Validation of satellite estimated convective rainfall products : A case study for the summer cyclone season of 2020

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सार – प्रस्तुत शोध ग्रीष्मकालीन चक्रवात ऋतु 2020 के दौरान राष्ट्रीय मध्यम अवधि पूर्वानुमान केंद्र (NCMRWF) में GFS प्रथम अनुमान क्षेत्रों का उपयोग करके Meteosat-8 (IODC) से प्राप्त संवहनी वर्षा उत्पादों के निष्पादनपर केंद्रित है। NCMRWF को EUMETCAST स्थलीय सेवा के माध्यम से वास्तविक समय में Metososat-8 (IODC) HRIT आँकड़े प्राप्त होते हैं। राष्ट्रीय मध्यम अवधि पूर्वानुमान केंद्र (NCMRWF) संवहनी वर्षा दर (CRR), RGB उत्पादों, और मेघ बिंबावलियों सहित तात्कालिक अनुमान उत्पादों को वास्तविक समय में व्युत्पन्न करता है तथा फिर उन्हें इंट्रानेट के माध्यम से भारत मौसम विज्ञान विभाग को उपलब्ध कराया जाता है। यहाँ हमने क्रमशः बंगाल की खाड़ी, अरब सागर में बने अम्फन और निसर्ग चक्रवातों पर विशेष ध्यान दिया। इन CRR उत्पादों का सत्यापन GPM मिशन द्वारा अंशांकित और समाहित किए गए वर्षा उत्पाद IMERG के साथ किया गया। दोनों क्षेत्रों में दोनों वर्षा उत्पादों के प्रत्येक ग्रिड की तुलना में संवेदी मेघ क्षेत्रों में एक अच्छा सामंजस्य देखने को मिला। मेघ क्षेत्र की वर्षण में संसूचन की संभावना (POD) और क्रांतिक सफलता सूचकांक बहुत अधिक (~1) है। दोनों चक्रवातों के दौरान मध्यम, तीव्र, अत्यधिक तीव्र वर्षा के क्षेत्रों में POD, सफलता के अनुपात बहुत अधिक (~1) हैं। हल्की वर्षा (0-10 मि.मी./घंटा) के क्षेत्रों के लिए POD कम है। CRR संवहनी मेघ विशिष्ट उत्पाद सेयह अनुमान लगाया गया जो स्तरीय मेघ क्षेत्रों में वर्षा को फिल्टर करता है। यह अध्ययन दर्शाता है कि विभिन्न अनुप्रयोगों के लिए वास्तविक समय वर्षा की निगरानी में CRR का उपयोग किया जा सकता है।

ABSTRACT. The present work is focused on the performance of convective rainfall products, derived from Meteosat-8 (IODC) at NCMRWF using GFS first guess fields during summer cyclone season 2020. NCMRWF receives Meteosat-8 (IODC) HRIT data in real-time through EUMETCAST terrestrial service. NCMRWF derives the nowcasting products, including Convective Rainfall Rate (CRR), RGB products and cloud imageries in real-time and made available to IMD through the National Knowledge Network (NKN). Here, we focussed on the Amphan and Nisarga cyclones, formed in the Bay of Bengal and the Arabian Sea respectively. The validation of these CRR products is carried against calibrated and merged precipitation product IMERG by GPM missions. Grid to grid comparison of both precipitation products shows a good agreement in convective cloud regions in both the cyclones. Probability of Detection (POD) and Critical success index is very high (~1) in the precipitating clouds region. POD, Success ratios are very high (~1) in the regions of moderate, intense, very intense spells during the two cyclones. The POD is low for light spell (0-10 mm/h) regions. This is expected from CRR a 'convective cloud' specific product, which filters out rainfall in stratiform cloud regions. This study shows that CRR can be used in near-real time rainfall monitoring for various applications.

Key words – Convective rainfall rate, NWCSAF, IMERG, Meteosat-8 (IODC), Satellite rainfall estimates.

1. Introduction

Cyclones are characterized by intense and widespread rainfall. It causes extensive destruction of property and life. It also induces flash floods in the cities and affects all kinds of transport like road, rail, aviation and shipping. Thus accurate estimation of rainfall caused by cyclones has always been important to the meteorological community for various applications. However, as cyclones originate and spend about 3/4th of their life span oversea, continuous monitoring of rainfall caused by them is not feasible with conventional observational methods. Since all the ground-based observations of rainfall have limitations of coverage and continuous monitoring, Satellite-based rainfall estimations have long been developed and used for various purposes. Such estimates have an advantage in Spatio-temporal domains with higher spatial coverage and continuous monitoring of rainfall not only over land but also over oceans. This makes satellites highly suitable to monitor the rainfall caused by cyclones over the ocean as well as remote lands. However, the satellite-based rainfall products also have limitations in the estimation of rainfall because of their very indirect nature of observation which

limits its accurate retrieval. Satellite sensors and orbits also affect the retrieval methods and thus the estimation.

From the 'IR' only estimates in the 1990s, the algorithms have advanced a lot to include radar/microwave-based calibrations and the use of numerical weather prediction (NWP) based model fields for improved retrieval estimation. The rainfall products are available in half-hourly, 3 hourly, daily, monthly time scales with each targeting a specific need. Cyclonic storms require these estimates on a shorter time scale of an hour or less. Geostationary satellites offer continuous monitoring but suffer from limited wavelengths they can employ. Low earth orbit (LEO) allows the use of more wavelengths for remote sensing like the microwave region inactive as well as passive mode. These microwave channels help in improved retrieval owing to their interaction with hydrometeors. But their observations are limited as they are placed in LEO orbits. Hence, a constellation of Low earth orbit satellites is often used for enhanced monitoring of rainfall in the tropical region. However, in the case of cyclones, only the continuous near-real-time monitoring helps the hydro-met and disaster management point of view. This high frequency spatial, temporal Spinning Enhanced Visible and InfraRed Imager - Indian Ocean Data Coverage (SEVIRI-IODC) has given a chance to produce Red, Green, Blue (RGB) composite, nowcasting atmospheric products that are useful to nowcaster. This makes geostationary satellites based rainfall estimates very crucial. Convective Rain Rate (CRR) rainfall products every 15 minutes using geostationary satellites, model-simulated fields and some available observational data (like Lightning strikes). But the utility of these products, for meteorological communities and disaster managers, depends upon the retrieval accuracy. Hence these estimates need to be validated.

In the present study, we have validated a pure Geostationary satellite-based near real-time rainfall CRR products containing Convective Rain Rate, CRR Rainfall Intensity (CRI) against another satellite-based but merged rainfall product Integrated Multi-SatellitE Retrieval for Global Precipitation Measurement (IMERG). A similar Hydro Estimator (HE) rainfall product has a high temporal, spatial resolution is available for the Indian region for real time assessment (Not used in the current study). The main difference between HE and CRR is that HE rain at a pixel is a combination of both convective and stratiform, whereas CRR estimates only for convective systems (https://mosdac.gov.in/data/doc/INSAT_3D_ATBD_MAY_2015.pdf; https://www.nwcsaf.org/Downloads/GEO/2018/Documents/Scientific_Docs/NWC-CDOP2-GEO-AEMET-SCI-ATBD-Precipitation_v2.1.pdf).

The primary objective of this product is to estimate the precipitation rate associated with convective clouds. It considers the InfraRed Water Vapor (IR-WV) brightness temperature difference for identifying deep convective clouds. Meteosat-8 SEVIRI and Radar data are combined to formulate the calibration functions which are then used to obtain CRR for each pixel. The rainfall rate is obtained as a function of IR brightness temperatures (BT) and the difference in IR-WV BT. A filtering process is carried out to remove stratiform rainfall. A number of corrections like cloud top temperature gradient correction (Vicente *et al*., 1998), orographic correction (Vicente *et al*., 2002) and moisture correction are applied to further refine the product. IMERG is a satellite-based rainfall product obtained using a constellation of 11 Global Precipitation Mission (GPM) satellites that includes India-France Megha-Tropiques. The multi-channel microwave humidity sounder Sondeur Atmosphérique du Profild' Humidité Intertropicale par Radiométrie (SAPHIR) on the Megha-Tropiques satellite provided by the Centre National D'Etudies Spatiales (CNES) of France and the Indian Space Research Organisation (ISRO) is also an input for the IMERG (Roca *et al*., 2015).

The precipitation estimates from various passive microwave sensors are inter-calibrated to the GPM combined instrument (CI) that includes GMI and DPR. Geostationary satellite IR channel based estimates are calibrated with microwave data. These two are then combined with morphing techniques to form a holistic GEO-LEO combined rainfall product. The final run of this product which is adjusted using gauge analysis data to provide rainfall at different time scales from half-hourly to monthly is found to be superior to most other widely used satellite-based rainfall products (Sharifi *et al*., 2016). Hence we compare the CRR against this highly advanced rainfall product.

The daily mean synoptic-scale accumulated rainfall will not justify the current needs of decision-makers like the transport, aviation sector, disaster management in real-time. A very high time-frequency forecast will justify extreme weather events like thunderstorms, flash flooding. But, the generation of NWP model forecasts at 15-minute intervals are highly computational to the model forecasters in day to day life. The collection of global observations in synoptic hours itself is a challenging task to the modelers in data assimilation due to various technical reasons. In such a condition the alternative way to give a very short range forecast every 15 minutes is possible with geostationary satellites over a limited area.

NWCSAF v2018 is a free software package utilized for creating very short-range forecasts up to 90 minutes using satellite, model and some available observation data
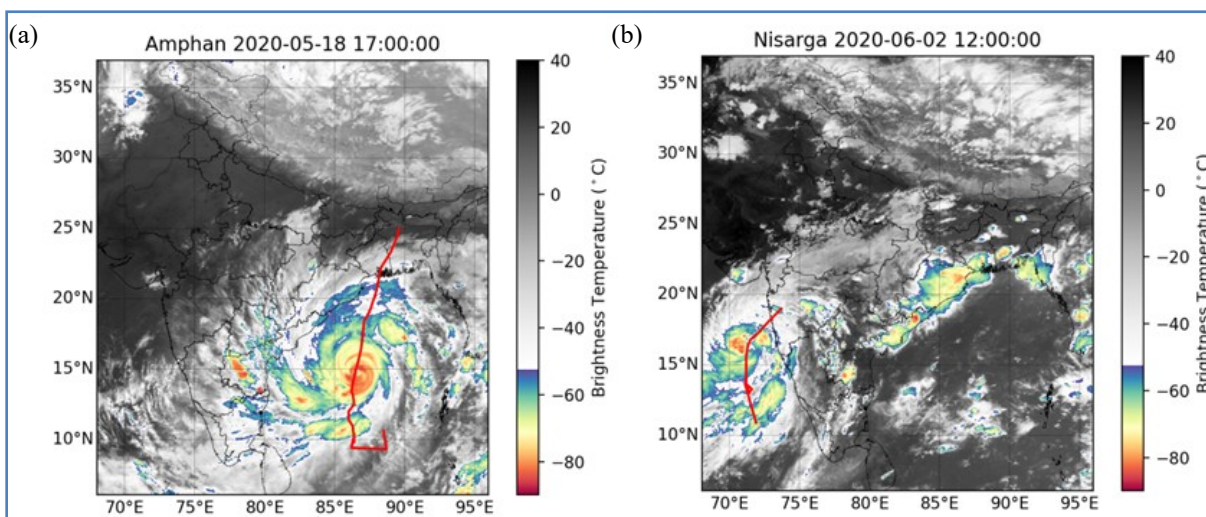
Figs. 1(a&b). (a) Spatial SEVIRI (IR-10.8μm) brightness temperature view on 2020-05-18_1700 UTC along with AMPHAN cyclone track from 2020-05-14_1800 UTC to 2020-05-21_0600 UTC at 6 hour interval and (b) Spatial SEVIRI (IR-10.8μm) brightness temperature view on 2020-06-02_1200 UTC along with NISARGA cyclone track from 2020-05-31_0600 UTC to 2020-06-03_1200 UTC at 6 hour interval (*Source* : IMD)

(like Lightning data). It is also necessary to check the quality of the product with real-time observations. So that a forecaster can believe the utilization in real-time. There are limitations like day time, night time availability of visible channels, contamination of Near InfraRed (NIR) in day time scan impact on the nowcast products. The CRR, CRR Intensity, CRR hourly accumulation product purely depends on IR, WV channels 10.8, 6.2 micron cloud top brightness temperature difference in the previous cycle to the current cycle (Dybbroe *et al.*, 2005).

The present works aim the validation of Convective Rain Rate intensity products from the NWCSAF package in real-time during AMPHAN and NISARGA cyclone life span. Section 2 describes the data structure, its retrieval and processing method for validation. Section 3 describes the methodology implemented for verification of qualitative *vs* quantitative. Section 4 describes the result and discussion. And Section 5 concludes with the conclusion.

2. Data

2.1. *Evaluation of AMPHAN cyclone*

The super cyclone AMPHAN originated in the southeast of the Bay of Bengal (BoB) and adjoining of the Andaman Sea with low pressure on 13th May, 2020 as a fresh low-pressure system (https://internal.imd.gov.in/press_release/20200614_pr_840.pdf). It became a Well Marked Low (WML) pressure system on 14th May, 2020 at the southeast of BoB, developed into Depression and intensified to Deep Depression (DD) on 16th May 2020. The DD moved northward and became a cyclonic storm on 16th May, 2020 evening. It underwent rapid intensification during subsequent 24 hours and accordingly intensified into a Very Severe Cyclonic Storm (VSCS) by the afternoon (0900 UTC) of 17th May, 2020, Extremely Severe Cyclonic Storm (ESCS) in the early hours of 18th (2100 UTC of 17th May) and intensified into a Super Cyclonic Storm (SuCS) around noon (0600 UTC) of 18th May, 2020. On 20th May, 2020 the super cyclonic storm hit Bangladesh coast as VSCS near latitude 21.65°N and longitude 88.3° E during 1530-1730 hrs IST (1000-1200 UTC), with a maximum sustained wind speed of 155 - 165 kmph gusting to 185 kmph. The SuCS eye view of AMPHAN on 2020-05-18_1700 UTC along with its track from 2020-05-14_1800 UTC to 2020-05-21_0600 UTC at every 6 hour location is shown in Fig. 1(a).

2.2. *Evolution of NISARGA cyclone*

The severe cyclonic storm started as a low pressure area formed over southeast & adjoining east central Arabian Sea and Lakshadweep area in the early morning (0530 hrs IST) of 31st May, 2020. Under favorable environmental conditions, it concentrated into a depression over east central and adjoining southeast Arabian Sea in the early morning (0530 hrs IST) of 1st June, 2020. It intensified into a deep depression over east central Arabian Sea in the early morning (0530 hrs IST) and into the cyclonic storm "NISARGA" at noon (1130 hrs IST) of 2nd June. It moved northwards till evening (1730 hrs IST) of 2nd June. Thereafter, it

TABLE 1

Convective Rain Rate precipitation flag information in mm/hr

Flag	0	1	2	3	4	5	6	7	8	9	10	11
Range	0.1-0.2	0.2-1	1-2	2-3	3-5	5-7	7-10	10-15	15-20	20-30	30-50	>50

gradually recurved north-eastwards and intensified into a severe cyclonic storm in the early morning (0530 hrs IST) of 3rd June, 2020. Further moving north-eastwards, it crossed Maharashtra coast close to south of Alibagh as a severe cyclonic storm with a maximum sustained wind speed of 100-110 kmph gusting to 120 kmph during 1230-1430 hrs IST of 3rd June. (https://mausam.imd.gov.in/backend/assets/press_release_pdf/Press_Release_dated_5 th_June_in_association_with_Severe_Cyclonic_Storm_Ni sarga1.pdf). The NISARGA cyclonic storm view from SEVIRI (IR-10.8µm) on 2020-06-02_1200 UTC along with the track starts from 2020-05-31_0600 UTC to 2020-06-03_1200 UTC at every 6 hour interval in Fig. 1(b).

2.3. *Convective rain rate*

The convective rain rate (CRR) is one of the nowcast products derived from the Meteosat-8 Indian Ocean Data Coverage (IODC) using NoWCasting Satellite Application Facility for GEOsatellite (NWCSAF/GEO v2018). The SAFNWC products generation is operationalized at the National Centre for Medium Range Weather Forecasting (NCMRWF) for producing very short range forecast products for nowcasting of weather since 10th November, 2019. High Rate Image Transmission (HRIT) Meteosat-8 IODC data has been utilised for the production of nowcasting products along with the CRR products. NWCSAF utilizes the model vertical profiles of temperature, relative humidity, pressure, the temperature at 2 m, dew point temperature at 2 m, U and V components at 850 hPa at its closet forecast times from Global Forecast System (GFS-1534). The GFS model description, Grid Statistic Interpolation (GSI), data sets used for data assimilation and its validation can be found in Johny *et al*., 2019; Prasad *et al*., 2017; Rani *et al*., 2014; Sridevi *et al*., 2019. Multi channel Meteosat-8 Infrared Region (IR) and Water Vapor (WV) data received from EUMETCAST service in real time with EUMETSAT license agreement.

The instantaneous CRR products are available at every 15 minute interval over Meteosat-8 full disk coverage at its highest resolution of 3 × 3 km. The CRR rainfall product gives qualitative information in the 11 intervals. Whereas, Convective Rainfall Intensity (CRI) gives the quantitative information in mm/h in every time step. The interval ranges are described in Table 1.

TABLE 2

IMD classification of instantaneous rainfall (mm)

| Type	Light Spell	Moderate Spell	Intense Spell	Very Intense Spell
Range	0-10	10-20	20-30	30-50

TABLE 3

Contingency table

2 × 2 Contingency Table		Event Observed through GPM (obs)	
		Yes/Occurred	No/Not Occurred
Event Observed (CRR)	Yes/Occurred	Hits (A)	False Alarm (B)
	No/Not Occurred	Missed (C)	Correct Negative (D)

Moreover, the instantaneous CRR at every 15 minutes in qualitative format may not match with the IMERG 30 minutes rainfall product. The methodology used to overcome this issue of comparing this qualitative product with a quantitative rainfall product is discussed in section 3.

2.4. *IMERG*

The state-of-art Integrated Multi-satellitE Retrievals for GPM (IMERG V6) produce high spatial (0.1 degrees) and high temporal (30 minutes) precipitation datasets which runs twice in near real time with early run of 4 hours latency with forward morphing (https://docserver. gesdisc. eosdis.nasa.gov/public/project/ GPM/MorphingIn V06IMERG.pdf), late runs with 14 hour latency with forward and backward morphing to monitor flash floods and drought monitoring purposes. A final run has a latency of 3.5 months with forward, backward morphing with monthly mean gauge observations for research purposes (Huffman *et al*., 2019). The Final run data (*download source* : https://gpm1.gesdisc.eosdis.nasa. gov/opendap/hyrax/GPM_L3/GPM_3IMERGHH.06/2020 /contents.html; last visit Oct-10, 2020) has been utilized for the Amphan cyclone period at 0.1° resolution at 30 minute interval. A calibrated precipitation variable (precipitation CAL) is utilized for the validation.
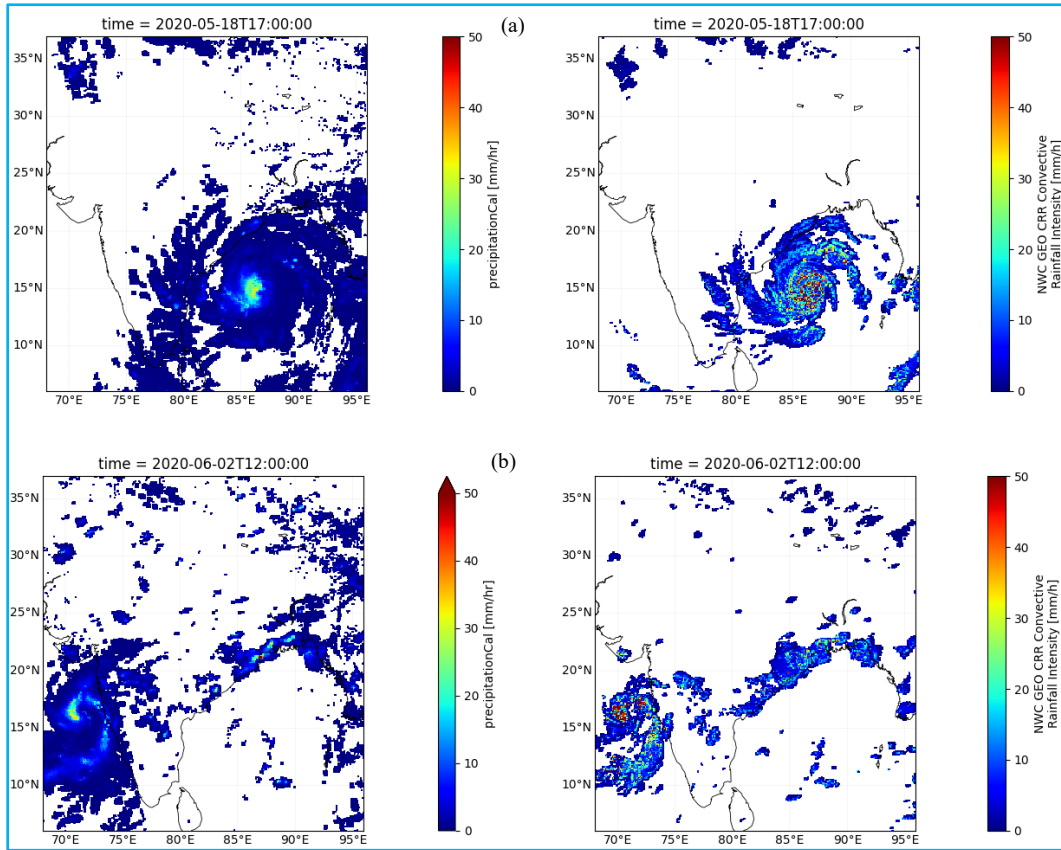
Figs. 2(a&b). Spatial precipitation map of Amphan [top panel (a)] and Nisarga [bottom panel (b)]. And the top right and bottom right panel shows the CRR product for the Amphan, Nisarga cyclones

3.   Methodology

CRR is available at a 15 minutes interval whereas the IMERG product is available at a 30 minutes interval. The average of two successive CRR product files over each pixel are assigned a higher category as per the qualitative information (Table 1). If the difference in two pixels is more than 6 then that pixel is assigned higher of the two categories. This is valid up to 0-8 flag numbers. The CRR, CRI products at 3 km resolution data is re-gridded to 10 km by applying the nearest neighborhood method with a radius of influence 6 km.

3.1. *Contingency table*

A 2 × 2 matrix contingency table is prepared by assuming IMERG data as observation and CRR data as prediction. A grid to grid comparison is applied based on the qualitative information provided in Tables 1& 2. The IMERG quantitative data is remapped to qualitative information over each pixel over the study period to facilitate comparison with CRR product. The domain of

interest is taken as 0-40° N latitude and 60° E-100° E longitude. Here, the contingency table is prepared for both land and ocean regions.

Initially, the work was carried out to check the probability of detection (POD) for each pixel as per the India Meteorological Department (IMD) instantaneous rainfall which comes in 4 categories as shown in Table 2. (Since CRR estimates rain rates of up to 50 mm/hr) Later, the same is implemented for the default CRR category. The POD, SR (1-FAR), bias and CSI are calculated based on the following equations (1, 2, 3 and 4).

$$POD = \frac{A}{A+C} \tag{1}$$

$$FAR = \frac{B}{A+B} \tag{2}$$
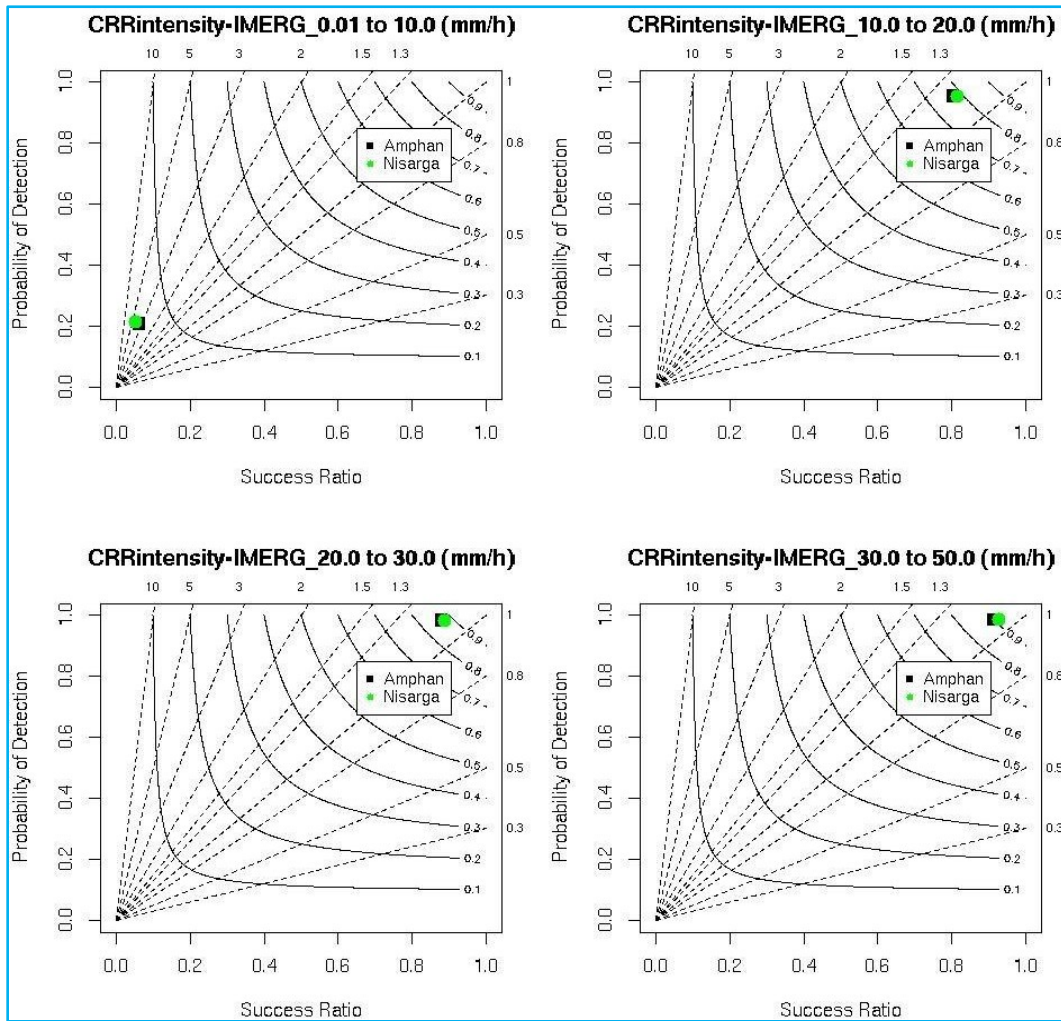
$$bias = \frac{A+B}{A+C} \tag{3}$$

Fig. 3. Performance diagram for validation of CRI with IMERG precipitation data in four categories. Dashed lines represent bias scores with labels on the outward extension of the line, while labeled solid contours are CSI

$$CSI = \frac{A}{A + B + C} \qquad (4)$$

4. Results and discussion

Precipitation due to convective clouds are higher than the stratiform clouds and their lifetime is also short as compared to the stratiform clouds (Tremblay, 2005). The aerial extent of convective clouds is a few kilometers horizontally and upto 18 km vertically due to the strong updrafts (Hong *et al*., 1999). The brightness temperature of overshooting clouds is more than that of stratiform clouds which relatively indicates the enhanced probability of higher precipitation.

The spatial map of Amphan, Nisarga cyclone precipitation images from IMERG and CRI shows the lower detection of stratiform clouds in the CRI product

(Fig. 1). The lower brightness temperature and its variation in the next time step also less in the stratiform clouds. Due to this reason, the detection of stratiform clouds is less in the CRI rainfall product. The calibrated IMERG rainfall shows less quantity of precipitation near the intense central feature of both cyclones. It's due to various factors like primarily no *in situ* observations over oceans and secondly the type of algorithm implemented for the correction of sensing of rainfall. The spatial extent of Amphan cyclone is less in the CRI product as compared to the IMERG (top panel form Fig. 2) and the areas that failed to get detected are stratiform clouds which are not detected by the CRR algorithm. And the same can be seen in the Nisarga cyclone also (bottom panel from Fig. 2).

The performance diagram is a representation of POD, SR, bias and CSI for observed, estimated value in a
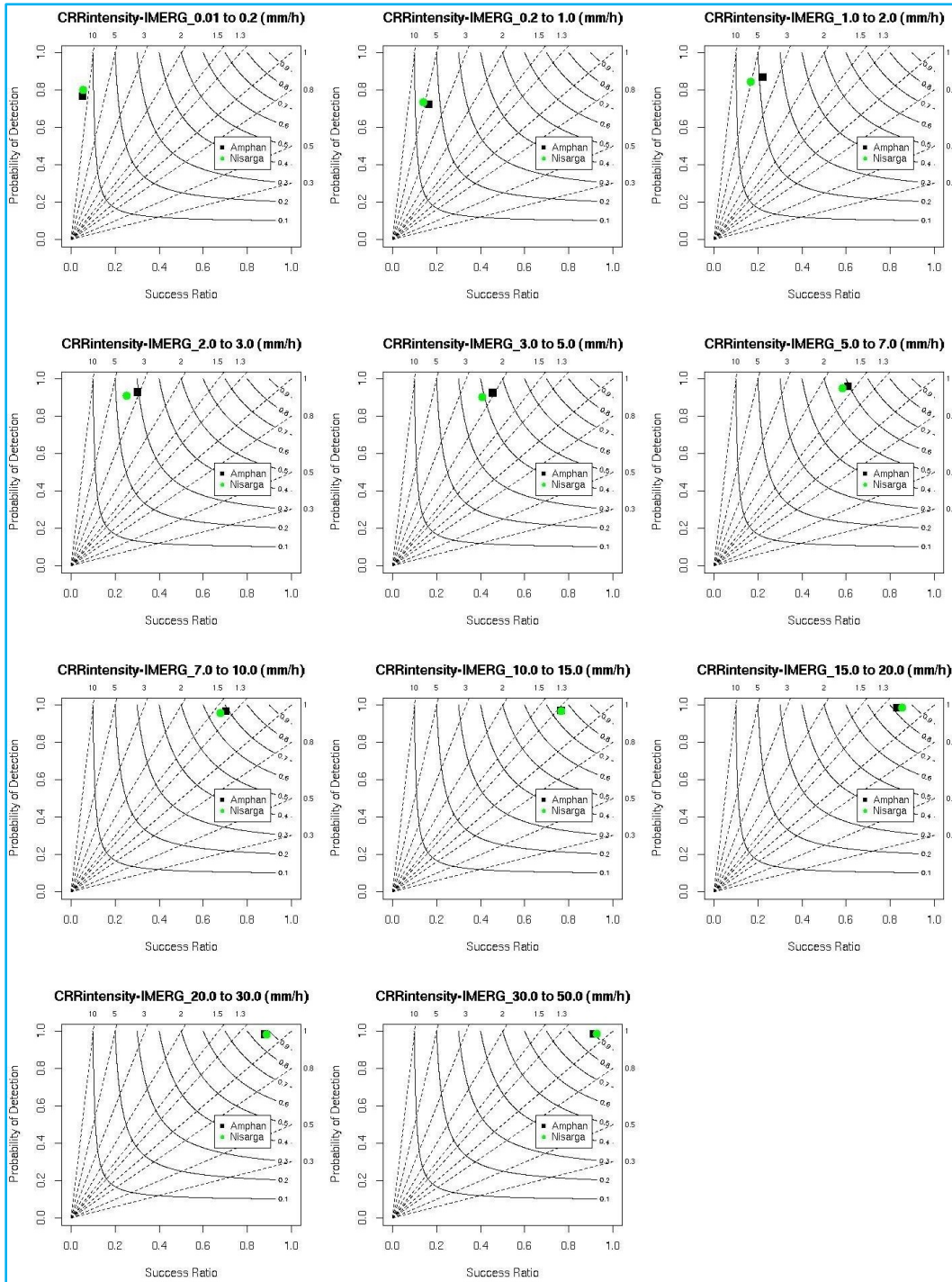
Fig. 4. Performance diagram for validation of CRR with IMERG precipitation data in 11 categories. Dashed lines represent bias scores with labels on the outward extension of the line, while labeled solid contours are CSR

single plot which is used to understand the accuracy of the rainfall estimations (Roebber, 2009). Initially, this analysis has been carried between IMERG and CRI data based on the IMD instantaneous rainfall categories (IMD, 2015) and the results are found in Fig. 3.

Fig. 3 represents the performance diagram based on IMD classification (Table 2). The POD, SR and CSI are poor in the light spell categories as expected. The CSI value is very low even if it's estimated value is not in the range (0-10 mm/h). And the POD, SR, CSI values are

high in the Moderate, Intense, Very Intense spell precipitation cases. The CRI product mainly works on the IR and water vapour channels. So, the CRR itself estimates more precipitation in convective rain clouds.

Further, in order to find out accuracy in Light spell precipitation category, we carried another classification based on default CRR categories (listed in Table 1). Fig. 4 shows good agreements in the lower precipitation conditions also. The SR is low indicating the higher FAR.

5. Conclusions

The CRR product algorithm from NWC_SAF GEO-CRR v4.0.1 based on Meteosat-8 (IODC) multi channel information is in very good agreement for the moderate, intense, very intense spell precipitation categories in cyclone period. The major drawback in the light spell is due to the lack of detection of stratiform clouds which causes low amounts of rainfall far away from the center of the cyclone. Also the spatial coverage of rainfall detection is low in case of CRR. The results show that CRR product is reliable and can be used in near real time analysis of rainfall in case of cyclones.

References

Dybbroe, A., Karlsson, K. G. and Thoss, A., 2005, "NWCSAF AVHRR cloud detection and analysis using dynamic thresholds and radiative transfer modeling. Part II: Tuning and validation", *J. Appl. Meteorol.*, **44**, 1, 55-71. doi : 10.1175/JAM-2189.1.

Hong, Y., Kummerow, C. D. and Olson, W. S., 1999, "Separation of Convective and Stratiform Precipitation Using Microwave Brightness Temperature", *J. Appl. Meteorol.*, **38**, 1195-1213.

https://doi.org/10.1175/1520-0450(1999)038<1195:SOCASP> 2.0.CO;2.

Huffman, G. J., Bolvin, D. T., Braithwaite, D., Hsu, K., Joyce, R., Kidd, C., Nelkin, E. J., Sorooshian, S., Tan, J. and Xie, P., 2019, "NASA Global Precipitation Measurement (GPM) Integrated Multi-Satellite Retrievals for GPM (IMERG)", NASA Algorithm Theoretical Basis Doc., version 06, 38 pp., https://pmm.nasa.gov/sites/default/files/document_files/ IMERG_ATBD_V06.pdf.

Johny, C. J., Singh, S. K. and Prasad, V. S., 2019, "Validation and Impact of SCATSAT-1 Scatterometer Winds", *Pure Appl. Geophys.*, **176**, 2659-2678. doi : 10.1007/s00024-019-02096-5.

Prasad, V. S., Johny, C. J., Mali, P., Singh, Sanjeev Kumar and Rajagopal, E. N., 2017, "Global retrospective analysis using NGFS for the period 2000-2011", *Curr. Sci.*, **112**, 2, 370-377. doi : 10.18520/cs/v112/i02/370-377.

Rani, S. I., Das Gupta, M., Sharma, P. and Prasad, V. S., 2014, "Intercomparison of Oceansat-2 and ASCAT Winds with In Situ Buoy Observations and Short-Term Numerical Forecasts Intercomparison of Oceansat-2 and ASCAT winds with *in situ* Buoy Observations and Short-Term Numerical Forecasts", *Atmos. - Ocean*, **52**, 92-101. doi : 10.1080/07055900. 2013.869191.

Roca, Rémy, Brogniez, Hélène, Chambon, Philippe, Chomette, Olivier, Cloché, Sophie, Gosset, Marielle E., Mahfouf, Jean Francois, Raberanto, Patrick and Viltard, Nicolas, 2015, "The Megha-Tropiques mission : a review after three years in orbit", *Earth Sci.* https://doi.org/10.3389/feart.2015.00017.

Roebber, P. J., 2009, "Visualizing Multiple Measures of Forecast Quality", *Weather Forecast*, **24**, 601-608. doi : 10.1175/2008 WAF2222159.1.

Sharifi, E., Steinacker, R. and Saghafian, B., 2016, "Assessment of GPM-IMERG and other precipitation products against gauge data under different topographic and climatic conditions in Iran: Preliminary results", *Remote Sens.*, **8**, p2. doi : 10.3390/rs 8020135.

Sridevi, C., Singh, K. K., Suneetha, P. and Durai, Vairamuthu R, 2019, "Rainfall forecasting skill of GFS model at T1534 and T574 resolution over India during the monsoon season", *Meteorol. Atmos. Phys.*, **132**, 1, 35-52. doi : 10.1007/s00703-019-00672-x.

Tremblay, A., 2005, "The Stratiform and Convective Components of Surface Precipitation", *J. Atmos. Sci.*, **62**, 1513-1528. https://doi.org/10.1175/JAS3411.1.

Vicente, G. A., Davenport, J. C. and Scofield, R. A., 2002, "The role of orographic and parallax corrections on real time high resolution satellite rainfall rate distribution", *Int. J. Remote. Sens.*, **23**, 2, 221-230. doi: 1ta0.1080/01431160010006935.

Vicente, G. A., Scofield, R. A. and Menzel, W. P., 1998, "The Operational GOES Infrared Rainfall Estimation Technique", *Bull. Am. Meteorol. Soc.*, **79**, 9, 1883-1893. doi : 10.1175/1520-0477(1998)079<1883:togire>2.0.co;2.