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IMSRA rainfall estimation validation and variability over Indian region during GAJA cyclone

SP. VIJAYALAKSHMI

Civil Engineering, Indian Institute of Science, Bangalore – 560 012, India

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e mail : vijai9111995@gmail.com

सार – मॉनसून ऋतु की तुलना में एक चक्रवाती परिघटना के दौरान वर्षा बहुत अधिक होती है, जिसके कारण मनुष्यों और मवेशियों को जीवन का नुकसान और गंभीर चोटें लगती हैं। ऐसी स्थितियों को रोकने के लिए वर्षा का सटीक आकलन आवश्यक है।

पूर्वानुमान से पहले इस बारे में पर्याप्त ज्ञान होना चाहिए कि वर्षा का स्थानिक वितरण कैसे होता है और यह समय–समय पर कैसे बदलता है आदि? इस अध्ययन में INSAT-3D इमेजर डेटा के साथ भारतीय क्षेत्र (विशेष रूप से तमिलनाडु में 16 और 17 नवंबर 2018 को) पर गाजा चक्रवात के दौरान वर्षा वितरण का अनुमान लगाने का प्रयास किया गया है। IMSRA (IMR) और IMC (IMSRA-संशोधित) डेटासेट का उपयोग गाजा चक्रवात के स्थल प्रवेश के दौरान किया जाता है, जो 0.1° × 0.1° स्थानिक विभेदन और 30 मिनट के अस्थायी विभेदन का है। विलय किए गए IMSRA डेटा उत्पाद IMC डेटासेट से प्राप्त किए गए हैं। प्राप्त परिणाम आईएमडी वर्षामापी डेटा, IMERG और GSMaP जैसे वैश्विक डेटा उत्पादों द्वारा मान्य है। विलय किए गए - IMSRA का प्रदर्शन अन्य सभी डेटासेट की तुलना में अच्छा है, जो विश्वसनीय वर्षा और एक अच्छा सहसंबंध (>0.5) दिखाता है।

ABSTRACT. Rainfall during a cyclonic event is very high compared to the monsoon seasons, which brings heavy damage to the lives of humans and cattle and other severe bruises. To prevent such conditions, an accurate estimation of rainfall is necessary.

Before prediction, there should be adequate knowledge about the spatial distribution of rainfall, also the temporal variation. This study attempts to infer the rainfall distribution during GAJA cyclone over the southern part of Indian region (Tamil Nadu, on 16 and 17 November, 2018) with the INSAT-3D IMAGER data. The IMSRA (IMR) and IMC (IMSRA-Modified) datasets are used during the landfall of the GAJA cyclone, which is of 0.1° × 0.1° spatial resolution and temporal resolution of 30 min. A Merged-IMSRA data product is derived from the IMC dataset. The results are validated by the IMD rain gauge data and global data products such as IMERG and GSMaP. The performance of Merged-IMSRA is better compared to other datasets, that show reliable rainfall and a good correlation (>0.5).

Key words – Tropical Cyclones, IMSRA, GAJA cyclone, Rainfall.

1. Introduction

Cyclone is a system of winds rotating inwards to an area of low barometric pressure with an anticlockwise (northern hemisphere) or clockwise (southern hemisphere) circulation. On the other hand, it is the warm core, originating in tropical or subtropical waters, with organized deep convection and closed surface wind circulation about a well-defined center.

Historical reports signify that the deadliest cyclones with the highest catastrophe and death tolls occurred in the Bay of Bengal (BoB). The four maritime states, Tamil Nadu (TN), Andhra Pradesh (AP), Orissa, and West Bengal, located on the east coast of India, are highly vulnerable to Tropical Cyclones (TCs).

Torrential rainfall (more than 30cm/hr) associated with TCs is the primary cause of the damage (IPCC). Heavy rainfall from a cyclone is usually spread over a wide area and causes large-scale soil erosion and the weakening of embankments. Heavy and prolonged rain, because of storms, causes flash floods, river floods, and submergence of low-lying areas causing loss of life and property. Duan *et al*., 2021 gives an insight into the behavior of cyclones formed over BoB and Arabian Sea.

The distribution of rainfall patterns during TCs depends on various factors, *i.e*., the internal dynamics of the cyclone and environmental characteristics. The cyclone translational speed significantly impacts the azimuthal asymmetries (vertical shear) of rainfall and the total rainfall duration at a location, as slow-moving systems are more likely to stay in a place than fast-moving systems (Bhomia *et al*., 2017). The vertical wind shear creates asymmetries in the inner-core field rainfall distribution pattern. The storm's intensity, environmental humidity, and underlying surface properties can influence the amount and distribution of rainfall received from a land-falling TC (Cerveny *et al*., 2000).

The INSAT 3D IMAGER data is used to observe the spatial distribution of rainfall during the GAJA cyclone. The IMR and IMC data products perform better for the southern region of INDIA. Also, it goes well with IMD station data (for rainfall). However, it has some limitations. This dataset can't be used for hilly terrain like Himalayan regions, as it overestimates the rainfall. This limitation due to the orographic effect is overcome by this study with the help of Merged-IMSRA.

Earlier, these datasets can't be compared with global datasets easily as the spatial resolution differs greatly. Merged-IMSRA dataset can be compared with global data sets like GSMaP, IMERG, etc., Also, it estimates rainfall better than IMR and IMC-derived products from INSAT 3D.

This study intends : (*i*) To study and analyze the INSAT-3D 1/2hourly data during GAJA cyclone occurrence and to obtain a mean rainfall distribution along with the TC (*ii*) To compare and validate it with the IMD station data, also with global products like GSMaP (Global Satellite Mapping of Precipitation) and IMERG (Integrated Multi-satellitE Retrievals for GPM).

2. Rainfall monitoring methods and the data used

Rainfall is an important prognostic parameter for determining the climatology and weather at a specific location. Thus, continuous and comprehensive monitoring and measuring of this parameter will assist in understanding the phenomenon and type of disaster derived.

2.1. *Surface rain gauges*

Specific instruments at fixed stations consistently observe the meteorological parameters. The globally accepted data represents the phenomenon which occurred at the site. The station data are used as *in situ* measurements to validate any rainfall-related study. The 350 rain gauge data are used in the present study. This data is collected from IMD Chennai (daily gridded data). The study was carried out from 14-19 November, 2018. As the downpour was heavy on 16 and 17 of November, the results are shown only for those two days.

2.2. *Satellite INSAT-3D (IMAGER)*

Satellite INSAT-3D was developed by Indian Space Research Organization (ISRO) and successfully launched on 26 July, 2013 using an Ariane 5 launch vehicle in French Guiana. It is an advanced weather satellite configured with an improved Imaging System and Atmospheric Sounder. It monitors land and ocean surfaces. The satellite is also designed to generate a vertical atmospheric temperature and humidity profile for weather forecasting and disaster management. The satellite carries four payloads of six-channel multispectral imagers, nineteen-channel sounders, a Data Relay Transponder (DRT) and a Search and Rescue Transponder. Thermal Infrared (TIR) spectral channel at a spatial and temporal resolution of 4 km and 30 mins. observation will be used as input parameters to the algorithm. Data: http://mosdac.gov.in. The algorithm applied thermal IR or atmospheric window bands at wavelengths 10.5 to 12.5 for this study (Gairola *et al*., 2015). The L1 product is used to retrieve rainfall using IMR and IMC algorithm. This is done to see where the lag is happening. Also, to know how the rainfall is being retrieved.

2.3. *Global Satellite Mapping of Precipitation (GSMaP)*

The GSMaP project was promoted for a study "Production of a high-precision, high-resolution global precipitation map using a satellite data," sponsored by Core Research for Evolutional Science and Technology (CREST) of the Japan Science and Technology Agency (JST). GSMaP is one of the Global Precipitation Measurement (GPM) JAXA standard products and rainfall products, released in near real-time or about four hours after observation on the global domain of 60° N to 60° S. The basic idea of the algorithm is to find the optimal precipitation for which the brightness temperature (Tbs) is calculated by the radiative transfer model that fits best with the observed Tbs (Aonashi *et al*., 2009). The dataset used in the GSMaP is passive microwave radiometer data from TRMM/TMI, Aqua/AMSR-E, ADEOS-II/AMSR, DMSP/SSMI (F13, 14, 15) and infrared radiometer data from globally merged (60° N - 60° S) pixel resolution IR brightness temperature data merged from all available geostationary satellites (GOES-8/10, METEOSAT-7/5 & GMS) provided by NCEP/CPC. This study used the daily dataset of GSMaP at grid resolution of 0.1° × 0.1° latitude and longitude at a temporal resolution of one hour. Dataset: ftp://hokusai.eorc.jaxa.jp.

2.4. *IMERG*

The IMERG intended to inter-calibrate, merge and interpolate "all" satellite microwave precipitation estimates, microwave-calibrated infrared (IR) satellite estimates, precipitation gauge analyses, and potentially other precipitation estimators at a good time and space scale for the TRMM and GPM eras over the entire globe. The system runs several times for each observation, first giving a quick estimate and successively providing better estimates as more data arrives. The final step uses monthly gauge data to create research-level products: Late-run and Early-run 30 min. datasets are available with 4 and 12 hours latency and the Final run data set of 30 min temporal resolution, spatial resolution is 0.1°× 0.1° of 2.5-month latency and format HDF5, used in this study. The dataset is available on the website: https://pmm.nasa.gov/data-access/downloads/gpm.

2.5. *Study area*

TN is in the southern part of India. Chennai is its capital city (formerly known as Madras). The union territory of Puducherry and the Southern Indian states of Kerala, Karnataka and AP surrounds TN. The Eastern Ghats bounds it by the north. The Nilgiri Mountains, the Meghamalai Hills, Kerala in the west. BoB in the east. The Gulf of Mannar and the Palk Strait in the southeast and the IO on the south. The state shares a maritime border with the nation of Sri Lanka. Fig. 1 shows the study area. Co-ordinates: 8°-13.09° N, 76.10°-80.27° E.

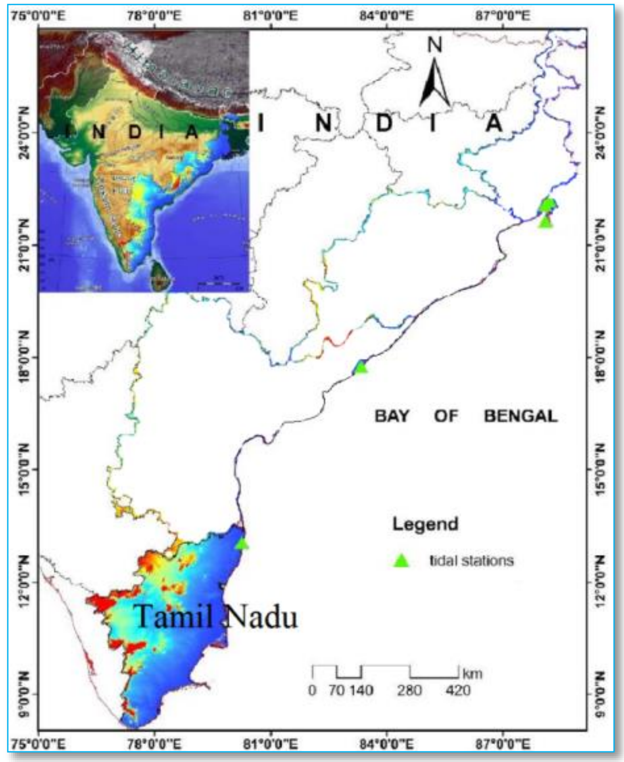


Fig. 1. Study area

3. Methodology

The study analyzed rainfall events during GAJA (2018) cyclone on November 16th and 17th. The INSAT 3D satellite L1-data products are taken for analysis. It is converted to IMR and IMC using IMSRA (INSAT Multispectral Rainfall Algorithm) and modified IMSRA, respectively. The variation of spatial rainfall can be seen from the plots and IMC's performance is better than IMR (Upadhyaya *et al*., 2016). The obtained IMR and IMC products are validated against the IMD rain gauge data, obtained a correlation of 0.58 and 0.52 shown in Figs. 5(a&b) & Figs. 6(a&b). Similarly, it is compared with IMRSA-Merged, GSMaP and IMERG in Figs. 5(c-e) & Figs. 6(c-e) respectively. The methodology adopted is described in Fig. 2.

A study by Vincenzo *et al*., 2018 briefly explains rainfall estimation using satellite observations. INSAT - 3D L1 dataset is downloaded on the cyclonic event. To the dataset IMSRA and Modified-IMSRA algorithms are applied to retrieve the rainfall. This procedure is doneto understand the rainfall retrieval procedure and also to know how the algorithm works. Then the IMC dataset is used to obtain the Merged-IMSRA dataset. This is generated using gridded IMD gauge data and the IMC dataset with the grid resolution of 0.1° × 0.1°. In order to make Merged-IMSRA data collocation (Gairola *et al*., 2010; Holl *et al*., 2010) is performed. Merged IMSRA = IMC + IMD. To achieve this, first, the IMC data should be corrected to get the value of IMC at the location of IMD station data. This value is obtained by bilinear interpolation, and the IMC value resulting from this is named as (IMC) BL. After, Cressman technique is used to correct the bias and to obtain the intended Merged-IMSRA data. Cressman Technique (Bob *et al*., 2000) developed by George Cressman in 1959. The technique interpolates station data to a user-defined latitude-longitude grid. Multiple passes are made through the grid at consecutively smaller radii of influence to increase precision. The radius of influence is defined as the maximum radius from a grid point to a station by which the observed station value may be weighted to estimate the value at the grid point. Stations beyond the radius of influence have no bearing on a grid point value. A new value is calculated for each grid point at each pass based on its correction factor. This correction

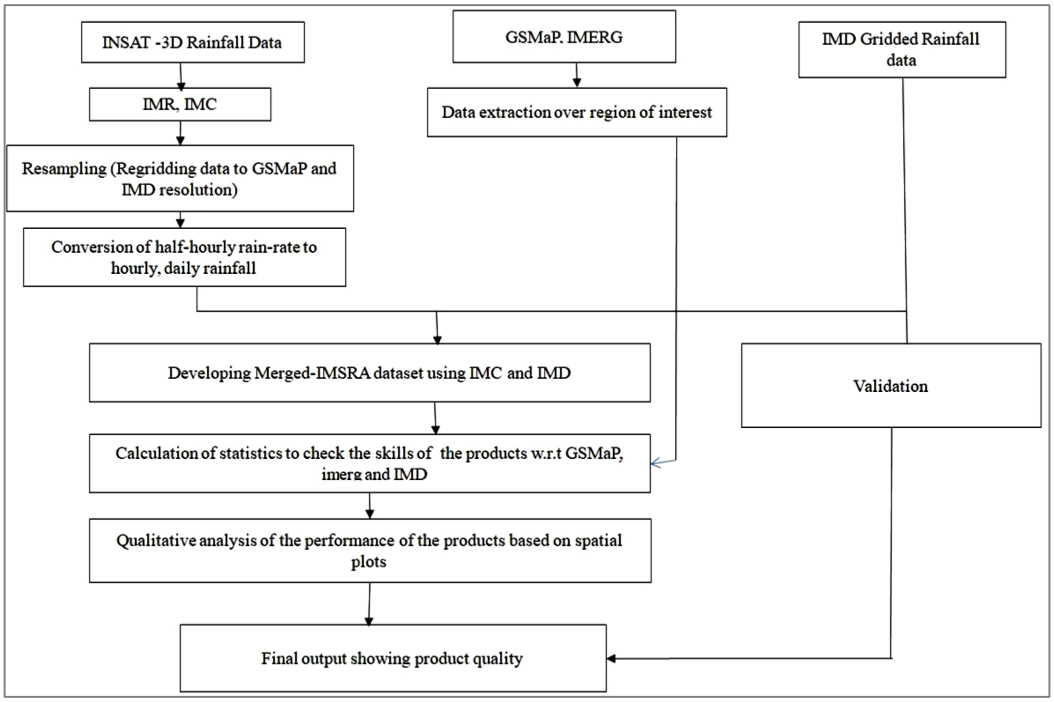


Fig. 2. Methodology

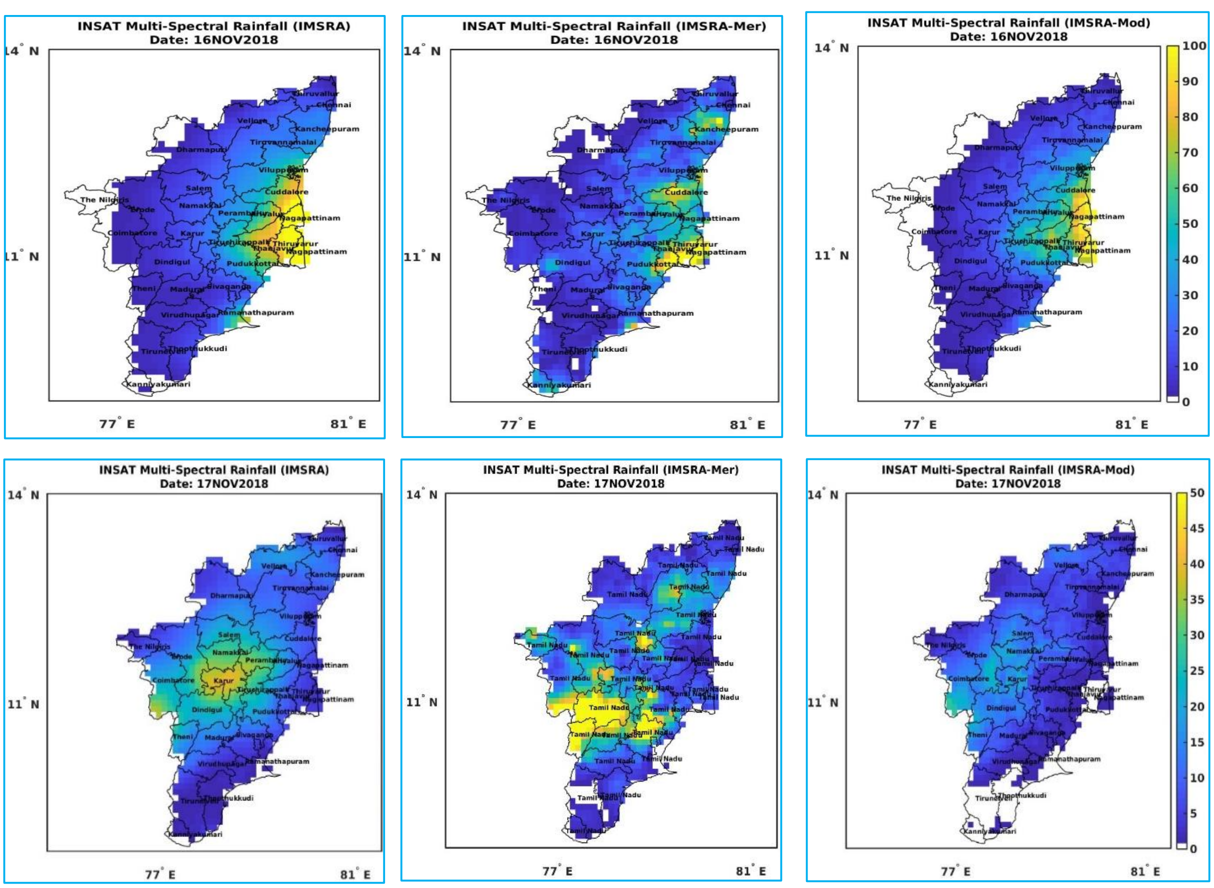


Fig. 3. Spatial distribution of different satellite products during GAJA cyclone on 16 and 17 November, 2018

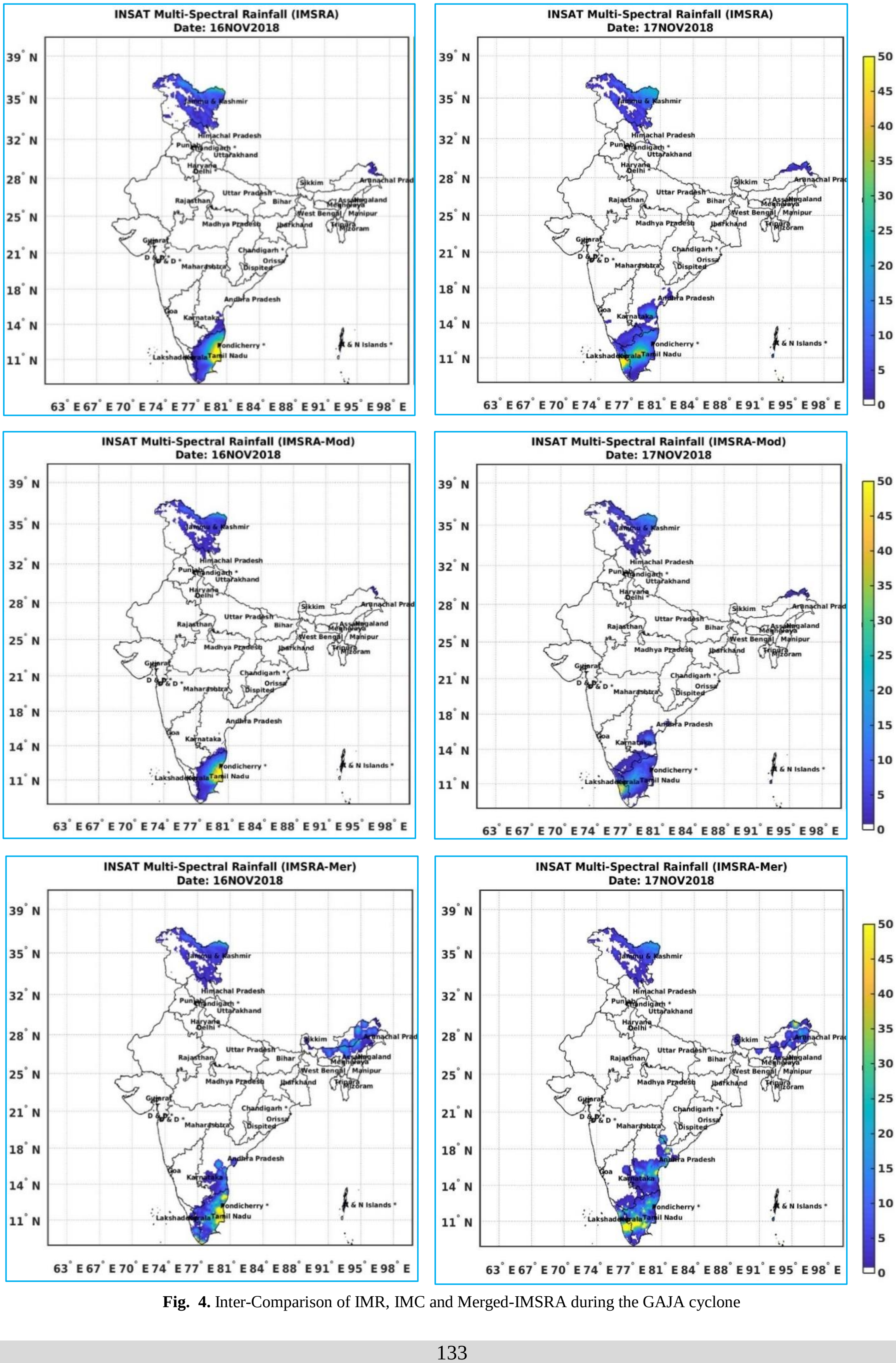


Fig. 4. Inter-Comparison of IMR, IMC and Merged-IMSRA during the GAJA cyclone

factor is determined by analyzing each station within the radius of influence. For each such station, an error is defined as the difference between the station value and a value arrived by interpolation from the grid to that station. A distance-weighted formula (shown below) is then applied to all such errors within the radius of influence of the grid point to arrive at a correction value for that grid point. The correction factors are applied to all grid points before the next pass is made. Observations nearest the grid point carry the most weight. As the distance increases, the observations carry less weight. The cressman function in grid calculates the weights as follows:

$$W = (R^2 - r^2)/(R^2 + r^2)$$

where, R = influence radius and r = distance between the station and the grid point. The weighting function is pictured below. The weight (W) is then applied as:

$$C = \sum(W_i \mathcal{E}_i) / \sum W_i$$

where, i = i^{th} number of radius of influence and $\mathcal{E}_i$ = IMD – (IMC)BL.

4. Results and discussion

This study intends us to know about the variability of rainfall over India's east coast (esp. in TN) during GAJA cyclone, estimate rainfall using IMR and validates it. The discussions are on how much is the rainfall, which all the areas had received much rainfall, satellite products which shows the significant result and how much bias and correlation. It is briefed by splitting into several sessions that explain the (*i*) Rainfall distribution of different products, (*ii*) Inter-comparison of IMC, IMR and Merged-IMSRA, (*iii*) Validation with the IMD rain gauge data, (*iv*) Comparison of global products with IMC Merged and (*v*) Inter-comparison of GSMaP and IMERG.

4.1. *Rainfall distribution of different products*

Rainfall captured during GAJA cyclone by different satellite products over India and region of interest (ROI) TN is displayed. If the plots shown in Fig. 3 are observed keenly, the difference in the spatial distribution of rainfall is seen clearly in different products. The plots show that on 16th November Karaikkal, Nagapattinam, Thanjavur, Pudukkottai, Thiruvarur and Cuddalore received more rainfall >100 mm. Also, the IMD report says the Thanjavur, Nagapattinam district received rainfall 100-140 mm, similar to rainfall obtained from the plots, on 17th November.

In Fig. 3 (17th November, 2018), rainfall is somewhat similar but, if the region and the amount of inundation are considered, there is a difference seen. Rainfall on the IMC plot has a value of 5-50 mm overall. However, it crossed TN and moved towards Kerala and rainfall of >30 mm is not prominent over any area, but, in IMR, rainfall is >40 mm in the central parts of TN, namely Karur, Pudukottai, Perambalur, Trichy. This is evident that the Merged-IMSRA estimates correctly than other datasets.

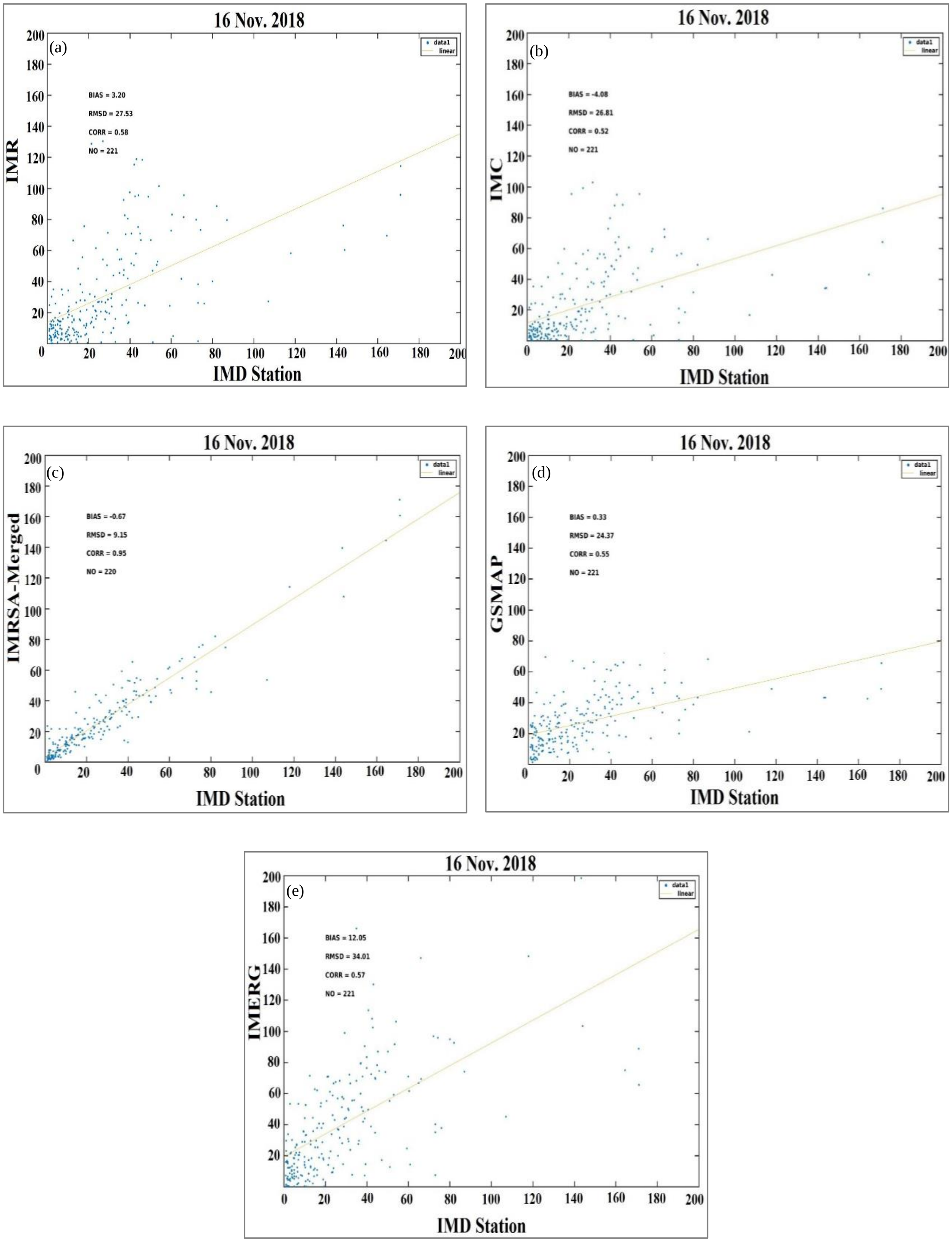
From the plots, it is evident that on 16th November, the low-lying near the coastal areas received more rainfall >100 mm; also, the IMD reports similar rainfall over the coastal region. Apart from TN, some parts of AP also show rainfall (IMD) clearly in Merged-IMSRA compared to IMR and IMC. Rainfall like pattern that is observed over the northern parts of India is not the actual rainfall that occurred during GAJA cyclone; that may be a glitch due orographic effect, but this is not seen in GSMaP, so we can say that GSMaP can rely upon when the ROI is over the hilly areas.

4.2. *Inter-comparison of IMR, IMC and Merged-IMSRA*

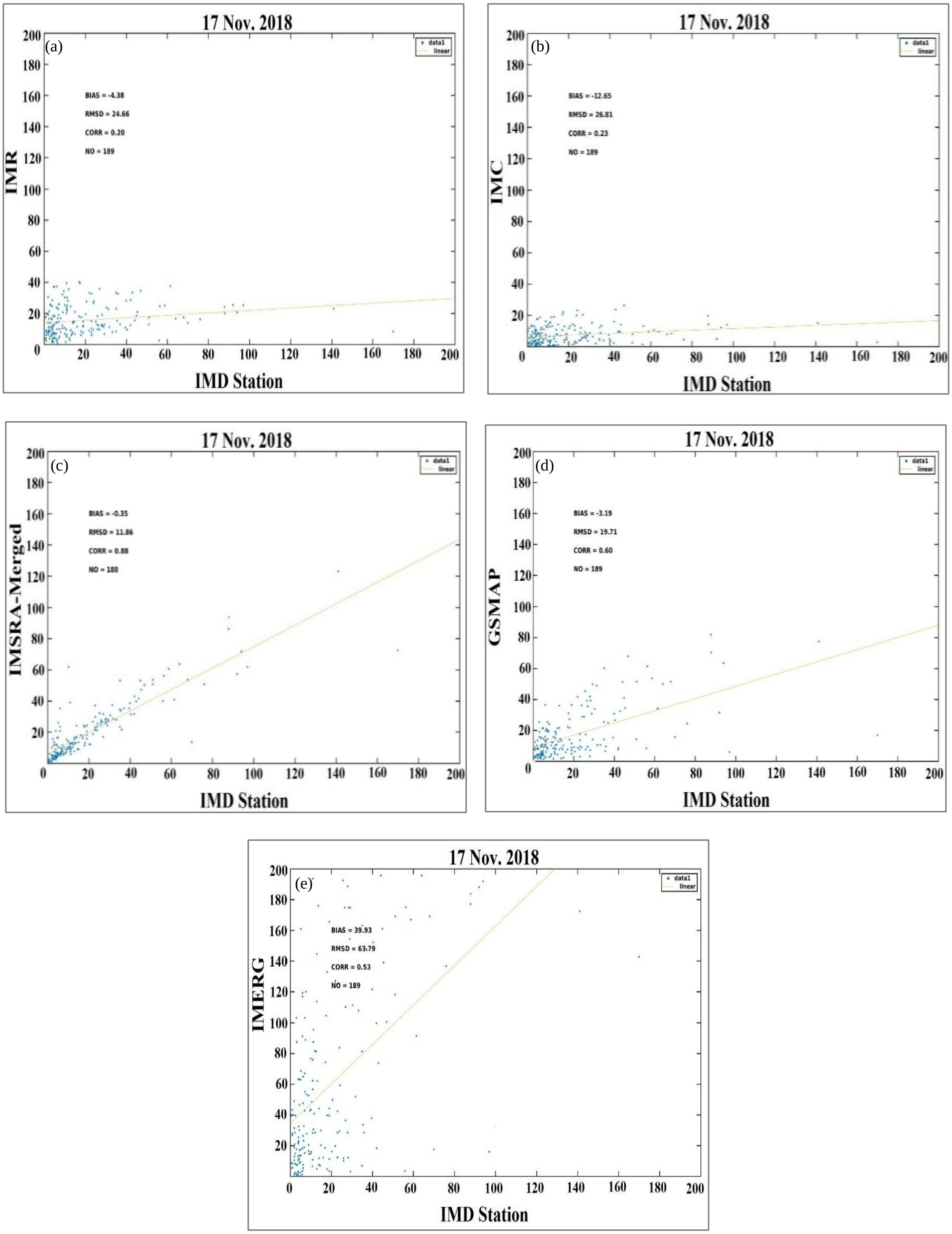
Fig. 4 shows the inundation area and the spatiotemporal variation of rainfall amount during GAJA cyclone over the Indian region. The IMR underestimates the amount of rainfall compared to other datasets. In Fig. 4, the amount of rainfall over the regions TN, Kerala and AP in Merged-IMSRA on 16th November are similar to the IMD gauge data than other datasets. The northern part of India shows rainfall that may be due to an orographic effect. This effect is comparatively less in the merged dataset. According to rainfall value, the merged dataset shows a well-defined value on 16th November, especially on 17th November, as the rainfall crossed the coastal part of TN. Rainfall amount shown in IMR and IMC is <15 mm and in some places >35 mm. According to IMD statement the rainfall on 17th November also >40 mm predominantly in most of the western TN and Kerala. This is picturized clearly in merged dataset than others. Also come parts of AP are inundated that is captured in merged dataset than others. Though the study area is TN, when the whole GAJA cyclone event need to be studied, the overall view (India) of variability during the event helps a lot.

4.3. *Validation with the IMD rain gauge data*

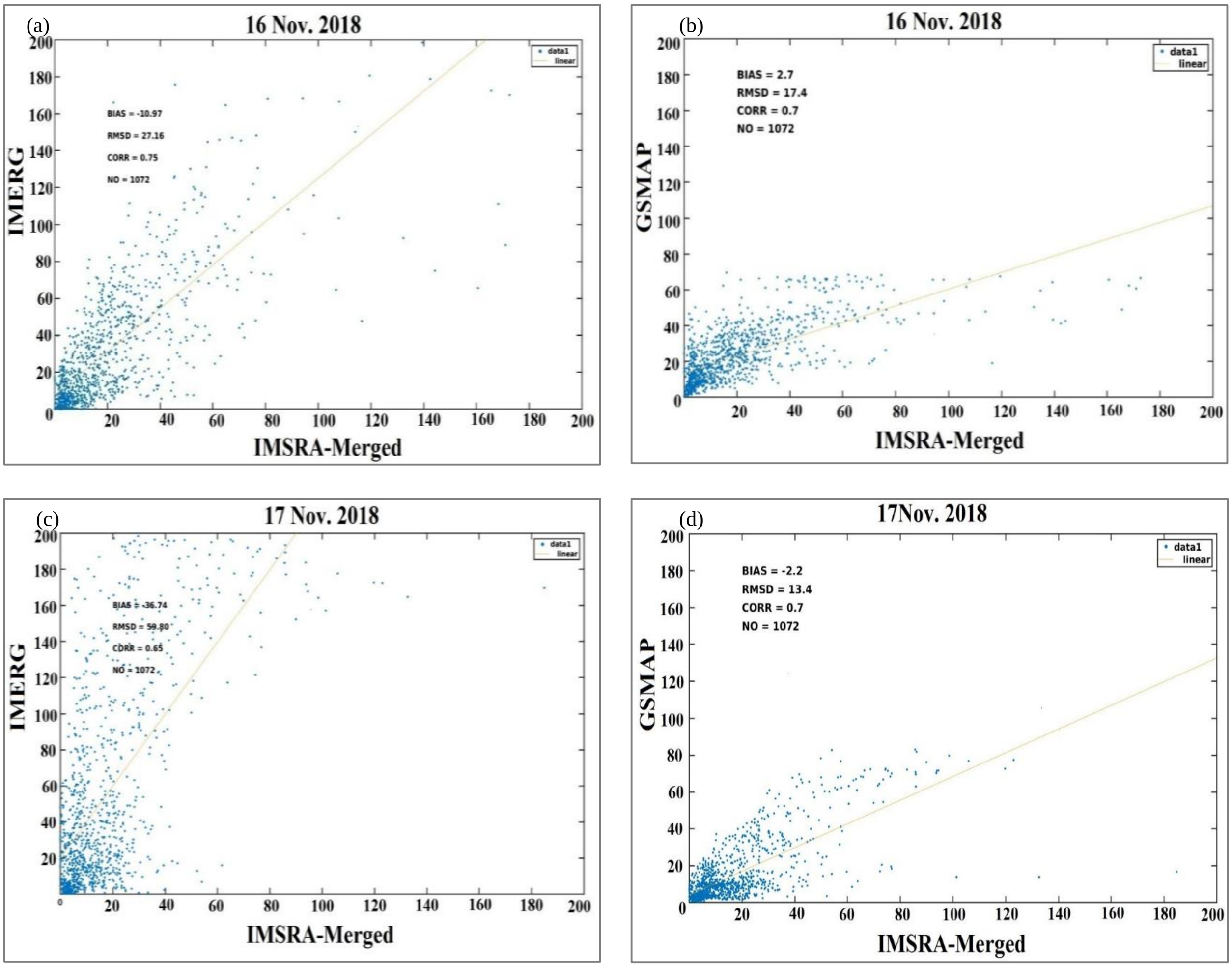
Uncertainties with the sparse gauge sampling data have to be verified before comparing rainfall values between the rain gauge and the satellite observations. This step is carried out mainly because satellite rainfall values are available in a gridded form, whereas the rain gauges are as points. The uncertainties are overcome by spatial



Figs. 5(a-e). Scatter plots of the INSAT-3D derived (a) IMR, (b) IMC, (c) Merged-IMSRA and (d) GSMaP and (e) IMERG with the IMD station data on 16th November, 2018



Figs. 6(a-e). Scatter plots of the INSAT-3D derived (a) IMR, (b) IMC, (c) Merged-IMSRA, and (d) GSMaP and (e) IMERG with the IMD station data on 17th November, 2018

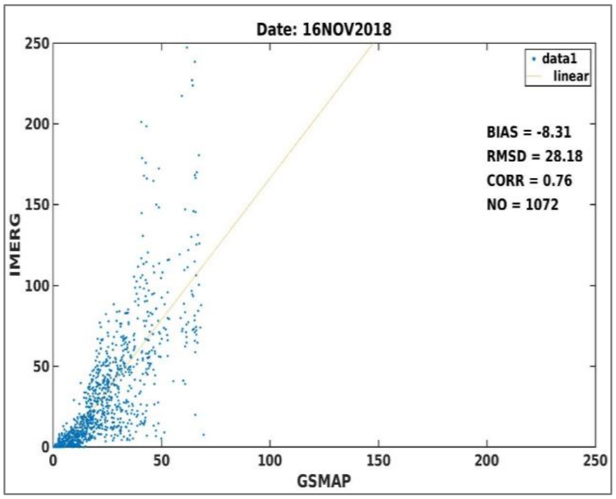


Figs. 7(a-d). Scatter plots Merged-IMSRA with GSMaP, IMERG on 16 and 17 November, 2018

interpolation or by average. However, interpolation might bring some uncertainties due to the density of precipitation gauges, systematic error and uncertainties associated with different interpolation methods (Roy Bhowmik & Das, 2007). In this paper, an ideal comparison with the gauge network is adopted by the Cressman technique, which helps convert the point gauge data into the grid form of a user-defined grid. The validation of GSMaP, IMERG, IMR, IMC, IMC-Merged with IMD station data is shown in Figs. 5(a-e) during landfall of GAJA cyclone on 16th November, 2018. The correlation coefficient (CC) is 0.58, 0.52, 0.95 respectively. And the CC for the global products for GSMaP and IMERG are 0.55 and 0.57, respectively. It shows the overall good performance of Merged-IMSRA for detecting rainfall and agrees well with the surface observations in general. Similarly, the Figs. 6(a-e) Scatter plots of the INSAT-3D derived (a) IMR, (b) IMC, (c) Merged-IMSRA (d) GSMaP and (e) IMERG with the IMD station data on 17th November, 2018. Our analysis on Figs. 5(a-e) & 6(a-e) also agrees well with the statement - The IMR underestimates heavy rainfall conditions (Mitra *et al.*, 2018).

From Figs. 5(c) & 6(c), it is evident that Merged-IMSRA has good relations with the IMD gauge station as most of the points lie on the line compared to (a), (b) and (d) while (e) has more sparse points and it overestimates rainfall saying 200 mm/day where the actual rainfall did not exceed 180 mm/day. The RMSD and the bias are less with merged datasets compared to others.

From Figs. 5(c) & 6(c) one thing is evident, on both days, Merged-IMSRA is performing well compared to other data sets. Also, the f1 score for merged dataset is 0.81 and this is the highest score among all other dataset.



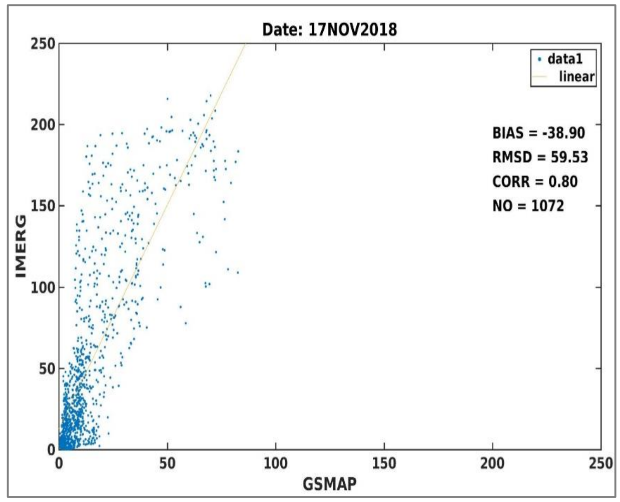


Fig. 8. Scatter plots GSMaP with IMERG on 16 and 17 November, 2018

TABLE 1

Validation of data products with the IMD station data

Data products	Date	Statistic		
		Bias	Corr	RMSD
IMSRA	16 Nov, 2018	3.20	0.58	27.53
	17 Nov, 2018	-4.38	0.20	24.66
IMSRA-Mod.	16 Nov, 2018	-4.08	0.52	26.81
	17 Nov, 2018	-12.65	0.23	26.81
IMSRA-Merged.	16 Nov, 2018	-0.67	0.95	9.15
	17 Nov, 2018	-0.35	0.88	11.80
GSMaP	16 Nov, 2018	0.33	0.55	24.37
	17 Nov, 2018	-3.19	0.6	19.71
IMERG	16 Nov, 2018	12.05	0.57	34.01
	17 Nov, 2018	39.93	0.53	63.79

Table 1 shows the statistical measures used to evaluate the developed data product. The number of station points used for the calculation is 221.

4.4. *Comparison with global products*

The global products, available at a resolution of 0.1° × 0.1°, compared with Merged-IMSRA (as the global products are also available in the merged form). Figs. 7(a-d) shows the scatter plots Merged-IMSRA with GSMaP, IMERG on 16 and 17 November, 2018.

TABLE 2

Validation of global products with Merged-IMSRA data

Data products	Date	Statistic		
		Bias	Corr	RMSD
GSMaP	16 Nov, 2018	2.7	0.7	17.4
	17 Nov, 2018	-2.2	0.7	13.4
IMERG	16 Nov, 2018	-10.97	0.75	27.16
	17 Nov, 2018	-36.74	0.65	59.80

TABLE 3

Comparison of GSMaP with IMERG

Data products	Date	Statistic		
		Bias	Corr	RMSD
GSMaP	16 Nov, 2018	-8.31	0.76	28.18
	17 Nov, 2018	-38.90	0.80	59.53

The scatter plots, (a) and (c) shows good CC value of 0.75 and 0.65 yet it overestimates rainfall of 200 mm as the actual rainfall ranges from 100-140 mm, that is why the bias values in both cases are high compared to plots, (b) and (d) which maintains the CC as 0.7 on both days of landfall. This is supported by Table 2 that tells the CC, bias and RMSD values.

From Fig. 7(c&d) it is observed that the global dataset IMERG and GSMaP are overestimating the

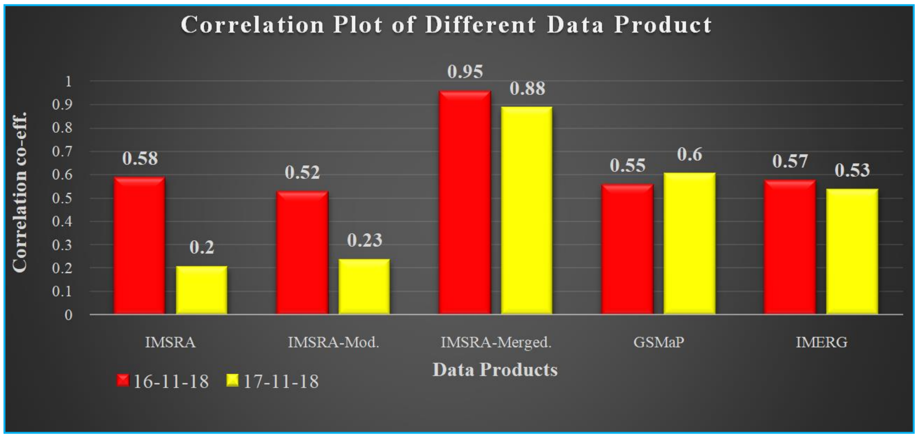


Fig. 9. Correlation plot of different data products

rainfall on 16th November compared to merged product as the points are scattered more on left side of the graph (*y*-axis) than the *x*-axis where the merged data rainfall value is plotted. Also the deviation from the mean value is less for merged product.

4.5. *Inter-Comparison of IMERG with GSMaP*

Both IMERG and GSMaP are compared. It is a merged products of the US and JAPAN with a resolution of 0.1° × 0.1° and a temporal resolution of 1 hour. Fig. 8 shows that the GSMaP rainfall is more reliable than IMERG as it is showing rainfall at 250 mm also, GSMaP is shows 100-110 mm, which is in rainfall range that is reported from the IMD. This is supported by Table 3 that tells the CC, bias and RMSD values.

The table depicts the reliability of global product. GSMaP is more reliable and has the most commonly used factor for comparison, *i.e.*, CC = 0.76 and 0.8, Bias is -8.31 and -38.9. When this data product is weighed upon our derived Merged-IMSRA dataset as shown in Table 2 the bias value is very less and the CC value is well reliable. This shows a remarkable point as this merged dataset can be in place of GSMaP and it is also reliable.

5. Summary and conclusions

This paper examines the potential utilization of INST-3D satellite-derived rainfall estimations, *i.e.*, IMR, IMC and IMC-Merged also use the global data GSMaP and IMERG. The statistical results showed good correlations between IMR, IMC, Merged-IMSRA, GSMaP-Gauge and IMERG products. The Merged-IMSRA gave a much better correlation (0.95, 0.88) than IMERG (0.51, 0.45) and GSMaP (0.55, 0.60) on comparison with ground-based measurements during GAJA cyclone (16, 17 November, 2018). From this, the performance of Merged-IMSRA is better compared to IMC and IMR and also shows good CC with the global data sets which is also a merged dataset. The statistics are represented by the Table 1.

The correlation between GSMaP and Merged-IMSRA (0.7, 0.7) is better than that of IMERG and Merged-IMSRA (0.75, 0.65) for GAJA cyclone. The CC between GSMaP and IMERG products (0.76, 0.80), but there was a significant overestimation by IMERG during GAJA cyclone. Hence, from Fig. 9 and Table 2, it is concluded that Merged-IMSRA performance is well than other products. The study is conducted for 4 days from 15 to 18 November, 2018, as the rainfall was dominant over the study area on 16 and 17 of November; the test evaluations are shown only for these days. Merged data product makes us easier to compare with the global data products by computational means and also need not make any modification or re-sampling (regrinding). As this work is done for only one cyclonic event (GAJA), this study has to be extended for all the cyclonic events and the monsoon season over a long period to see the consistency of the result. This study used to created database of the rainfall events associated with the tropical cyclone and applied in models for prediction of rainfall.

Disclaimer : The contents and views expressed in this research paper/article are the author's views and do not necessarily reflect the views of the organizations they belong to.

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