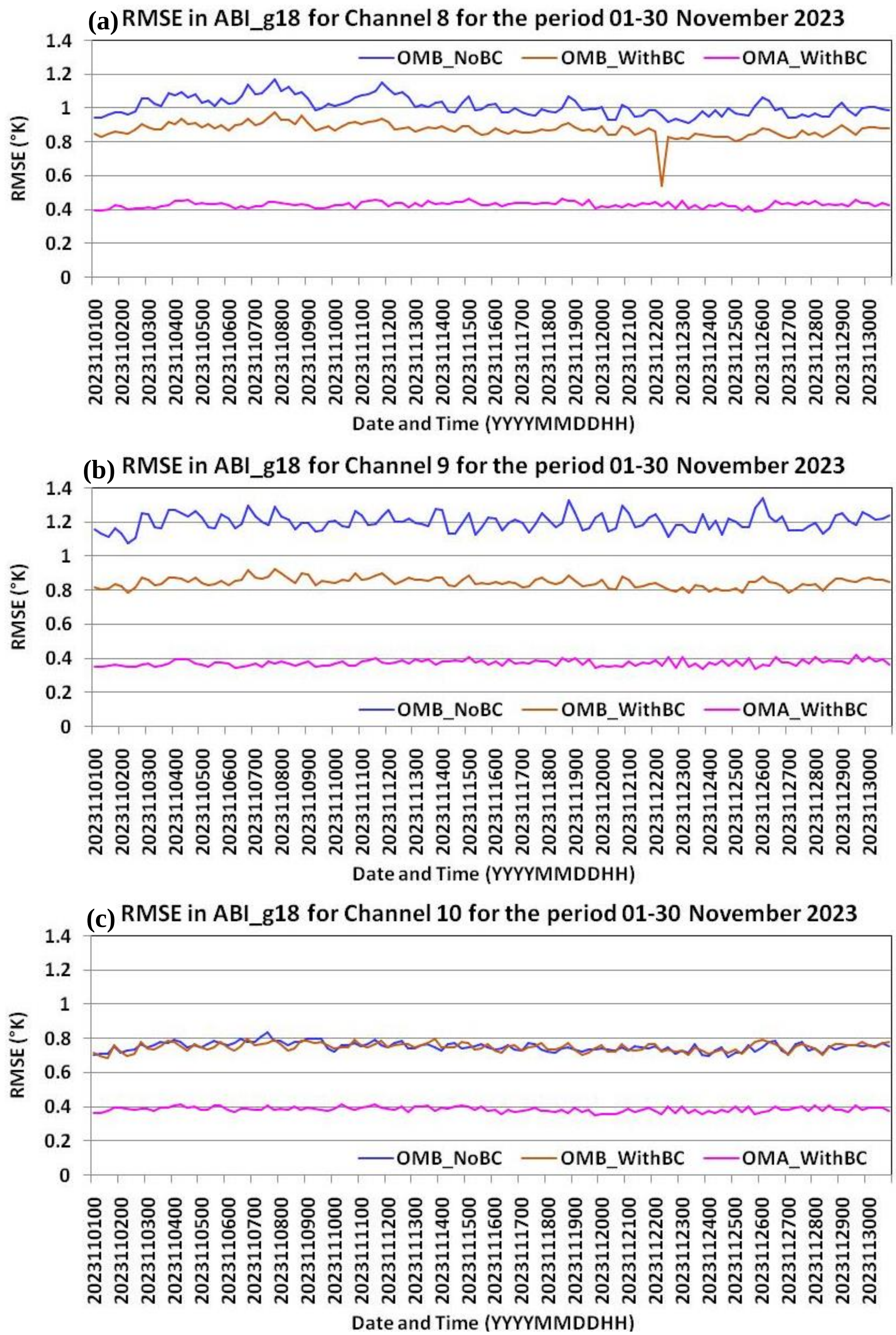

Figure 18: RMSE (K) in the background and analysis innovations in the observations from GOES-18 (a) channel-8, (b) channel-9, and (c) channel-10 for the period 01-30 November 2023.

7. Summary

Monitoring of satellite observations is crucial for optimizing their use in the NWP models. Also, the evaluation of a new satellite product is necessary for its consistency check for its plausible application to improve the global assimilation suite. The assimilation of such critical observation is recommended to enhance the understanding of the atmospheric parameters on a global scale. The comparison of the GOES-18 observation over GOES-16 suggests that more number of observations are assimilated from GOES-18 satellite radiances than that of GOES-16 satellite data.

Quality control is the most important aspect of satellite data assimilation, specifically the threshold value of the QC procedure to produce the detailed analysis after the observation quality check. The improved diagnostic package represents the actual number of observations assimilated in each assimilation cycle and it is clearly seen from the analysis. An improvement of ~ 70-80 % is noticed in terms of mean bias in the analysis compared to the background.

The daily as well as monthly statistics suggest that the analysis field with bias correction improved significantly over the background for all the assimilated channels. It is also noticed that the analysis field with the upgraded diagnostic tool gives lesser error and the error range within ± 2° K. This suggests that the assimilation of GOES-18 observation will provide a positive impact on the global analysis field and so as the forecast system.

Author's Contribution:

Dr. Sujata Pattanayak contributed to GSI code upgradation to utilize the GOES-18 data in NGFS global data assimilation, Observation Sensitivity Experiment (OSE) for a month to assess the performance of GOES-18 radiance observation in NGFS, upgradation in the radiance diagnostic code of the GSI system, analysis of the result, and manuscript writing.

Dr. K. B. R. R. Hari Prasad contributed to the NGFS running suite, diagnostic code for the GSI system and manuscript writing.

Dr. S. Indira Rani contributed to the supervision and review of the manuscript.

Dr. V. S. Prasad contributed to the conceptualization of the manuscript.

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