



Comparative analysis of sub-division wise rainfall INSAT-3D vs. Ground based observations

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सार – दक्षिण-पश्चिम मानसून ऋतु में वर्षा की निगरानी और मापन दोनों ही बहुत महत्वपूर्ण और कठिन कार्य हैं। यह मुख्य रूप से महत्वपूर्ण है क्योंकि यह कृषि के लिए वरदान, सामाजिक और आर्थिक दोनों गतिविधियों के लिए भविष्य का आड़ना है और इसका मापन (जमीन और दुर्गम स्थान) कठिन है। इस वर्तमान कार्य में लेखकों ने हाल ही में अंतरिक्ष अनुप्रयोग केंद्र (SAC), इसरो द्वारा विकसित इन्सैट -3 डी के कार्यों को जानने का प्रयास किया है, जिसमें प्रत्येक उपखंड के लिए उन्नत वर्षा एल्गोरिदम (हाइड्रो अनुमानक और संशोधित आईएमएसएआरए) के साथ भूमि पर वास्तविक वर्षा आंकड़ों की अभिनति (वास्तविक उपग्रह) द्वारा गणना की गई है। भारतीय अधिकार क्षेत्र के प्रत्येक उपखंड के लिए साप्ताहिक, मासिक और ऋतुनिष्ठ अभिनति की गणना करके दक्षिण-पश्चिमी मानसून ऋतु -2021 के लिए विश्लेषण किया गया है। यह देखा गया है कि दोनों एल्गोरिदम वास्तविक डेटा के साथ एक समान तरीके से व्यवहार करते हैं (दोनों एक साथ वृद्धि या कमी प्रदर्शित करते हैं) और ज्यादातर उपग्रह में वास्तविक डेटा ~20-40 मिमी अधिक आकलन होता है। कुछ उपखंडों में, अभिनति 40-70 मिमी (कोंकण और गोवा को छोड़कर) की सीमा तक पहुंच गया। लगभग 40% उपखंडों में 0 से 20 मिमी की सीमा के भीतर अभिनति होता है, हालांकि साप्ताहिक, मासिक या ऋतुनिष्ठ भिन्नता उपखंड और परिमाण के अनुसार भिन्न होती है। दोनों एल्गोरिदम साप्ताहिक, मासिक और ऋतुनिष्ठ संचित वर्षा मानों के प्रवृत्तियों को दर्शाते हैं और अच्छा प्रदर्शन करते हैं। संशोधित IMSRA (IMC) एल्गोरिदम मॉनसून सीजन -2021 के दौरान भारी वर्षा की घटना को छोड़कर थोड़ा बेहतर (15-20%) प्रदर्शन किया है। भारी और बहुत भारी वर्षा दोनों ही स्थितियों में हाइड्रो एस्टिमेटर्स विशेष रूप से पर्वतीय क्षेत्रों में आईएमसी एल्गोरिथम की तुलना में बेहतर (~ 10-12%) प्रदर्शन किया है। अत्यधिक भारी वर्षा के मामलों में दोनों एल्गोरिदम एक ही तरीके से व्यवहार करते हैं और परिघटनाओं को पकड़ते हैं, हालांकि यह परिमाण के अनुसार भिन्न होता है। मानसून 2021 को वर्षा के ऋतुनिष्ठ विश्लेषण से पता चलता है कि 8 उपखंडों में 50-60 मिमी की सीमा में ऋणात्मक अभिनति हैं और 24 उपखंडों में 0-20 मिमी की सीमा में नकारात्मक अभिनति हैं, कोंकण और गोवा को छोड़कर, तटीय कर्नाटक और अंडमान और निकोबार द्वीपों में धनात्मक अभिनति हैं। इसलिए, वास्तविक प्रेक्षण वर्षा मापन नेटवर्क को मजबूत करने और बड़े डेटासेट के साथ एल्गोरिदम के प्रदर्शन की फिर से जांच करने की आवश्यकता है ताकि बदलते परिदृश्य के अनुसार वर्तमान एल्गोरिदम को फिर से ट्यून किया जा सके।

ABSTRACT. Rainfall monitoring and measurement during the south west monsoon season both are very important and crucial activities. It is important mainly because it is a boon for agriculture, a mirror for future for both social and economic activities and crucial for its measurements (ground as well as remote). In this current works authors made an attempt to know the performance of recently Space Application Centre (SAC), ISRO developed INSAT-3D improved rainfall algorithms (Hydro Estimator and corrected IMSARA) with actual ground based rainfall data by calculating the bias (Actual - Satellite) for each sub-division. The analysis is done for the southwest monsoon season - 2021 in by calculating weekly, monthly and seasonal bias for each sub-divisions of Indian domain. It is seen that both the algorithms behave in a similar fashion (both show increase or decrease, simultaneously) with actual data and mostly satellite have overestimation with actual data ranges from ~ 20-40 mm. In some sub-divisions, bias reached within the range 40 -70 mm (except Konkan & Goa). Almost 40 % of the sub-divisions have bias within 0 to 20 mm range, however

the variation on weekly, monthly or seasonal differs subdivision and magnitude-wise. Overall, both the algorithms capture and perform well the trends in weekly, monthly and seasonal accumulated rainfall values. Corrected IMSRA (IMC) algorithms perform slightly better (15-20 %) except heavy rainfall episodes during the monsoon season -2021. In both the heavy and very heavy rainfall cases Hydro Estimators pick up well and perform better (~ 10 -12 %) than the IMC algorithm especially over orographic areas. In extremely heavy rainfall cases both the algorithms behave in the same manner and capture the events although it is differing magnitude wise. Seasonal analysis of monsoon 2021 rainfall shows that 8 sub-divisions have negative biases in the range of 50-60 mm) and 24 sub-divisions have negative biases in the range of 0-20 mm, except Konkan & Goa, Coastal Karnataka & A & N Islands have positive biases. Therefore, there is need to strengthen the actual observation rainfall measuring network and re-examine the performance of algorithms with larger datasets so that current algorithms re-tuned as per changing scenario.

Key words – INSAT Multispectral Rainfall Algorithm (IMSRA), IMC, INSAT-3D, Meteorological Sub-divisions.

1. Introduction

India is an agricultural country and more than 80 % of the population lives in Rural India and mainly depends on agriculture. Agriculture is the backbone of the Indian economy and it is the source of employment of approximately 58 % labour and up to 20 % contribution in Gross Domestic Product (GDP) of India based on the Economic Survey 2020-2021 (web-link). Monsoon rainfall from June to September is the boon for the Indian economy and farmers. Many Government activities like budget allocations, schemes, new policies, subsidies, crop plans etc. depend on the monsoon rainfall distribution. The uneven distribution of rainfall is a major concern of the Government and the livelihood of farmers and other end users of the society.

Many schemes were initiated by the government of India to improve the agriculture sectors like Krishi UDAN 2.0 scheme in October 2021 at 53 airports in India especially for Northeast and tribal regions. The scheme proposes assistance and incentive for movement of agri-produce by air transport. The Prime Minister of India launched 35 new crop varieties in September-2021 which are climate resilience and higher nutrient content and Union Ministry of Agriculture distributed about 83 lakh seed kits to the farmers.

The progress of Agriculture mainly depends on the monsoon rainfall during June to September months every year. India Meteorological Department (IMD) is the nodal agency for long range forecasts of monsoon during the month of April and end of May every year. Rainfall data is collected through a dedicated network of rain gauges, Automatic Weather Stations owned by the IMD and other state agencies. This actual data is collected and compiled throughout the year. Other Central agencies like Central Water Commission (CWC) also utilize this data along with their own river basin data to provide the forecast for river basin and such allied sectors. To increase the accuracy in the forecast with sufficient lead time as per the requirements of type weather event a dense network of observations is required. In most of the land areas like

rugged terrain, hilly regions are still data sparse regions. Therefore other recent advancements in sources of Radar and Satellite remote sensing data play an important role in increasing the accuracy of prediction. In this current work authors have made an attempt to utilize both the ground as well Satellite based estimates as an exercise of subdivision wise validation of satellite data for the year 2021 Monsoon.

It is known that INSAT-3D estimates are advantageous, because it can provide data on places where the ground observations do not present. However, in general, the INSAT-3D/3R based estimates data contain bias, as they are estimated through algorithms that transform the sensor's response into quantitative rainfall values. Other possibilities of INSAT estimates may come from the number of ground observations used by the algorithms as the reference in determining the rainfall values.

World over during last few years synergetic rainfall estimates data sets based on both (Infrared and Microwave) polar as well as Geostationary Satellite in a high spatial and temporal frequency domain are generated to monitor tropical rainfall events (Adler and Negri, 1988, Adler *et al.*, 1994; Todd *et al.*, 2001; Gairola and Krishnamurti 1992; C. Kidd *et al.*, 2003; Espinoza and Harshvardhan, 1996; Ferraro and Marks, 1995; Cheng and Collier, 1993; Joyce *et al.*, 2004).

It is known that land based observations of measuring the actual rainfall are not sufficient for global rainfall assessment as about 70% of the Earth is covered with water. Therefore, space borne measurement and monitoring of rainfall is essential to provide global coverage both on land and ocean in frequent intervals of time with quite high resolution.

Several other satellite based techniques are available in the literature based on the IR data (Gairola *et al.*, 2012; Gairola *et al.*, 2015; Bushair *et al.*, 2015) related to monsoon studies. Rainfall is highly variable throughout the globe (D. A. Vila *et al.*, 2009; Gruber *et al.*, 2000;

Houze, 2012; Huffman, *et al.*, 2001.). Satellite estimates based on Infrared techniques on the fact that precipitations are likely produced by the convection that is related to cold/bright clouds (C Prigent, 2010). With the recent technological developments of launching the newest generation of geostationary satellites world over, various rainfall estimation algorithms were coming up with gradual updates based on the feedback and comparison with actual occurrence of the rainfall. In the recent past developments in Geostationary satellite activities different algorithms were operationally active in estimation of rainfall like Geostationary Operational Environmental Satellite GOES-I-M series; (Vicente *et al.*, 1998; Ba *et al.*, 1998; Ba & Gruber, 2001) Lasmono, Risyanto Farid and Harjana Tehuh, 2021 for Himawari-8 Infrared Channels and METEOSAT Second Generation, MSG (Schmetz *et al.*, 2002). Other contributors (Cheng *et al.*, 1993,) in the past utilized visible (VIS) and infrared (IR) Imager's data for the rapid temporal update cycle needed to capture the growth and decay of precipitating clouds. Infrared channel based estimation for climatological studies are widely used by (Arkin, 1979; Arkin and Meisner, 1987; Arkin & Xie, 1994). Hydro Estimator (HE) method involves both convective as well as non-convective type of precipitation environment with suitable corrections /adjustment for wet dry environment, warm top modification along with orography with parallax corrections with the help of temperature dependent parameter suitable for Indian domain.

Singh *et al.*, 2018 validated INSAT-3D derived rainfall estimates (HE and IMSRA), GPM (IMERG) and GLDAS 2.1 model rainfall product with the gridded rainfall & NMSG data over IMD's meteorological subdivisions during monsoon season 2015-2016. The validation was performed at 10 km spatial resolution monthly basis and found reasonable with IMD gridded data sets at $0.25^\circ \times 0.25^\circ$ with correlation 0.81 and 179.52 with HE data sets and 0.87 and 105.13 mm respectively. This study is different in which actual area weighted rainfall observation collected daily basis at the Hydrology Division of IMD during the South West Monsoon is compared with wet pixel based average of INSAT-3D derived rainfall for both HE and modified IMSRA (now known as IMC) ISRO algorithms. However, there is always a need to develop a dense observational network to compare and validate the space observations with the actual rainfall which is often extremely variable over time and space.

Therefore rainfall estimates through satellite need validation before utilizing in operational weather forecasting or Numerical Weather Models. An attempt has been made in this work to validate INSAT - 3D sub-division wise rainfall estimate with actual rainfall data for

monsoon year 2021. The subsequent portions of the work are data and methodology results and discussion and references cited related to work. This study will be very useful to utilize the satellite derived rainfall products sub-division wise more judiciously in future.

2. Data and methodology

INSAT-3D/3R rainfall as well ground based rainfall data has been taken from India Meteorological Department (IMD), Mausam Bhawan, Lodi Road, New Delhi. INSAT - 3D/3R satellite datasets in HDF-5 format are generated operationally daily at satellite division, IMD by two different algorithms (developed by Space Application Centre, ISRO), Hydro-Estimator (HE), and Modified INSAT Multispectral Rainfall. These pixel wise data sets have 4.0×4.0 km resolution and are reprocessed sub-division wise through recently developed Python code Programme. To calculate the subdivision wise rainfall we have taken areal average of wet pixels for each pass and sub-division and then calculated total daily accumulated rainfall. From this reprocessed subdivision wise data sets for both satellite estimates we have generated accumulated weekly rainfall data sets as per the week's nomenclature at Hydrology division of IMD for the entire south west monsoon season-2021. Rainfall data sets, one based on actual ground observations (collected from Hydrology division, IMD) and other generated from INSAT-3D rainfall data sets were compared subdivision wise as weekly, monthly and seasonal basis. Both the data sets (actual as well as satellite) is divided into 17 weeks as per the hydrology division of IMD (03-06-21, 10-06-21, 17-06-21, 24-06-21, 01-07-21, 08-07-21, 15-07-22, 22-07-21, 29-07-21, 05-08-21, 12-08-21, 19-08-21, 26-08-21, 02-09-21, 09-09-21, 16-09-21 & 23-09-21). The daily rainfall data sets satellite data are generated as per IMD criteria. Then weekly and monthly and seasonal data sets have been generated for both satellites as well as actual observed rainfall data. For comparison purposes, bias (weekly, monthly and seasonal) for each meteorological subdivision is calculated for the monsoon season 2021 (June to September-2021). The Bias is calculated of the actual and satellite data as per the formula given below:

$$\text{BIAS} = \frac{1}{N} \sum_{i=1}^N (Y_i' - Y_i)$$

where, Y_i and Y_i' are the real time subdivision-wise ground based actual data and INSAT-3D satellite based estimate respectively and N is the number of days.

At the sub-division boundary some of the pixels may lie in the boundary of the adjacent subdivision, then if it is partially filled ($\leq 25\%$) then it is rejected, otherwise based

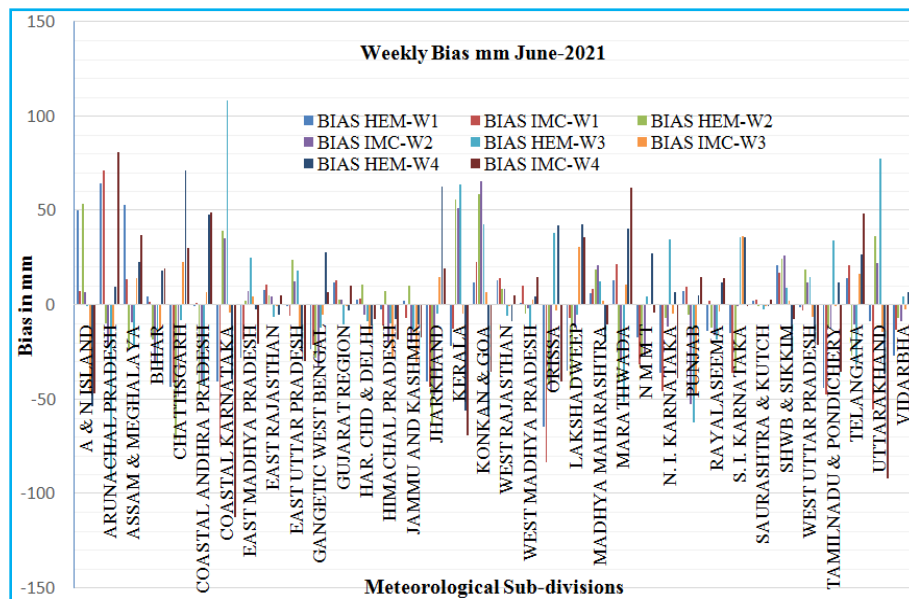


Fig. 1. Weekly bias in mm June-2021 (Actual vs. INSAT-3D)

on the area covered by the pixel (50 % or more) in other subdivision, it will be counted in other sub-division.

3. Result and discussions

Keeping the special importance of Indian Summer Monsoon Rainfall which is an average of about 125 cm annual rainfall of the country & more than 75% of the annual rainfall is received in the four rainy months of June to September. Real time monitoring of rainfall data from all ground observing stations is of prime importance for agricultural, irrigation operations including government policy decisions, country's revenue and relief works.

INSAT-3D satellite derived rainfall estimated from HE and IMC method are compared with actual rainfall data of Daily Rainfall Monitoring System (DRMS) network received at IMD in terms of weekly, monthly and seasonal biases for all the 36 sub-divisions of India.

In modified IMSRA or IMC retrieval, the environmental correction factor module has been dropped as it is adding more errors due to different de-correlation lengths of rainfall and relative humidity & precipitable water. Orographic correction (or Global bias correction) is added and computed on the basis of a climatological ratio bias between IMSRA and TRMM-3B42 for the orographic regions. It is seen from the study that both the algorithms behave in the similar manner, if one picks up the rainfall values on higher sides than other algorithms also pick up the same, although magnitude wise it is different. In General, if the rainfall is organized and

continues for many hours or even days then this continuity is well captured by IMC better than HE. But in case of heavy rainfall episodes HE performs better than IMC in most cases. This is seen in high weekly rainfall cases in this study.

3.1. Weekly analysis

Figs. (1-4) represents the weekly rainfall biases during the months of June, July, august and September-2021. During the first week of June (03-09) 8 Sub-divisions (A & N Islands, Arunachal Pradesh, Assam & Meghalaya, Chhattisgarh, Coastal Karnataka, Jharkhand, Orissa, Tamilnadu and Puducherry) have biases in the range of \pm (40 to 70 mm) and other 28 sub-divisions \pm (0 to 20 mm) for both the algorithms (Fig. 1). During second week of June (10-16) 6 sub-divisions (A & N Islands, Chhattisgarh, Coastal Andhra Pradesh, Jharkhand, Orissa, and Lakshadweep) have biases in the range of \pm (40-70 mm), 5 sub-divisions \pm (20-40 mm) and 26 sub-divisions \pm (0-20 mm). During 3rd week of June (17-23) 6 sub-divisions (Coastal Andhra Pradesh, Coastal Karnataka, SHWB & Sikkim, NMMT and Uttarakhand) have biases in the range \pm (40-70 mm), 6 sub-divisions 20- 40 mm and 24 sub-divisions 0-20 mm) and similarly on 4th Week of June (24-30) 7 sub-divisions have \pm (40-70 mm), 2 sub-divisions \pm (20-40 mm) and 27 sub-divisions \pm (0-20 mm) ranges of biases with the actual DRMS data of IMD (Fig. 1).

During the month of July, up to 13th July-2021 the monsoon advanced throughout the country (India). The

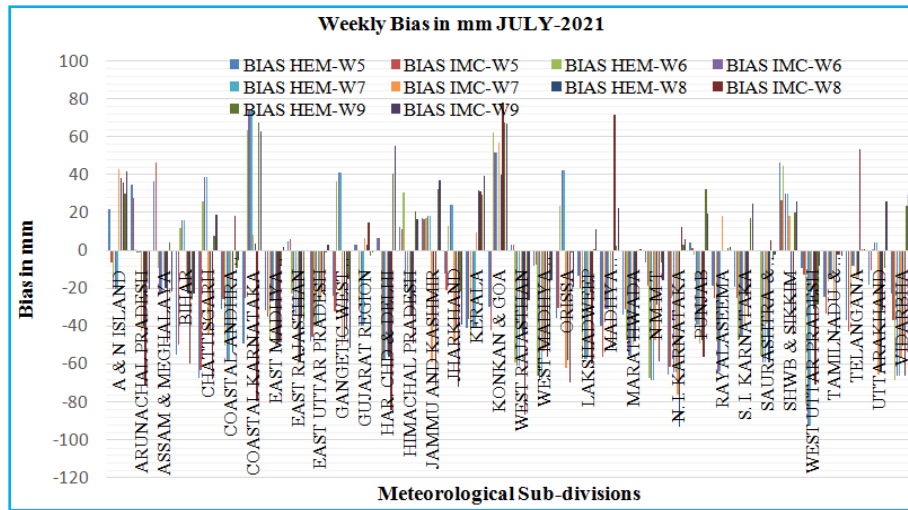


Fig. 2. Weekly bias in mm July-2021 (Actual vs. INSAT-3D)

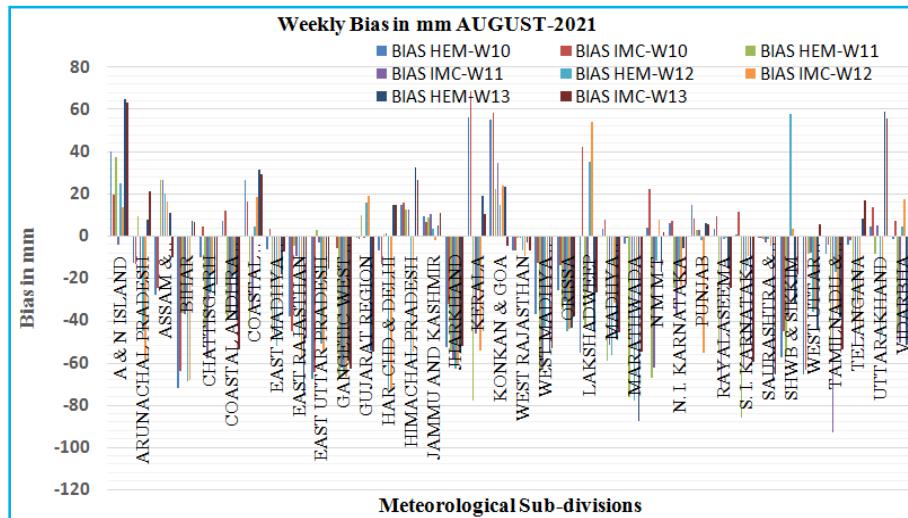


Fig. 3. Weekly bias in mm August-2021 (Actual vs. INSAT-3D)

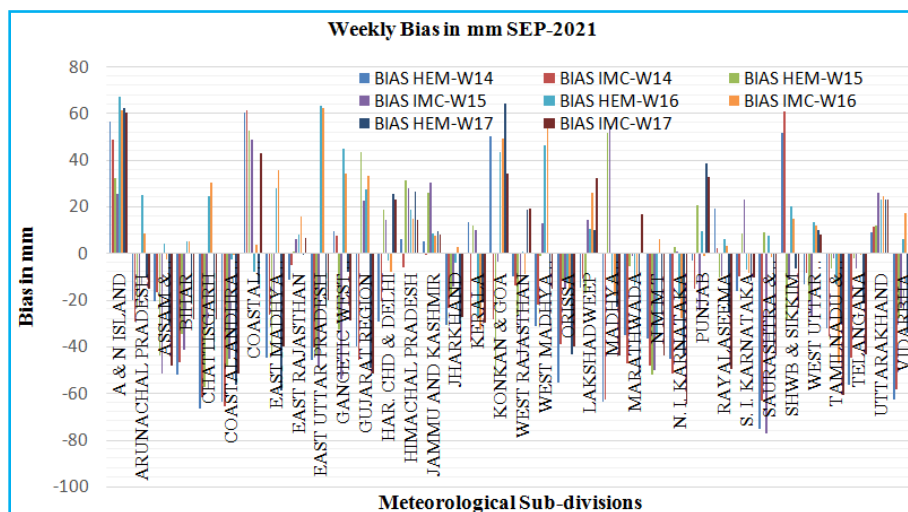


Fig. 4. Weekly bias in mm September-2021 (Actual vs. INSAT-3D)

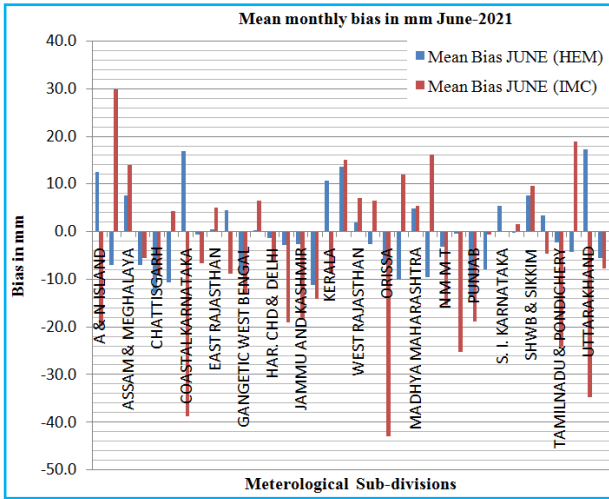


Fig. 5. Mean monthly bias in mm June-2021 (Actual vs. INSAT-3D)

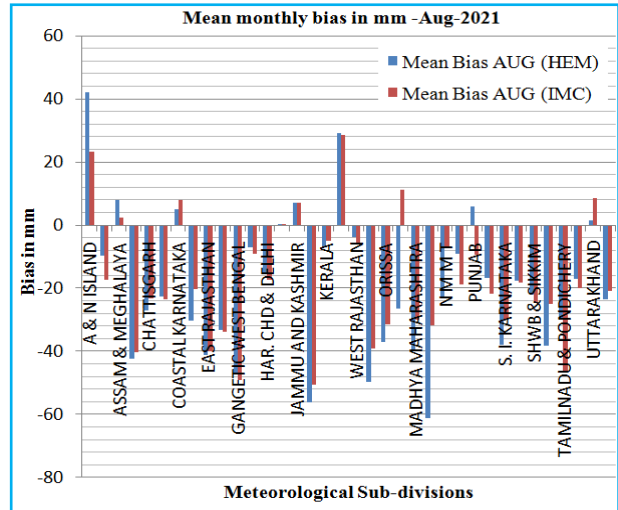


Fig. 7. Mean monthly bias in mm August-2021 (Actual vs. INSAT-3D)

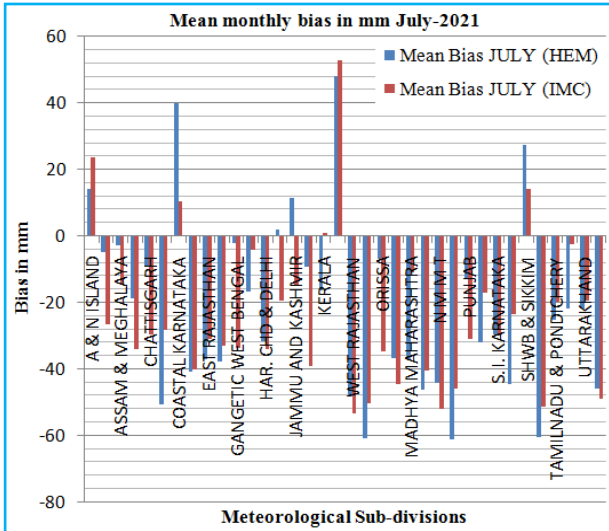


Fig. 6. Mean monthly bias in mm July-2021 (Actual vs. INSAT-3D)

South West monsoon activities progresses mostly in surges accompanied with hiatus in between. Therefore, in association with the continued prevalence of moist easterly winds from the Bay of Bengal in the lower tropospheric levels, enhanced cloud cover and scattered to fairly widespread rainfall activity into most parts of Rajasthan, Punjab, some more parts of Haryana and West Uttar Pradesh on 12th July after a hiatus period. These periods are well captured by both the satellite derived estimate algorithms (Fig. 2). During the 5th Week of July (25th June -1st July) 7 sub-divisions have biases in the range of \pm (40-70 mm), 10 sub-divisions in \pm (20-40 mm) and 19 sub-divisions in \pm (0-20 mm). In 6th Week of July (2-7) there are 13 sub-divisions \pm (40-70 mm), 11 sub-divisions \pm (20-40 mm) and 12 sub-divisions \pm (0-20 mm) range. Seventh week of July (8-15) have 21 sub-divisions have biases \pm (40-70 mm), 4 sub-divisions \pm (20-40 mm)

and 11 sub-divisions (0-20 mm) ranges. Eight week of July (15-22) 23 sub-divisions have biases \pm (40-70 mm), 3 sub-divisions \pm (20-40 mm) and 10 sub-divisions \pm (0-20 mm) ranges. Ninth week of July (23 -29) has biases at 3 sub-divisions \pm (40-70 mm), 9 sub-divisions \pm (20-40 mm) and 24 sub-divisions \pm (0-20 mm). Rainfall occurrence during monsoon season were affected by many factors like position of the monsoon trough, Tibetan high, off shore vortices, Somali jet, low pressure systems in Bay of Bengal (BoB) or Arabian Sea and sometimes cyclonic activities during September like Gulab in BoB (04-08 September-21) and Shaheen over the Arabian Sea (30th September - 4th October-2021). These epochs are also captured by both the algorithms but differ in magnitude with actual rainfall data. For more realistic comparison modification in the current algorithms a dense rainfall monitoring ground based network is required.

During 10th week (30th July -5th August) 9, nil & 27 sub-divisions have biases in the range of \pm (40-70 mm), (20-40 mm) and (0-20 mm) respectively. In the 11th week of August (06-12) 14, 3 & 18 sub-divisions have biases in the range of \pm (40-70 mm), (20-40 mm) and (0-20 mm) respectively. In the 12th Week of August (13-19) 10, 1 & 25 sub-divisions have biases in the range of \pm (40-70 mm), (20-40 mm) and (0-20 mm) respectively. Similarly, 13th Week of August (20-26) 11, 1 & 24 sub-divisions have found biases in the range of \pm (40-70 mm), (20-40 mm) and (0-20 mm) respectively (Fig. 3). During the 14th Week (27th August -2nd September) 14, 2 & 22 sub-divisions have found biases in the range of \pm (40-70 mm), (20-40 mm) and (0-20 mm) respectively. In the 15th Week (3rd September -9th September) 7, 6 & 13 sub-divisions have found biases in the range of \pm (40-70 mm), (20-40 mm) and (0-20 mm) respectively. During 16th week

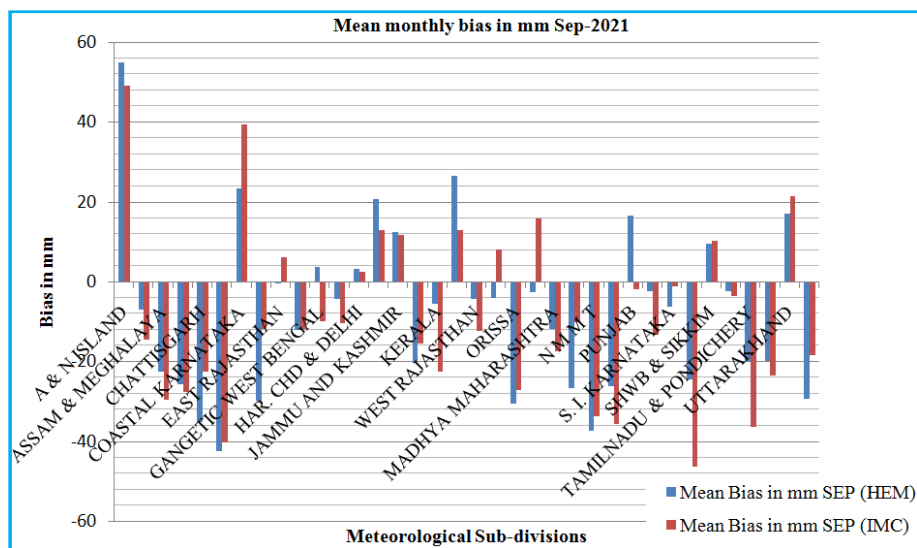


Fig. 8. Mean monthly bias in mm September-2021 (Actual vs. INSAT-3D)

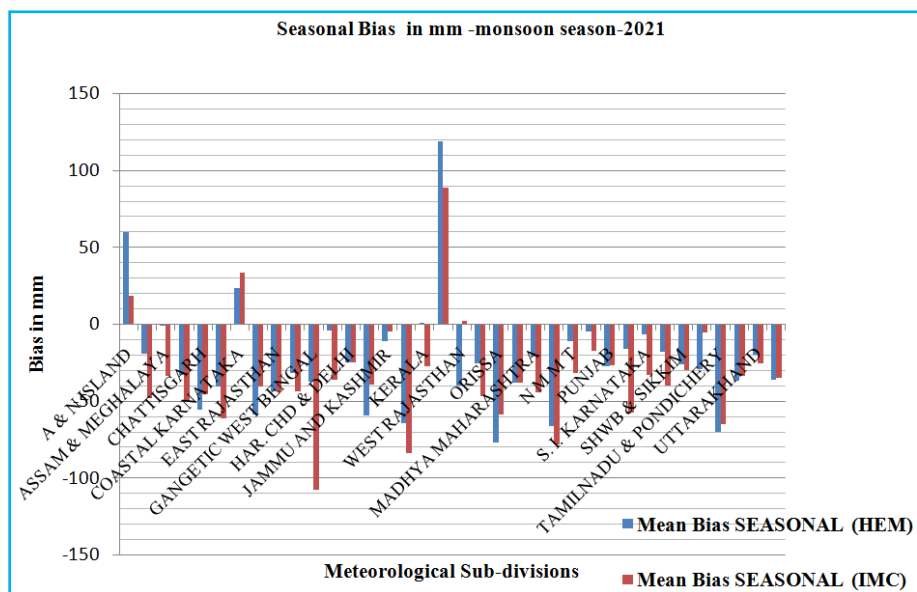


Fig. 9. Mean seasonal bias in mm July-2021 (Actual vs. INSAT-3D)

of September (10th -16th) 4, 5 & 27 sub-divisions have found the biases in the range of ± (40-70 mm), (20-40 mm) and 0-20 mm) respectively. During the last week of monsoon September (17th -23rd) 10, 9 & 17 sub-divisions have biases in the range of ± (40-70 mm), (20-40 mm) and (0-20 mm) respectively (Fig. 4). The weekly analysis shows that there is uniformity or consistency in the biases and almost all the sub-divisions behavior is different week by week. It shows the highly variable nature of the monsoon rainfall and its distribution is different both in magnitude and impact wise in the entire Indian domain.

3.2. Monthly analysis

Monthly biases from both the satellite algorithms are shown in Figs. 5, 6, 7 & 8 for the months of June, July, August and September respectively. During June month only 1 sub-division Orissa had bias in the range ± (40-70 mm) & 3, 32 sub-divisions had biases ± (20-40 mm) and 0-20 mm) respectively (Fig. 5). During July month 12, 18 & 6 sub-divisions have biases in the range ± (40-70 mm), (20-40 mm) and 0-20 mm) respectively (Fig. 6). In the August month 07, 18 & 11 sub-divisions have biases in the

range \pm (40-70 mm), (20-40 mm) and (0-20 mm) respectively (Fig. 7). During the month of September 1, 7 & 28 sub-divisions have biases in the range \pm (40-70 mm), (20-40 mm) and (0-20 mm) respectively.

3.3. Seasonal analysis

It is seen that satellite derived estimates for both the algorithms shows over estimation with actual observed rainfall values except 3 sub-divisions (Konkan & Goa, Coastal Karnataka & Andaman & Nicobar Islands). The biases with HE and IMC for these three sub-divisions have 108 mm, 23 mm 68 mm & 88 mm, 33 mm, 18 mm respectively. It shows that HE algorithm performance is better for the monsoon season-2021 as compared to IMC.

On the other hand IMC performed slightly better (~12-16%) in season for positive bias cases in most of the sub-divisions except Gangetic West Bengal (GWB) where IMC bias is of the order 107 mm. The possible reason may be orography and lack of dense networks. Overall seasonal analysis shows that 8 sub-divisions have negative biases in the range of 50-60 mm) and 24 sub-divisions have negative biases in the range of 0-20 mm (Fig. 9). Therefore, even though both the satellite algorithms capture monsoon rainfall occurrences well, there is a need to pursue more such studies in future so the issues related to Orography and unprecedented rainfall can be addressed better and accordingly the satellite algorithms can be tuned over Indian Domain. At the same time, there is a need to strengthen the ground based daily rainfall monitoring network to monitor and represent monsoon rainfall more realistically. The satellite precipitation estimate algorithms (HE and IMC) used in this work have advantages of the VIS and IR bands which include high spatial resolution as well as the possibility of frequent temporal sampling from Geostationary platforms. These techniques produce highly smoothed depictions of instantaneous rainfall fields and are found very useful only when averaged over larger space and/or time scales, and then only when carefully calibrated for the region and season. Therefore, sub-divisions which have larger spatial coverage perform better and have less bias than the smaller geographical domain. Ground based methods are also associated with errors in terms of sampling, measurement and estimation, therefore, the observed differences between INSAT-3D estimates and a ground based estimate can also be attributed to errors in both compared sensors. The ground based rain gauge data which is used to estimate mean areal rainfall accumulation in each observation is corrupted with measurement error, which is a function of gauge exposure, instrument type and, mainly, the wind speed. Therefore, each subdivision has biases with different magnitudes. In future, Radar based estimates along with satellite estimates may

improve the accuracy of the subdivision wise rainfall, although radar based techniques also have its own sources of errors and problems.

The current algorithms of HE and IMC have their own limitations especially during monsoon season where tropical/stratiform Mix categories clouds are present as compared to convective type of developments and with additional challenges in complex terrain regions (Kuligowski *et al.*, 2016). The accumulated rainfall values show more rain as compared to actual observed rainfall values in most of the sub-divisions during the entire monsoon season. The possible reason is twofold: One non availability of high dense rainfall measuring ground based network and second rainfall occurrence over a place is sometimes localized and not measured by any rain gauge network and this development is captured by the satellite. In an orographic area the rainfall process is modified by complex terrain characteristics and it is difficult to model such small scale processes which are mainly dependent on the large scale features embedded in induced localized circulations which sometimes produces unexpected rainfall and it may or may not be continuous in nature. To capture such epochs during monsoon season we need a high dense observation network as well as multispectral/hyper-spectral imaging with better orographic correction algorithms.

Both the satellite derived methods capture and perform well which are seen through the trends in weekly, monthly and seasonal accumulated rainfall values but have limitations over coastal as well as orographic regions. The behavior of both the algorithms is the same and captures well the rainfall episodes during the entire season. The sub-divisions where well defined persistent cloud development was seen performs better in IMC and the areas or sub-divisions where heavy rainfall was observed HE methods performs well. So, it was mixed behavior, no methods were perfect and representative of actual observed rainfall occurrences.

4. Conclusions

(i) This study is very useful to utilize the satellite derived estimates for those regions where rain gauge networks are less dense areas as supplement more realistically and this will further improve the decision of impact based forecasting.

(ii) Overall performance of both satellite estimates (HE & IMC) capture and perform well which are seen through the trend in weekly, monthly and seasonal accumulated rainfall values.

(iii) Most of the sub-divisions have overestimated rainfall with actual DRMS values; however rain gauge

measurements are also associated with uncertainties in their measurements. Therefore satellite based estimates can be used with proper biases, calculated in this work.

(iv) Weekly biases vary sub-division wise for each week and show both positive as well negative biases.

(v) Mean monthly biases during the months of June and September have both positive and negative bases (~50 % sub-divisions) except July and August. During the month of June the value of rainfall bias in case of IMC is more than HE algorithm. In the month of July, August and September no such trend in the biases is seen. Both the algorithms behave almost in the same manner.

(vi) Seasonal analysis shows that 8 sub-divisions have negative biases in the range of 50-60 mm) and 22 sub-divisions have negative biases in the range of 0-20 mm.

(vii) The strength and imitations of sub-division wise satellite derived estimates can be grouped based on this study and the same can be further retuned with large data sets of different year monsoon seasons.

(viii) Both the algorithms of INSAT-3D rainfall estimate produce highly smoothed depictions of instantaneous rainfall fields and are found very useful only when averaged over larger space and/or time scales, and then only when carefully calibrated for the region and season. Therefore, sub-divisions which have larger spatial coverage perform better and have less bias than the smaller geographical domain.

(ix) There will be observed differences between INSAT-3D estimates and a ground based estimate due to errors associated in the measurements of sampling and estimation for both compared sensors (ground vs remote).

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References

- Adler, R. F. and Negri, A. J., 1988, "A satellite infrared technique to estimate tropical convective and stratiform rainfall", *J. Appl. Meteorol.*, **27**, 30-51.
- Adler, R. F., Huffman, G. J. and Keehn, P. R., 1994, "Global tropical rain estimates from microwave-adjusted geosynchronous IR data", *Remote Sens. Rev.*, **11**, 125-152.
- Arkin, P. A., 1979, "The relationship between fractional coverage of high cloud and rainfall accumulations during GATE over the B-scale array", *Mon. Wea. Rev.*, **106**, 1153-1171.
- Arkin, P. A. and Xie, P., 1994, "The Global Precipitation Climatology Project: First algorithm intercomparison project", *Bull. Amer. Meteor. Soc.*, **75**, 401-419.
- Arkin, P. A. and Meisner, B. N., 1987, "The relationship between large-scale convective rainfall and cold cloud over the western hemisphere during 1982-84", *Mon. Wea. Rev.*, **115**, 1, 51-74.
- Ba, M. B. and Gruber, A., 2001, "GOES Multispectral Rainfall Algorithm (GMSRA)", *J. Appl. Meteorol.*, **40**, 1500-1514.
- Ba, M. B., Rosenfeld, D. and Gruber, A., 1998, "AVHRR multispectral derived cloud parameters : relationship to microwave scattering signature and to cloud-to-ground lightning", Prepr. 9th Conf. Satellite Meteorology and Oceanography, AMS, 408-411.
- Barrett, E. C. and D. W. Martin, 1981 : The Use of Satellite Data in Rainfall Monitoring. Academic Press, p340.
- Bushair M. T., Mahesh, C. and Gairola R. M., 2015, "Assessment of Kalpana-1 Rainfall product over Indian Meteorological Sub-Divisions during the Summer Monsoon Season", *Journal of Indian Society of Remote Sensing*, 2015
- C. Kidd, Kniveton, D. R., Todd, M. C. and Bellerby, T. J., 2003, "Satellite Rainfall Estimation Using Combined Passive Microwave and Infrared Algorithms", *Journal of Hydrometeorology*, **4**, 1088-1104.
- Cheng, M., Brown, R. and Collier, C. G., 1993, "Delineation of precipitation areas using METEOSAT infrared and visible data in the region of the United Kingdom", *J. Appl. Meteorol.*, **32**, 884-898.
- C. Prigent, 2010, "Precipitation retrieval from space: An overview", *Comptes Rendus Geoscience*, **342**, 380-389.
- Espinoza, R. C., Jr. and Harshvardhan, 1996, "Parameterization of solar near-infrared radiative properties of cloudy layers", *J. Atmos. Sci.*, **53**, 1559-1568.
- Ferraro, R. R. and Marks, G. F., 1995, "The development of SSM/I rain-rate retrieval algorithms using ground-based radar measurements", *J. Atmos. Oceanic Technol.*, **12**, 755-770.
- Gairola, R. M. and Krishnamurti, T. N., 1992, "Rain rates based on SSM/I, OLR and rain gauge data sets", *Meteorol. Atmos. Phys.*, **50**, 165-174.
- Gairola, R. M., Prakash, S. and Mahesh, C., 2012, "Synergistic use of Kalpana-1 and raingauge data for rainfall estimation : A case study over Gujarat", Workshop on Meteorological Satellite Kalpana : A decade of Service to the Nation. Ahmedabad, India, October 2012.
- Gairola, R. M., Prakash, S. and Pal, P. K., 2015, "Improved rainfall estimation over the Indian monsoon region by synergistic use of Kalpana-1 and rain gauge data", *Atmósfera*, **28**, 1, 51-61.

- Gruber, A., Su, X., Kanamitsu, M. and Schemm, J., 2000, "The comparison of two merged rain gauge-satellite precipitation datasets", *Bull. Am. Meteorol. Soc.*, **81**, 2631-2644.
- Houze R. A. Jr. and Houze R. A. Jr., 2012, "Orographic effects on precipitating clouds", *Reviews of Geophysics*, **50**, RG1001, doi:10.1029/2011RG000365.
- Huffman, G. J., Adler, R. F., Morrissey, M. M., Bolvin, D. T., Curtis, S., Joyce, R., McGavock, B. and Susskind, J., 2001, "Global precipitation at one-degree daily resolution from multisatellite observations", *J. Hydrometeorol.*, **2**, 36-50.
- Joyce, R. J., Janowiak, J. E., Arkin, P. A. and Xie, P., 2004, "CMORPH: A method that produces global precipitation estimates from passive microwave and infrared data at high temporal and spatial resolution", *Journal of Hydrometeorology*, **5**, 3, 487-503.
- Kuligowski, Robert J., Li, Y., Hao, Y. and Zhang, Y., 2016, "Improvements to the goes-r rainfall rate algorithm", *J. Hydrometeor.*, **17**, 1693-1704. 10.1175/JHM-D-15-0186.1.
- Lasmono, Farid, Risyanto and Tehuh, Harjana, 2021, "Himawari-8 rainfall estimation from infrared channels based on machine learning methods", AIP Conference Proceedings 2366, 050004 (2021); <https://doi.org/10.1063/5.0060010>.
- Singh, Anil Kumar, Singh, Virendra, Singh, K. K., Tripathi, J. N., Kumar, Amit, Sateesh, M. and Peshin, S. K., 2018, "Validation of INSAT-3D derived rainfall estimates (HE & IMSRA), GPM (IMERG) and GLDAS 2.1 model rainfall product with IMD gridded rainfall & NMSG data over IMD's Meteorological Sub-divisions during monsoon", *MAUSAM*, **69**, 2, 177-192.
- Todd, M. C., Kidd, C., Kniveton, D. and Bellerby, T. J., 2001, "A combined satellite infrared and passive microwave technique for estimation of small scale rainfall", *Journal of Atmospheric and Oceanic Technology*, **18**, 5, 742-755. ([https://doi.org/10.1175/1520-0469\(2001\)058<0742:ACSIAP>2.0.CO;2](https://doi.org/10.1175/1520-0469(2001)058<0742:ACSIAP>2.0.CO;2))
- Vicente, G. A., Scofield, R. A. and Menzel, W. P., 1998, "The Operational GOES Infrared Rainfall Estimation Technique", *Bulletin of the American Meteorological Society*, **79**, 9, 1883-1898.
- Vila, D.A., Goncalves, L., G. G. D., Toll, D. L. and Rozante, J. R., 2009, "Statistical evaluation of combined daily gauge observations and rainfall satellite estimates over continental South America", *Journal of Hydrometeorology*, **10**, 533-543.
- Web links: <https://www.downtoearth.org.in/news/agriculture/agri-share-in-gdp-hit-20-after-17-years-economic-survey-75271>.

