NMRF/TR/06/2024

TECHNICAL REPORT

Development of Near Real-time Blended Rainfall Product

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National Centre for Medium Range Weather Forecasting
Ministry of Earth Sciences, Government of India
A-50, Sector-62, NOIDA-201309, INDIA

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Document Control Data Sheet

1	Name of the Institute	National Centre for Medium Range Weather Forecasting
2	Document Number	NMRF/TR/06/2024
3	Date of publication	July 2024
4	Title of the document	Development of Near Real-time Blended Rainfall Product
5	Type of Document	Technical Report
6	No. of pages	14
7	Number of References	9
8	Author (s)	Neha Rajput, Amarjyothi K, Venkatrami Reddy, Preveen Kumar D
9	Originating Unit	NCMRWF
10	Abstract	Blending satellite data (such as GSMaP_NOW and INSAT-3D/INSAT-3DR) with Doppler Weather Radar (DWR) data yields significant advantages and insights, enhancing the ability to monitor, analyze, and forecast weather conditions. The integration of satellite and DWR data ensures comprehensive coverage, addressing the limitations of each individual source. Satellites provide broad, consistent coverage, while DWRs offer high-resolution local data, particularly useful in areas with sparse satellite observations. Combining these data sources allows for cross-verification, enhancing the accuracy and reliability of precipitation estimates. This blended approach improves the detection and monitoring of extreme weather events, such as cyclones, as shown in this study. The blended Near Real-Time (NRT) products from satellite and radar data offer a holistic view of precipitation patterns, invaluable for meteorologists, hydrologists, and disaster management authorities.
11	Security classification	Non-Secure
12	Distribution	Unrestricted Distribution
13	Key Words	Blended Rainfall Product; DWR Rainfall INSAT-3D/INSAT-3DR, GSMAP.

Contents

सारांश

उपग्रह डेटा (जैसे जीएसमेप _नाउ और इनसेट-3D/ इनसेट-3DR) को डॉपलर वेदर रडार (DWR) डेटा के साथ मिश्रित करने से महत्वपूर्ण लाभ और अंतर्दृष्टि प्राप्त होती है, जिससे मौसम की स्थिति की निगरानी, विश्लेषण और पूर्वानुमान करने की क्षमता बढ़ जाती है। उपग्रह और डीडब्ल्यूआर डेटा का एकीकरण प्रत्येक व्यक्तिगत स्रोत की सीमाओं को संबोधित करते हुए व्यापक कवरेज सुनिश्चित करता है। उपग्रह व्यापक, सुसंगत कवरेज प्रदान करते हैं, जबकि डीडब्ल्यूआर उच्च-रिज़ॉल्यूशन स्थानीय डेटा प्रदान करते हैं, विशेष रूप से विरल उपग्रह अवलोकन वाले क्षेत्रों में उपयोगी होते हैं। इन डेटा स्रोतों के संयोजन से क्रॉस-सत्यापन की अनुमति मिलती है, जिससे वर्षा अनुमानों की सटीकता और विश्वसनीयता बढ़ती है। जैसा कि इस अध्ययन में दिखाया गया है, यह मिश्रित दृष्टिकोण चक्रवात जैसी चरम मौसम की घटनाओं का पता लगाने और निगरानी में सुधार करता है। उपग्रह और रडार डेटा से मिश्रित नियर रियल-टाइम (एनआरटी) उत्पाद वर्षा पैटर्न का समग्र दृश्य प्रस्तुत करते हैं, जो मौसम विज्ञानियों, जल विज्ञानियों और आपदा प्रबंधन अधिकारियों के लिए अमूल्य है।

की-वर्ड: मिश्रित वर्षा उत्पाद, डप्लर मौसम रडार वर्षा, इनसेट-3D, इनसेट-3DR, जीएसमेप

Abstract

Blending satellite data (such as GSMaP_NOW and INSAT-3D/INSAT-3DR) with Doppler Weather Radar (DWR) data yields significant advantages and insights, enhancing the ability to monitor, analyse, and forecast weather conditions. Integrating satellite and DWR data ensures comprehensive coverage, addressing the limitations of each source. Satellites provide broad, consistent coverage, while DWRs offer high-resolution local data, particularly useful in areas with sparse satellite observations. Combining these data sources allows for cross-verification, enhancing the accuracy and reliability of precipitation estimates. This blended approach improves the detection and monitoring of extreme weather events, such as cyclones, as shown in this study. The blended Near Real-Time (NRT) products from satellite and radar data offer a holistic view of precipitation patterns, invaluable for meteorologists, hydrologists, and disaster management authorities.

Key words: Blended Rainfall Product; DWR Rainfall INSAT-3D/INSAT-3DR, GSMAP

Introduction

Precipitation is a key component of hydrological processes and the global water cycle. Knowledge about the spatial and temporal variation of daily rainfall and rain rate is helpful in flood forecasting, climate model validation, hydrological modelling, and climate monitoring. Rainfall is an essential geophysical parameter for agricultural-dominated lands, such as India. The near real-time satellite precipitation products (SPP) are very significant in various fields, such as weather forecasting and early warning systems. Timely information allows for early warning of extreme weather events, such as cyclones, floods and heavy rainfall, helping to mitigate risks and prepare for emergencies. Quality and quantity of rainfall data in terms of accuracy and reliability plays an important role in water, climate, and environmental studies and applications. The effect of topographic features on the performance of a single SPP revealed overestimation or underestimation of specific convective rainfall events. In general, no single rainfall product better represents rainfall in near real-time. To overcome the limitations of using a single rainfall product, combining information from DWR rainfall and different SPPs has become an emerging approach which is widely known as 'blending' (Beck et al., 2017). Blending involves the optimal use of satellite sensors but also satellite rainfall products to provide optimal rainfall estimates. This report aims to generate a high-quality gridded rainfall estimation dataset to capture the best spatiotemporal patterns and the magnitude of rainfall in near real-time over India. Blending satellite and radar rainfall products involves combining the strengths of both data sources to improve the accuracy and resolution of precipitation estimates. The capability of weather radar in monitoring precipitation at high spatial and temporal scales has come in handy and has stimulated great interest and support within the hydrological and meteorological communities. The high-resolution radar data gathered in real-time has become increasingly important for operational flood forecasting. Weather radars have many advantages over rain gauges because of their extended area coverage and high-resolution measurements. Weather radar measurements can also be beneficial to the design of urban drainage systems.

1. Data

For this, we have used satellite and Doppler weather radar (DWR) data and monitoring them is crucial for maintaining its timeliness, continuity, quality, reliability, and utilizing the data in generating new weather products. Here, we describe in detail the data sets used to make the Near Real-Time (NRT) blended product.

1.1 Satellite Data

1.1.1 GSMaP_Now

The Global Satellite Mapping for Precipitation (GSMaP) is an hourly global precipitation map of 0.1 × 0.1 degree provided by the Japan Aerospace Exploration Agency (JAXA). The Global Precipitation Measurement (GPM) mission was developed in Japan as the Japanese GPM standard product (Hou et al., 2014; Skofronick-Jackson et al., 2017). This high-resolution and highly frequent precipitation product is a blend of Infrared (IR) and passive microwave (PMW) sensor observations from geostationary and low earth orbit (Kubota et al., 2020). GSMaP products are developed using the PMW retrieval algorithm, PMW-IR algorithm and gauge adjustment algorithm. The PMW algorithm converts the microwave imager's brightness temperature (Tb) data into rainfall values using a radiative transfer model. The Kalman filter method integrates the estimated rainfall values with infrared radiometer (IR) data in the following step. Thus, it is known as the PMW-IR algorithm.

From November 2007, near real-time processing of the GSMaP was started by JAXA, which was majorly updated in September 2014 after the launch of the GPM core observatory and in January 2017. After the launch of GPM, the GSMaP product can be classified into four categories. The standard product, near real-time product, real-time product and reanalysis product. Table 1 shows the details of the GSMaP products (Kubota et al.,2020). GSMaP has a real-time product, namely GSMAP_NOW.

Table 1. GSMaP product list in the GPM era

Product name	**Variables**	**Resolution**	**Latency**	**Update interval**
Standard Product	Hourly Precip Rate (GSMaP_MVK)	Horizontal: 0.1 × 0.1 deg lat/lon Temporal: 1 hour	3 days	1 hour
	Gauge-adjusted Hourly Precip Rate (GSMaP_Gauge)			
	Hourly Precip Rate (GSMaP_NRT)		4 hours	

Near-real-time product	Gauge-adjusted Hourly Precip Rate (GSMaP_Gauge_NRT)			
Real-time product	Hourly Precip Rate (GSMaP_NOW)		0 hours	0.5 hour
Reanalysis product	Hourly Precip Rate (GSMaP_RNL)		Occasionally reprocesses past periods of data	
	Gauge-adjusted Hourly Precip periods data Rate (GSMaP_Gauge_RNL)			

For the present product, GSMaP_Now's rain rate is used. GSMaP_NOW uses passive microwave measurements, which are accessible within a half-hour after measurements. After that, using a cloud motion vector from a geostationary satellite, a half-hour extrapolation of rainfall maps toward the future direction. Thus, a "quasi-real-time" hourly rainfall map is estimated at every half hour. GSMaP_Now and GSMaP-NRT-Gauge achieve acceptable hydrological feasibility in daily streamflow simulations. The GSMAP_Now provides global precipitation estimates at finer spatiotemporal resolution and has shown to be better than other contemporary multi-satellite precipitation products over most parts of the globe (Shi et al. 2021).

1.1.2 INSAT-3D/INSAT-3DR

For India's telecommunications, meteorology, broadcasting, and search and rescue needs, the Indian Space Research Organization (ISRO) launched a series of multipurpose Geostationary satellites, the Indian National Satellite (INSAT), in 1982. INSAT is the largest domestic communication system in the Asia Pacific Region. In the INSAT series, INSAT 3D and INSAT 3DR are working. Both satellites provide observations half-hourly, with a 15-minute time difference between them. A multipurpose geosynchronous satellite, INSAT-3D launched on 26 July 2013 while INSAT3DR launched on 8 September 2016. Both satellite carries three payloads: Meteorological (MET), Data Relay Transponder (DRT) and Satellite Aided Search and

Rescue (SAS & R) (Kumawat et al., 2023). The Imager and the Sounder are two meteorological instruments under the MET payload. The Imager- Very High Resolution Radiometer (VHRR) operated on six spectra channels. These six channels cover four ranges of spectrum-visible (VIS), Near Infrared (NIR), Mid Wave Infra-Red (MWIR), and Infra-Red (IR). The sounder has 19 channels. Among them, 18 channels are IR, and one is VIS channel. There are major two improvements are incorporated in INSAT-3DR. One of them is that night time pictures of low clouds and fog using MWIR band and the other is that imaging can be done in the split band TIR channel with two separate windows (10.2–11.2 and 11.5–12.5 μm regions) with 4 km spatial resolution provides estimation of sea surface temperature with better accuracy (kumawat et al., 2022). Table 2 provides the specifications of INSAT-3D and INSAT-3DR Imager channels (Singh et al., 2016).

Table – 2. INSAT-3D and INSAT-3DR Imager channels specifications

Channel Number	**Channel wavelength (μm)**	**Description**	**Purpose**	**Spatial resolution (km)**
1	0.55-0.75	Visible	Clouds, surface features	1
2	1.55-1.70	Short-wave infrared	Snow, ice, and water phases in clouds	4
3	3.8-4.0	Medium-wave infrared	Clouds, fog, fire	4
4	6.5–7.1	Water vapour	Upper-troposphere water vapour	8
5	10.3–11.3	Long-wave infrared window	Cloud top and surface temperature	4
6	11.5–12.5	Long-wave infrared window	Lower-tropospheric moisture	4

1.2 DWR Data

At NCMRWF, we receive Doppler Weather Radar (DWR) data from a network of 26 radars. The India Meteorological Department (IMD) operates the DWR network with two scan strategies: short-range and long-range. DWR provides more accurate and timely rainfall data, enabling the implementation of early warning systems for severe weather events. DWR is able to provide rainfall measurements down to the model grid scale, whereas the rain gauge-based products are simply interpolations to each model grid using a limited number of observation points (Doviak & Zrnic, 1993). The augmentation of Doppler's capability to weather radar (DWR) has brought a drastic change in understanding the structure of thunderstorms, cyclones, and other precipitating cloud systems because of the availability of wind information and precipitation intensity.

Table – 3. List of DWR stations whose data is used in a blended product.

S.No	Station Name	Short Name	Frequency	Single/Dual Polarimetric
1	Delhi(Palam)	VIDP	S band	Single
2	Delhi(HQ)	DEMS	C band	Dual
3	Patiala	VICH	S band	Single
4	Srinagar	VISR	X band	Dual
5	Jaipur	VIJP	C band	Dual
6	Lucknow	VILK	S band	Single
7	Patna	VEPT	S band	Single
8	Mohanbari	VEMN	S band	Single
9	Agartala	VEAT	S band	Single
10	Kolkata	VECC	S band	Single
11	Paradeep	VEBS	S band	Single
12	Visakhapatnam	VEVZ	S band	Single
14	Machilipatnam	VOMP	S band	Single
15	Chennai	VOMM	S band	Single
16	Karaikal	VOKL	S band	Single
17	Hyderabad	VOHY	S band	Single
18	Goa	VAGO	S band	Single
19	Mumbai	VABB	S band	Single

20	Bhopal	VABP	S band	Single
21	Bhuj	VABJ	S band	Single
22	Nagpur	VANP	S band	Single
23	Mukteshwar	VIDN	X band	Dual
24	Delhi(Ayanagar)	VIDD	X band	Dual
25	Kufri	VISM	X band	Dual
26	Jammu	VIJU	X band	Dual
27	Landsdowne	VILN	X band	Dual
28	Sriharikota	VOSK	S band	Dual

Note: (S band, (~2-4 GHz), C band (~4-8 GHz) and X band (~8-12 GHz))

The table indicates various operational DWR systems, operating frequencies, and capabilities, with some equipped for dual polarimetric functions. The heterogeneity in radar poses a challenge for integrating them into operational products and deriving products such as rainfall estimates. The following table provides the details of the DWR, their short names and operation frequency, and their polarimetric capabilities.

2. Pre-processing and Methodology

2.1 Pre-processing of DWR data

The operational radar operates in two modes, single Pulse Repetition Frequency (PRF) and dual PRF modes. The single PRF mode basically obtains long-range data, and the radar runs in this mode at two elevations. The dual PRF mode resolves the range ambiguities, and in this mode, most of the atmosphere is sampled as the radar scans the atmosphere from 10 different elevation angles. In addition to this, NCMRWF receives DWR data from a network of 26 radars. The IMD operates the DWR network with two scan strategies: short-range and long-range. DWR provides more accurate and timely rainfall data, enabling the implementation of early warning systems for severe weather events. Hence, a composite of radar rainfall is derived and included in the blended NRT product.

The first step includes pre-processing the raw radar data to correct for artefacts, noise, and biases. This process involves filtering, noise removal, and adjustments. Initially, all DWRs undergo automated quality control checks to eliminate anomalies or inconsistencies such as outliers, noise, or sudden data spikes.

Creating a composite product by combining multiple DWR data every 15 minutes involves several key steps: data retrieval, alignment, and aggregation. First, ensure you have access to time-stamped DWR data from multiple sources, collected at 15-minute intervals. Next, align the data from different sources based on their timestamps to ensure that data from different radars at the same time are combined. Then, choose an appropriate method for data aggregation, such as averaging, taking the maximum value, or applying a weighted sum. Finally, for each 15-minute interval, combine the data from the different sources using the chosen aggregation method to generate the composite product.

The radar reflectivity factor depends on the number and diameter of raindrops in the radar sample volume. Since the rain rate (R) also depends on the number and diameter of the raindrops, the Z and R can be linked. The relation of the form $Z = aR^b$ is generally used to estimate R from radar-measured Z. Nevertheless, the coefficients of this relation cannot be determined uniquely.

2.1.1 Temporal Consistency Checks

Compare radar data with data from satellite imagery to ensure temporal consistency and detect any discrepancies or outliers. This comparison involves cross-referencing the radar-derived precipitation estimates with those obtained from satellite sensors at the same time intervals. Additionally, this process helps to detect outliers that may indicate sensor malfunctions, calibration errors, or transient atmospheric phenomena that were not captured by the radar. Ensuring temporal consistency between these two data sources enhances the reliability of the composite product and provides a more accurate representation of weather conditions. This step is crucial for validating the accuracy of the radar data and improving the overall quality of the integrated dataset used for weather analysis and forecasting.

2.2 Pre-processing of the SPP

Pre-processing satellite precipitation product (SPP) involves several steps to ensure that the data is accurate, consistent, and suitable for further analysis or blending with other data sources. Here’s a detailed guide to the pre-processing steps.

2.2.1 Temporal Alignment

We have gathered data from GSMaP_Now, a satellite-based precipitation monitoring system, to ensure real-time accuracy and comprehensive coverage. In addition, we are utilising data from INSAT-3D or INSAT-3DR for the previous hour.

These satellites provide vital meteorological and environmental information, which enhances our ability to analyse weather patterns and monitor precipitation. The combination of real-time GSMaP_Now data and INSAT-3D/INSAT-3DR data allows for a more thorough understanding of recent weather events and their potential impacts. To convert half-hourly satellite data to hourly data, we aggregate the data from the two half-hour intervals within each hour. The two half-hourly precipitation data must be aggregated to make hourly precipitation data.

2.2.2 Resampling

The GSMAP_Now, INSAT-3D/INSAT-3DR and DWR data must be sampled to the same spatial resolution of 4 km. The GSMAP_Now is downscaled to 4 km, and INSAT-3D/INSAT-3DR and DWR data are projected to match the target grid. This might involve upscaling or downscaling the resolution. Also, we have ensured all data are in consistent units (e.g., millimetres per hour for rainfall rates).

2.3 Methodology

The algorithm is efficient enough for real-time or near-real-time applications, especially if used for operational weather forecasting or disaster response. The description of the algorithm is given below. This report shows how the GSMAP_NOW, INSAT3D/INSAT3DR, and DWR rainfall have been used to compute a blended near real-time product every half-hourly. Once the DWR and SPP are pre-processed according to the methods mentioned above, they will be used in the following way, as mentioned in the flow chart, figure 1. The derived composite of radar rainfall is included in the blended NRT product. Blending satellite and DWR-derived rainfall data, which complement each other and fill gaps in coverage, is particularly useful in remote or inaccessible regions. By effectively blending satellite and radar rainfall products, the algorithm can leverage the strengths of both data sources to provide a more accurate and reliable precipitation estimate. GSMaP_Now demonstrates comparable precipitation monitoring capabilities to the evaluated near-real-time.

2.3.1 Static Weight

Alternatively, use a static weighting scheme where predetermined weights are assigned based on the historical performance of each data source.

2.3.2 Blending Algorithm

Here, the first step is to calculate a weighted average of the satellite and radar rainfall estimates for each grid cell. In the current blended product, three measurements namely DWR, INSAT-3D/INSAT-3DR and GSMaP_NOW measurements are blended and the blended measurements product is given at each half hour with a spatial resolution of 4 km over the Indian subcontinent. The figure shows the procedure of blending the measurements for the operational near real-time (NRT) blended product.

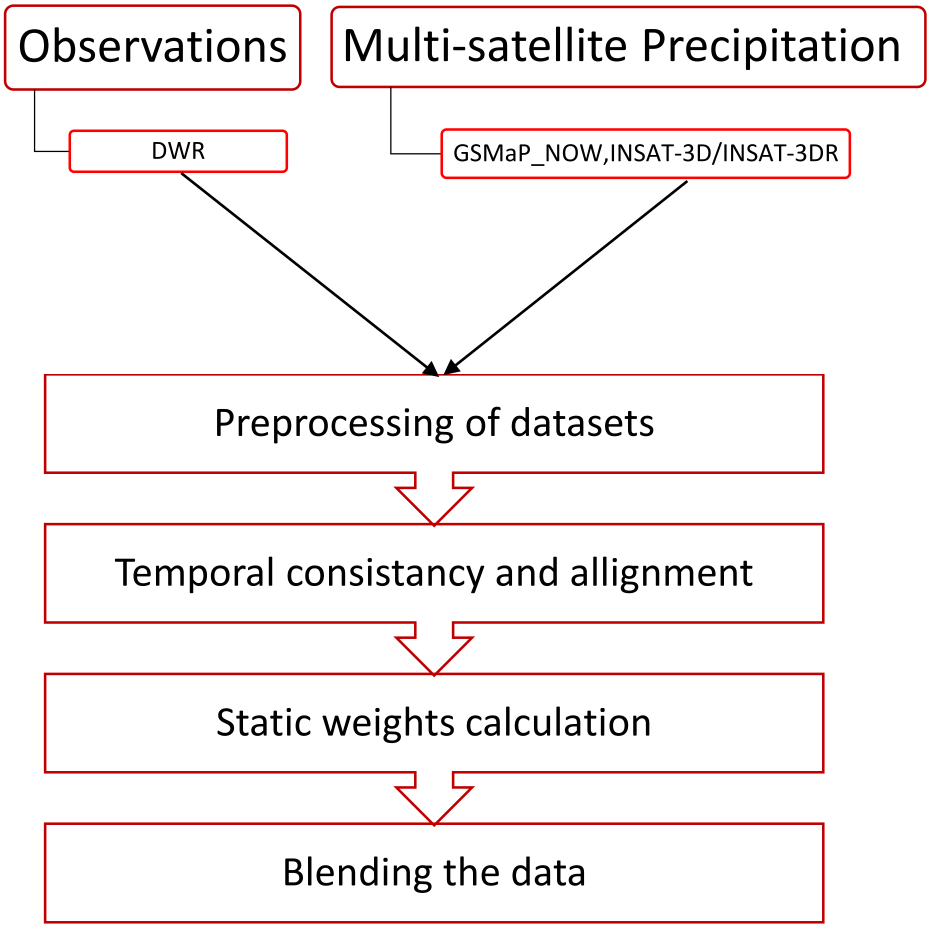

Figure 1 The flow chart of the procedure of NRT blended rainfall product

3. Case Study of Michaung Cyclone

A case study of a severe cyclonic storm Michaung which formed in the Bay of Bengal on 1st December, 2023 is presented. Michaung became a deep depression on 2nd December, 2023 and developed into a cyclonic storm thereafter. The cyclone gradually moved northwest and reached towards the eastern coast of India. Figure 2 (a and b) shows the blended NRT product on 4th December, 2023 at 08:00 and 08:30 UTC respectively. Similarly, Figure 2 (c and d) shows the same cyclonic rainfall pattern during 10:00 and

10:30 UTC. From these figures, it is clear that a strong cyclonic circulation causing rainfall greater than 64mm/hr over the Chennai region. By detecting changes in rainfall intensity and distribution, these systems can issue alerts and mitigate potential impacts.

Blended NRT data provided by blending satellite and DWR observations is indispensable for weather monitoring, especially in the case of severe weather.

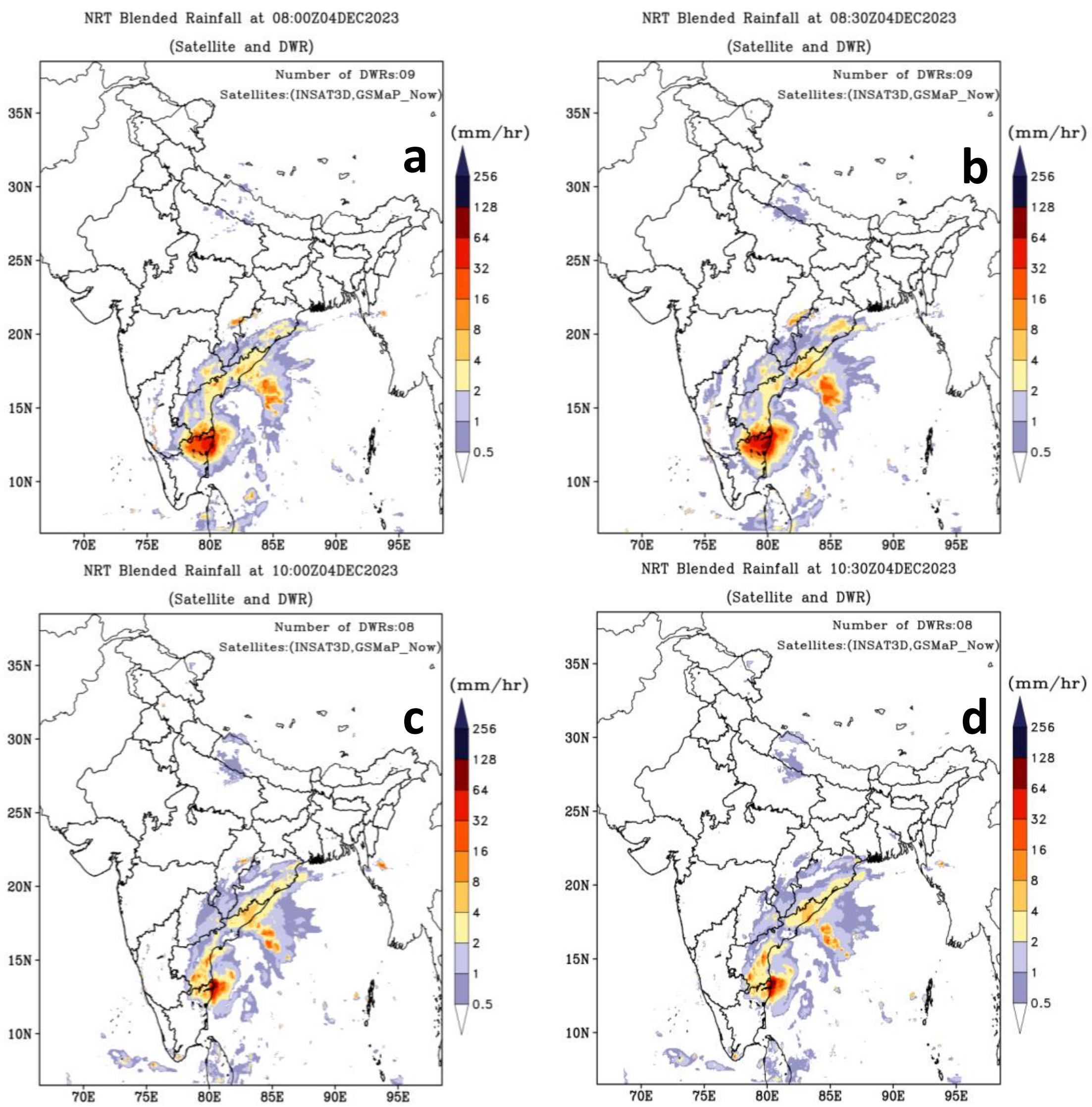

Figure 2: Blended NRT rainfall product during cyclone Michaung on 4th December, 2023 at (a), 0800 UTC, (b) 0830UTC, (c) 1000UTC and (d) 1030 UTC respectively.

This product is operational at NCMRWF, and the animations are available in three different versions: past hourly, past three hourly, and past six hourly.

4. Concluding Remark

A near real-time (NRT) product plays a critical role in providing timely, accurate, and actionable information for a wide range of applications. This fosters improved risk assessments and enhanced resilience to extreme weather events. Here, a new near real-time blended product, namely blended NRT, provides up-to-date information on precipitation patterns, which in turn helps make timely decisions regarding weather-related hazards such as floods, landslides, etc. DWR provides more accurate and timely rainfall data, enabling the implementation of early warning systems for severe weather events. Hence, a composite of radar rainfall is derived and included in the blended NRT product. By blending satellite and DWR-derived rainfall data, which complement each other and fill gaps in coverage, particularly in remote or inaccessible regions.

Blending satellite data (such as GSMaP-NOW and INSAT-3D/INSAT-3DR) with Doppler Weather Radar (DWR) data yields several significant advantages and insights. The integration of SPPs and DWR data ensures comprehensive coverage, addressing the limitations of each source. Satellites provide broad, consistent coverage, while DWRs offer high-resolution local data, particularly useful in areas with sparse satellite observations. Combining these data sources allows for cross-verification, enhancing the accuracy and reliability of precipitation estimates. The blended approach improves the detection and monitoring of extreme weather events, such as heavy rainfall and storms. This is crucial for timely warnings and disaster preparedness, ultimately reducing the impact on vulnerable populations. The blending process involves pre-processing steps like noise reduction and adjustment, which improve the overall quality of the data. Filling Gaps in Data: Satellite data can fill gaps in radar coverage, particularly in remote or inaccessible regions where radar infrastructure is lacking. Conversely, DWR data can provide detailed insights in areas where satellite data might be less precise due to factors like cloud cover.

The blended NRT (Near Real-Time) satellite and radar data products offer a more holistic view of precipitation patterns. These products are invaluable for meteorologists, hydrologists, and disaster management authorities.

In conclusion, blending satellite and DWR data significantly enhances the ability to monitor, analyse, and forecast weather conditions. By leveraging the strengths of both data sources, this integrated approach provides a more accurate, reliable, and comprehensive understanding of precipitation, which is essential for effective weather prediction and disaster management.

Acknowledgements

We sincerely thank the GSMaP research communities and ISRO (INSAT-3D/INSAT-3DR) for making the satellite rainfall data available for this work and we extend our gratitude to the India Meteorological Department (IMD) for providing the Doppler Weather Radar (DWR) data.

Authors' contributions:

Neha Rajput: Conceptualization, Data curation, Methodology, Formal analysis, Validation, Writing – original draft.

Amarjyothi k: Conceptualization, Methodology, Writing – review & editing.

Venkatarami Reddy: Validation.

Preveen Kumar D: Writing – review & editing.

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