Qualitative evaluation of the high resolution satellite precipitation products with dense surface rain gauge observations in Odisha over a time period

Abstract

The study aims to the Hydro-Estimator Method (HEM) has been used as the noble approach for analysing the heavy rainfall episodes over entire Odisha using the INSAT-3D satellite- derived rainfall estimates. The findings demonstrate that, in terms of the frequency of rainfall occurrences, INSAT-3D satellite rainfall products clearly illustrated both the spatial and temporal variability in rainfall pattern of Odisha. The performance statistics with IMERG and daily merged satellite retrieved rainfall show that both the dataset corelated well with the HEM with a small deviation. For heavy rainfall events, HEM shows good skill and correlation in detecting heavy rainfall with an accuracy of 20 mm and good pattern matching with actual rainfall. Entire Odisha is considered as study area, which is located in the eastern part of India. It comprises of 30 districts and of 314 blocks spreading over an area of 155707 km^2. The state has 30 districts, which are further divided into 314 revenue blocks. The rainfall data (1 year; 2016) for all the blocks of Odisha has been obtained from Special Relief Commissioner (SRC), Government of Odisha and subjected to further analysis process. The satellite derived rainfall estimates *viz.*, HEM, were evaluated with rain gauge based gridded data *viz.*, IMD-GRIDDED Dataset for the year 2016 over the Odisha region at the summer monsoon period. The satellite derived rainfall estimates HE have exhibited some good results with the IMD-GRIDDED Dataset its average R^2 on a daily basis for different blocks is 0.34 and on a monthly basis it is 0.44. RMSE has also been determined to different block for JJAS month. The average RMSE on daily basis is 17.7 and on monthly basis is 94.6 as shown in bias maps.

Keywords: *Daily merge satellite gauge (DMSG), Hydro-Estimator Method (HEM), INSAT-3D, precipitation,* Odisha**.**

1. Introduction

Normally precipitation is considered as one of the vital input data in different hydrologic models. Thus acquisition of more reliable and accurate precipitation data became highly essential for better hydrologic prediction and water resource management on local, regional and global scale. Traditionally, the acquisition of precipitation data is often limited to ground-based observations (using rain gauges and/or ground-based weather radars) although these surface-based observations usually suffer from low spatial coverage, especially in developing regions where ground-based observations are rare or even unavailable.

In recent years, different research groups showed keen interest in developing high resolution gridded rainfall data sets. (Huffman *et al*. 1997, Xie and Arkin 1997). For validating the same high resolution observed rainfall data are also required to examine and model the intra-seasonal oscillations like the Madden-Julian Oscillation (MJO) over the Indian region. Gridded rainfall data sets are beneficial for regional studies on the hydrological cycle, climate variability and evaluation of regional models. Keeping the above facts in view the present study is aimed to compare the most widely used global high-resolution satellite precipitation product HYDRO-ESTIMATOR (HE daily 0.1 degree resolution) with the dense rain gauge network observations and to verify the block level rainfall forecasting. Most of the studies on rainfall were on macro-scale and all India basis. However, not much studies have been made on a micro-scale (block level) for the states in general and Odisha in particular. Hydro Estimator (HE) rain rate at pixel level are estimated at half hourly basis using different algorithms. The daily, weekly and monthly accumulated rain fall for HEM and IMSRA product is also computed and disseminated operationally. The Hydro-Estimator (H-E) is a high spatial and temporal scale rain estimation technique which was initially developed by NOAA for GOES. It is remodeled and applied to INSAT-3D satellite observations. The H-E method operational with INSAT-3D uses Imager thermal 4 infrared observations (at 10.7 µm) along with environmental parameters taken from Numerical Weather Prediction (NWP) model. HE is closer to Actual Rainfall observations (Anil Singh et al 2015).

2. Methodology

2.1. Study Area

Entire Odisha is considered as study area, which is located in the eastern part of India. It comprises of 30 districts and of 314 blocks spreading over an area of 155707 km^2, and are bounded between 17˚49′ to 22˚31′ N latitudes and 81˚31′ to 87˚29′ E longitude. The state experiences a tropical climate, characterized by high temperatures, high humidity, medium to high rainfall and short and mild winters. Odisha has been divided into ten agroclimatic zones based on the climate type. The normal rainfall in the state is 1451.2 mm. About 75% to 80% of the total rainfall is received within June to September. The frequent visit of floods, droughts, and cyclones in almost every year in varying intensity registers (480 km) coastline that is prone to climate-mediated cyclones and coastal erosion. Odisha as this disaster capital of India because of its longer vulnerable to climate change. Agricultural lands are worst affected by hydro meteorological disaster like extreme rainfall, draught, cyclones, flood, heat waves, cold waves, tsunamis and earthquake.

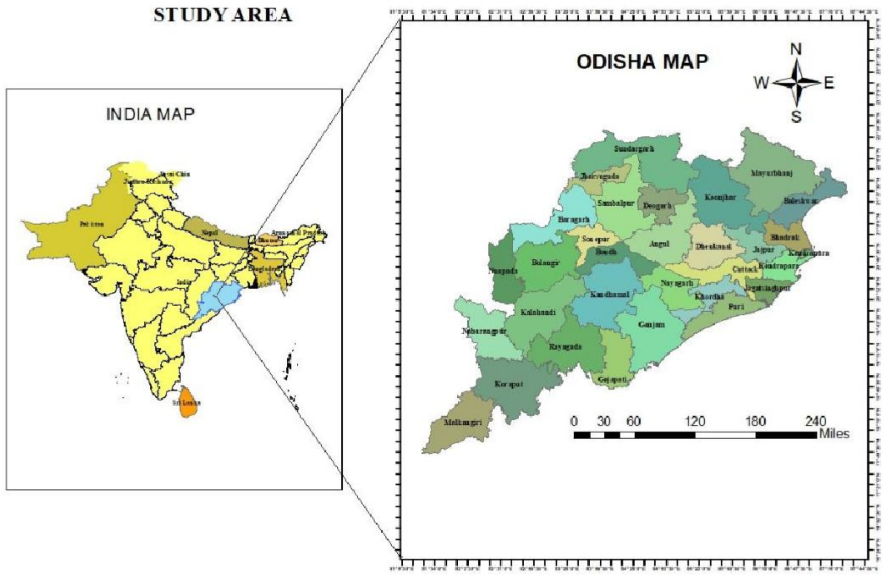

fig: 1 Map indicating the study area

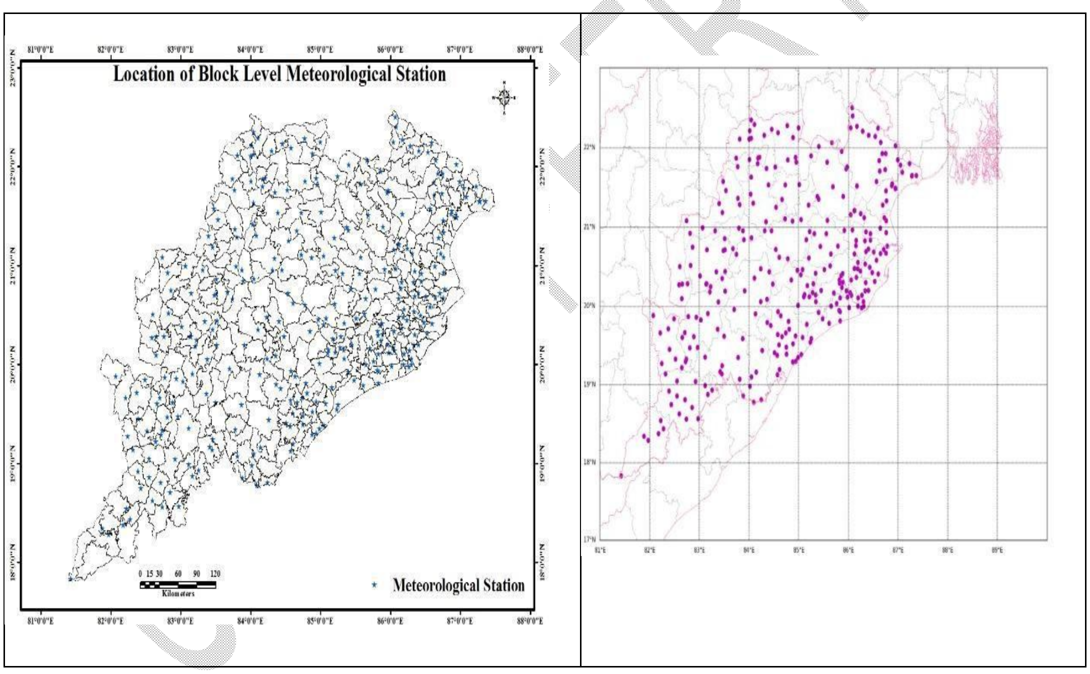

fig: 2 spatial distributions of all blocks of Odisha state

2.2. Nature and sources of data

The state has 30 districts, which are further divided into 314 revenue blocks. The rainfall data (1 year; 2016) for all the blocks of Odisha has been obtained from Special Relief Commissioner (SRC), Government of Odisha and subjected to further analysis process.

2.3. Data and Model Used

The Hydro-estimator (H.E) provides pixel-scale, half-hourly precipitation rate measurements over land and oceans. The algorithm was develop for the use of H.E based on IR cloud top temperatures, temperature variation and gradients to produce rainfall rate estimates along with NCEP/GFS parameters and an earth elevation model on a half -hourly basis. Rain is estimated dynamically for each pixel using different relationships between convective/ stratus types of cloud. The spatial and temporal resolution of the products are taken in half hourly duration at Pixel level. The dimension of this product is 81° S - 81° N and 3°-163° E, but for this study the daily rainfall estimate accumulated over the Odisha region is used for determining the monthly accumulated rainfall from MMDRPS, New Delhi. The description of HE algorithm can also found elsewhere in (Kumar and Varma, 2017). The algorithm had undergone major revision in 2015 in order to improve the orographic precipitation and modified algorithm was made operational from mid-August, 2015 (Varma et al., 2017).

2.4. NWP models used for verification of forecasting

The NWP models used in this study are primitive equation spectral global models with state-of-the-art dynamics and physics (Kanamitsu, 1989) that are adopted from the National Centre for Environmental Prediction (NCEP). This GFS model confirmed to a dynamical earth system modelling framework (ESMF) and its code was restructured to exercise many options for the updated dynamics and physics. The physics and dynamics option of the GFS model used in this study at T574L64 resolution is shown in Table 1.

The GFS T574L64 (~ 25 km horizontal over the tropics) suggested by Durai et al. 2011 was implemented at IMD New Delhi in IBM-based high-performance computing systems (HPCS). The GFS T574 model is developed basing on the Eulerian dynamical framework. The assimilation system for GFS T574 is a global three-dimensional variational technique, based on the NCEP grid point statistical interpolation (GSI 3.0.0) scheme (Kleist et al. 2009), which is the next generation of spectral statistical interpolation (SSI). The details about this model are discussed in the study made by Durai and Bhowmik (2014). The GFS-T1534L64 at ~ 12 km in horizontal resolution and in the vertical there are 64 hybrid sigma-pressure layers with the top layer centred around 0.27 hPa (~ 55 km) runs operationally on ADITYA HPCS twice a day (00 and 12 UTC) at Indian Institute of Tropical Meteorology (IITM), Pune since 1st

December 2016 to give deterministic forecast in the short to medium range. The initial conditions for the GFS model until 30th June 2016 were generated from the NCEP-based global three-dimensional variational (3D-VAR) Grid point Statistical Interpolation (GSI 3.0.0) scheme and subsequently from 1st July 2016, from the NCEP-based ensemble Kalman filter (EnKF) component of hybrid global data assimilation system (GDAS) run on BHASKARA HPCS at the National Centre for Medium Range Weather Forecasting (NCMRWF).

2.5. Comparison of HE with observation data

For the 2016 monsoon season, HE is brought at 0.1° resolution using a Box averaging interpolation scheme. The daily cumulative rainfall products are used to determine the monthly accumulated rainfall of HE products. Using monthly accumulated rainfall estimate products, IMD subdivision wise rainfall maps and bias map with IMD rainfall gridded/NMSG rainfall dataset are prepared for all these rainfall products individually and statistical analysis is carried out in terms of R^2 and RMSE. Using these values, scatter plots are generated on a monthly and seasonal basis over the Odisha region. For each rainfall product, a line graph is plotted and the zonal monthly accumulated mean is determined on a sub-divisional basis.

- **STEPS**

1. We recorded INSAT 3D HEM data in geo tiff format.
2. Extraction of the block shape files of Odisha.
3. Masking of extracted shape file with INSAT 3D HEM data.
4. Removal of blocks which do not have HEM data.
5. Zonal statistics are prepared.
6. Figure out the maximum, minimum, mean and standard deviation.

2.6. Verification of block level weather forecasting

In this study, the 3 hourly generated daily 24 h accumulated rainfall forecast (03 UTC of previous day to 03 UTC of forecast valid day) over the Odisha monsoon region from the GFS T574 model at 25 km resolution for 122 days from 1st June to 30th September 2016 were used for the day 1 and day 3 forecasts. The rainfall forecast verified for the 00 UTC model run against daily rainfall observations at the model resolution of 25 km. The daily observed gridded rainfall at 25 km resolution was collected from IMD's National

Data Centre (NDC), Pune and which were based on the merged rainfall data i.e. combining gridded rain gauge observations over the land areas and global precipitation measurement (GPM) satellite- estimated rainfall data over the sea areas using a successive correction algorithm (Durai et al. 2010; Mitra et al. 2014). The efficiency GFS at resolution is evaluated for day 1 to day 3 forecasts of rainfall in terms of several accuracy and skill measures.

2.7. Downscaling procedure

Several models with different resolution are used for forecasting various weather parameters for three, four and five days. A 25km resolution GCM(T-574) was used for forecasting of rainfall and cloud quantity for five days and three days forecast was done for other weather parameters by using 9km WRF model. For obtaining the forecast value of any weather parameters the regular grid point. Values are used depending on the distance of the location from the regular grid points. If the location is very near to a grid point the forecast value for the location can be consider as same as the grid point value but when it is away from the regular grid points the four grid points surrounding the station are considered. To obtain the forecast value at specific location the interpolated value from the four surrounding grid points are used. For validation of the forecasted values verification study was conducted for 278 blocks for which data was readily available leaving aside the rest of the blocks (38) of Odisha state, as the state for these blocks was not available. The skills for rainfall (Yes/No) rainfall are not so good for almost all the blocks and quick value addition for improving the skills of the forecast is required for some of the blocks. The details about the quick value addition and scope for improvement are given in the conclusion part of the paper.

3. Result and Discussion

3.1. Comparison of the most widely used global high-resolution Satellite precipitation product HYDRO-ESTIMATOR in detail with the dense rain gauge network observations.

Here, evaluation and comparison of global high-resolution Satellite precipitation product HYDRO-ESTIMATOR (HE daily 0.1 degree resolution) with dense surface rain gauge network observations for the 249 Blocks of Odisha region for June, July, August, and September of year 2016 are discussed as INSAT 3D HE are not available for rest of blocks.

Table: 1 Quantitative Precipitation Estimate

Quantitative Precipitation Estimate		
Product Name	**Spatial Resolution**	**Temporal Resolution**
Three ThreeDIMG_L2B_HEM	**Four km**	**Thirty minutes**

For the present analysis, it has been used the daily rainfall data archived at the MOSDOC, India Meteorological Department (IMD), Delhi. The INSAT 3D HE data is recorded in geo-tiff format. We removed blocks which do not have HE data. Zonal statistics are prepared. Then figure out the maximum, minimum, mean and standard deviation. Here only those blocks were included which have higher values of correlations.

3.2 Details about comparison and validation of HE for different blocks

The comparison of INSAT 3D HE rain products with rain gauge observed data has been done and determined the correlation and RMSE on a daily and monthly basis which are shown in fig 3a-l as a scatter plot. The HE shows good fit results as its average R^2 on a daily basis for different blocks is 0.34 and on a monthly basis it is 0.44. RMSE has also been determined to different block for JJAS month. The average RMSE on daily basis is 17.7 and on monthly basis are 94.6 as it is shown in the table 2.

Here we are discussing some blocks which having comparatively higher scores. Mame of the blocks which have shown a good R^2 on a daily basis are Kaptipada(0.5), Ghasipura (0.54), Basudebpur (0.66), Soro (0.54) and Tihidi (0.53). Some blocks having very good scores as their RMSE is higher (>25),those blocks are Jasipur, Jarigan, Joda, Kakatapur, Koida, Koraput, Kotpada, Kujang, Dashmantapur, Dhankauda, Balikuda, Binjharpur, Cuttuck, Lakshmipur, Lamptapur, Mohana, Nandahandi, Narayanapur, Narayanpatna, Nawarangpur, Aul, Pottangi, Rajkanika, Similiguda. We can say that these blocks having high skills for HE and rain gauge comparison, so INSAT 3D HE rainfall products can be further used without any value addition.

3.3. Verification of block level rainfall forecasting

The NCEP GFS run at IMD is a primitive equation spectral global model with state of art dynamics and physics (Kanamitsu, 1989; Kalnay*et al.*, 1990; Kanamitsu, *et al.*, 1991; Moorthi *et al.*, 2001, Durai *et al.*, 2010; Saha *et al.*, 2010). The GFS T574L64 (~25 km horizontal over the tropics), adopted by National Centre for Environmental Prediction (NCEP), was implemented at IMD, New Delhi.

The verification study was carried out for all the blocks for which data was available for 276 blocks and for the remaining, no data at block level could be obtained. The skill for rainfall is not so good for all the blocks. Hence, quick value addition is required for improving the skill of forecast for some of the blocks. Some of the blocks have negative correlation and some of the blocks have a positive correlation for both Day1 and Day 3.

Table 2: Block wise RMSE and correlation on a daily and monthly basis

S.No.	STATION	RMSE-daily	RMSE monthly	R^2 daily	R^2 monthly
1	Angul	16.43	84.13	0.01	0.22
2	Aska	11.36	51	0.13	0.06
3	Astaranga	21.91	116.18	0.25	0.56
4	Athagad	17.8	66.61	0.02	0.39

5	Athmallik	16.8	92.5	0.06	0.24
6	Aul	27.45	112.97	0.15	0.08
7	Attabira	15.85	102.33	0.11	0.04
8	Badachana	17.31	37.38	0.22	0.58
9	Bahalda	16.27	85.7	0.09	0.01
10	Bahanaga	18.56	56.29	0.3	0.8
11	Balangir	12.84	74.14	0.21	0.51
12	Baleswar	15	58.37	0.24	0.01
13	Balianta	18.01	73.21	0.24	0.78
14	Baliapal	17.99	93.92	0.11	0.06
15	Balikuda	25.5	122.69	0.1	0.27
16	Balisankara	18.91	122.25	0.14	0.98
17	Bamra	15.77	91.33	0.09	0.05
18	Banarpal	14.31	68.31	0.02	0.2
19	Bandhugaon	24.35	117.25	0.04	0.05
20	Bangiriposhi	16.49	61.7	0.26	0.66
21	Bangomunda	11.42	110.22	0.12	0.22
22	Banspal	22.05	97.4	0.07	0.96
23	Baragaon	14.92	44.66	0.1	0.93
24	Barang	19.18	69.78	0.05	0.25
25	Bargarh	15.24	77.07	0.24	0.62
26	Baripada	15.26	91.99	0.16	0.13
27	Barkot	13.05	93.19	0.13	0.16
28	Barpali	13.17	43.14	0.12	0.75
29	Barsahi	12.61	42.56	0.09	0.04
30	Basta	15.69	63.26	0.16	0.05
31	Basudebpur	19.61	115.43	0.66	0.59
32	Begunia	12.15	53.01	0.02	0.04
33	Bellaguntha	10.52	63.11	0.04	0.4
34	Belpara	15.16	108.42	0.12	0.17
35	Betanati	10.27	39.1	0.28	0.7
36	Bhadrak	21.29	93.91	0.4	0.21
37	Bhandaripokhari	24	80.62	0.22	0.76
38	Bhanjanagar	10.99	42.24	0.19	0.63
39	Bhatli	18.09	53.72	0.22	0.11
40	Bhawanipatna	16.02	68.85	0.02	0.03
41	Bhograi	19.3	66.26	0.09	0.2
42	Bhubaneswar	17.94	122.37	0.07	0.48
43	Bhuban	12.68	63.45	0.11	0.04
44	Bijatola	22.27	160.85	0.11	0.29
45	Bijepur	12.45	30.57	0.09	0.79

46	Binika	10.89	61.79	0.16	0.08
47	Binjharpur	25.76	101.8	0.15	0.13
48	Biramaharajpur	12.87	97.15	0.07	0.24
49	Biridi	19.65	62.73	0.08	0.35
50	Bisoi	23.2	203.61	0.23	0.47
51	Bisra	14.19	70.59	0.07	0.07
52	Bissam-Cuttack	15.19	80.9	0.05	0.11
53	Boden	15.76	128.49	0.19	0.41
54	Bolagad	14.7	49.27	0.01	0.16
55	Borigumma	20.84	85.69	0.19	0.71
56	Boudh	13.39	82.33	0.06	0.26
57	Bramhagiri	15.95	92.55	0.12	0.16
58	Buguda	14.41	42.35	0.06	0.01
59	Champua	19.56	98.69	0.05	0.17
60	Chandahandi	17.77	80.24	0.03	0.16
61	Chandrapur	15.45	62.22	0.03	0.18
62	Chhatrapur	15.18	99.28	0.08	0.76
63	Chilika	12.73	74.68	0.12	0.03
64	Cuttack-Sadar	26.59	90.5	0.02	0.02
65	Dabugan	21.55	152.5	0.23	0.3
66	Danagadi	11.5	54.59	0.46	0.94
67	Dasamantapur	28.44	143.46	0.05	0.08
68	Dasapalla	11.5	25.65	0.1	0.22
69	Dasarathpur	22.68	99.58	0.4	0.93
70	Delanga	14.19	77.97	0.04	0.07
71	Deogaon	12.48	88.81	0.27	0.48
72	Dhamanagar	20.36	77.56	0.34	0.59
73	Dhankauda	31.57	177.21	0.02	0.17
74	Dharakote	14.57	34.79	0.14	0.84
75	Dharamgarh	14.37	68.54	0.12	0.38
76	Dharmasala	13.28	24.17	0.41	0.65
77	Digapahandi	18.21	53.36	0.05	0.42
78	Dunguripali	14.86	30.96	0.04	0.7
79	Ersama	24.64	75.11	0.26	0.99
80	Gandia	15.68	36.59	0.04	0.68
81	Gania	10.13	36.42	0.23	0.71
82	Ganjam	13.91	102.87	0.05	0.54
83	Ghasipura	8.25	32.63	0.54	0.8
84	Ghatgaon	10.59	56.41	0.09	0.04
85	Golamunda	13.39	90.52	0.02	0.02
86	Gopabandhunagar	17.76	100.7	0.08	0.07

87	Gop	23.49	143.21	0.1	0.07
88	Gudari	11.57	61.28	0.04	0.35
89	Gurundia	18.47	68.27	0.24	0.3
90	Harbhanga	11.95	55.55	0.17	0.01
91	Harichandanpur	13.08	97.3	0.18	0.2
92	Hemgiri	20.83	103.67	0.07	0.41
93	Hindol	13.96	60.13	0.01	0.07
94	Hinjilicut	15.68	62.91	0.03	0.21
95	Jagannathprasad	12.8	42.33	0.11	0.11
96	Jagatsinghapur-p	19.24	86.38	0.23	0.16
97	Jajapur	22.84	128.53	0.19	0.03
98	Jaleswar	17.34	36.13	0.06	0.16
99	Jamda	12.88	38.55	0.16	0.65
100	Jashipur	25.46	168.19	0.23	0.02
101	Jatani	21.67	87.13	0.03	0.18
102	Jayapatna	17.05	108.73	0.07	0.03
103	Jharbandh	12.87	48.01	0.31	0.26
104	Jharigan	25.03	157.15	0.01	0.03
105	Jharsuguda	14.33	51.72	0.19	0.03
106	Jhumpura	19.87	141.06	0.17	0.27
107	Joda	25.87	175.86	0.05	0.1
108	Jujomura	12.63	113.07	0.15	0.11
109	Junagarh	18.07	111.93	0.16	0.01
110	Kabisuryanagar	15.66	83.68	0.03	0.01
111	Kakatpur	25.77	149.17	0.08	0.25
112	Kalampur	18.65	94.96	0.06	0.54
113	Kalimela	15.79	93.42	0.04	0.48
114	Kalyanasingpur	14.56	99.72	0.28	0
115	Kamakhyanagar	9.94	58.7	0.17	0.37
116	Kanas	15.05	60.4	0.04	0.18
117	Kaniha	6.82	35.04	0.33	1
118	Kankadahad	12.76	71.27	0.34	0.57
119	Kantamal	19.63	58.41	0.06	0.03
120	Kantapada	19.33	57.14	0.14	0.78
121	Kaptipada	9.46	47.79	0.56	0.58
122	Karanjia	24.84	196.74	0.27	0.96
123	Kashipur	23.09	200.41	0.2	0.03
124	Kendujhar	17.6	118.95	0.13	0.04
125	Khaira	21.98	117.71	0.14	0.04
126	Khairput	19.85	174.25	0.14	0.03

127	Khallikote	14.42	39.96	0.09	0.29
128	Khandapada	16.72	101.68	0.03	0.83
129	Khaprakhol	20.03	151.24	0.05	0.01
130	Khariar	16.06	95.3	0.27	0.31
131	Khordha	16.12	45.45	0.01	0.06
132	Khunta	17.52	97.31	0.09	0.03
133	Kishorenagar	20.66	63.18	0.01	0.23
134	Koida	26.12	135.88	0.06	0.47
135	Kokasara	13.06	64.93	0.17	0.26
136	Kolabira	16.56	91.06	0.05	0.51
137	Kolnara	12.52	103.39	0.06	0.01
138	Komna	19.44	159.62	0.16	0.35
139	Koraput	32.7	322.43	0.02	0.26
140	Korei	19.22	46.18	0.25	0.55
141	Kosagumuda	22.61	206.14	0.07	0.52
142	Kotpad	25.85	94.32	0.16	0.62
143	Krushnaprasad	11.76	67.73	0.23	0.02
144	Kuanrmunda	14.24	76.97	0.08	0.62
145	Kuchinda	14.8	55.29	0.18	0.58
146	Kujang	27.78	123.11	0.11	0.21
147	Kukudakhandi	13.59	61.98	0.07	0.35
148	Kuliana	12.7	36.32	0.16	0.96
149	Kundra	21.75	157.38	0.13	0.13
150	Kutra	13.86	50.98	0.04	0.76
151	Lahunipara	17.96	77.13	0.07	0.03
152	Laikera	18.45	76.39	0.03	0.01
153	Lakhanpur	21.89	150.41	0.14	0.68
154	Lakshmipur	34.4	227.73	0.01	0.08
155	Lamptaput	41.91	470.93	0.06	0.04
156	Lathikata	10.43	59.1	0.27	0.28
157	Lephripara	18.84	84.92	0.04	0.28
158	Loisinga	12.88	42.31	0.14	0.6
159	Madanpur-Rampur	19.62	32.05	0.01	0.25
160	Mahanga	22.74	67.74	0.05	0.24
161	Malkangiri	14.97	81.93	0.22	0.18
162	Maneswar	20.59	135.14	0.12	0.06
163	Mathili	19.27	107.82	0.13	0.13
164	Mohana	25.34	246.86	0.13	0.66
165	Muniguda	18.88	82.16	0.04	0.21
166	Muribahal	14.89	22.08	0.19	0.95
167	Muruda	12.17	59.71	0.3	0.65

168	Naktideul	21.38	135.41	0.01	0.04
169	Nandahandi	30.09	163.33	0.01	0.18
170	Narayanpatna	26.84	209.91	0.19	0.2
171	Narla	14.14	56.7	0.03	0.51
172	Naugaon	21.47	136.02	0.09	0.07
173	Narasinghpur	11.74	56.31	0.22	0.02
174	Nawarangpur	26.42	144.67	0.1	0.05
175	Nayagarh	14.19	29.33	0.04	0.09
176	Niali	22.96	90.69	0.1	0.15
177	Nilagiri	16.95	127.47	0.26	0
178	Nimapada	21.23	112.98	0.03	0.11
179	Nischintakoili	16.54	70.33	0.16	0
180	Nuapada	15.92	135.29	0.12	0
181	Odapada	18.77	107.87	0.01	0.02
182	Oupada	13.53	53.68	0.22	0.01
183	Padmapur	14.05	79.86	0.01	0.39
184	Paikmal	14.37	71.09	0.1	0.06
185	Palalahada	13.26	68.03	0.33	0.38
186	Paparahandi	24.2	169.01	0.02	0.27
187	Parajang	15.92	62.11	0.03	0.59
188	Patnagarh	14.53	89.88	0.13	0.14
189	Patrapur	15.04	79.88	0.04	0.5
190	Pipili	17.84	109.89	0.05	0.76
191	Podia	19.88	104.61	0.01	0.66
192	Odagaon	12.81	11.13	0.06	0.84
193	Pottangi	42.75	471.63	0.11	0.68
194	Puintala	14.91	84.95	0.09	0.29
195	Puri	21.29	150.28	0.1	0.39
196	Purusottampur	14.55	113.38	0.06	0.48
197	R-Udaygiri	20.33	187.17	0.07	0.13
198	Raghunathpur	18.83	96.8	0.17	0.04
199	Raighar	18.14	140.53	0.36	0.91
200	Rairangpur	17.88	138.53	0.14	0.55
201	Rajkanika	28.01	122.01	0.1	0.12
202	Rajnagar	36.52	130.39	0.05	0.21
203	Ramanguda	15.47	54.27	0.13	0.45
204	Ranapur	11.72	55.45	0.08	0.06
205	Rangeilunda	11.19	70.82	0.12	0.01
206	Raruan	14.5	63.02	0.28	0.63
207	Rasagovindpur	12.66	39.96	0.21	0.34

3.4 The skill scores used for verification study

The standard skill scores are used for rainfall and other weather parameters for verification study (Murphy and Katz, 1985).

Error structure for different variables for rainfall

Parameter **Error structure**

Rainfall if observed r/f is out by

Usable:- 2.5 mm < Diff ≤ 5 mm for ≤ 10 mm 25% of observed < Diff ≤ 50% of

Observed for > 10 mm Unusable:-

Diff > 5 mm, observed for ≤ 10 mm Diff > 50% of observed for > 10mm

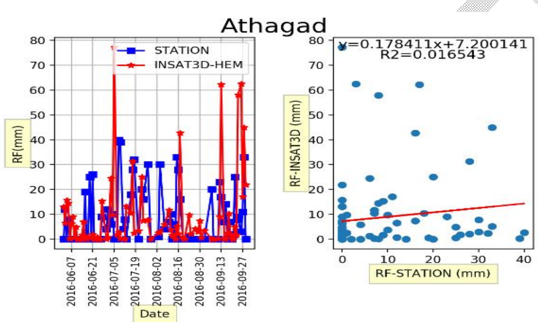

fig 3 a

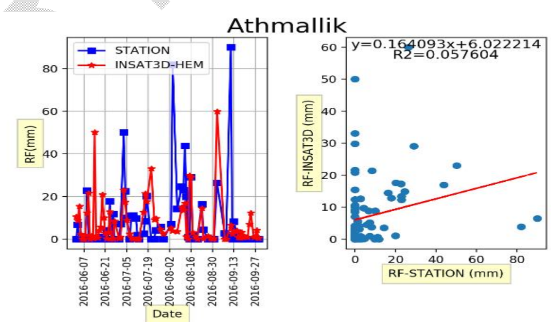

fig 3b

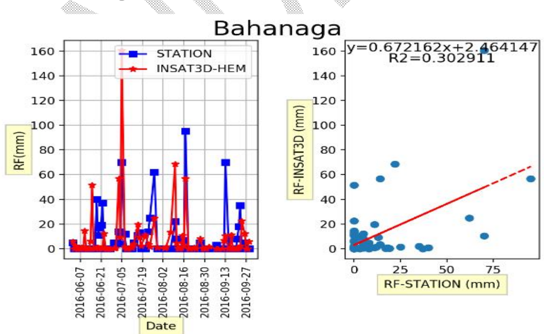

fig 3c

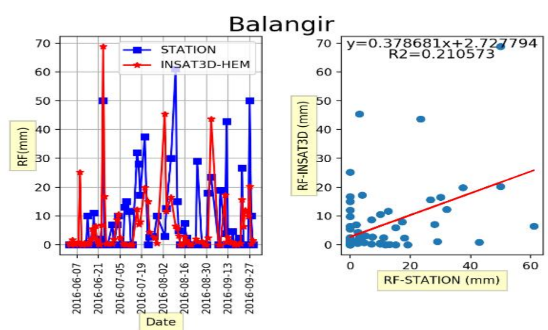

fig 3d

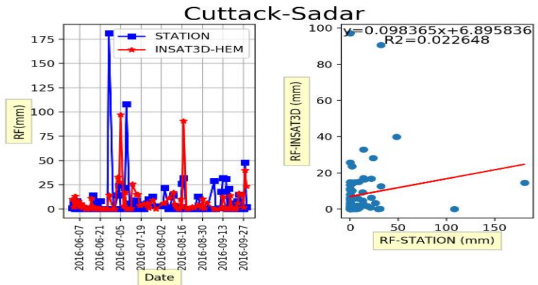

fig 3e

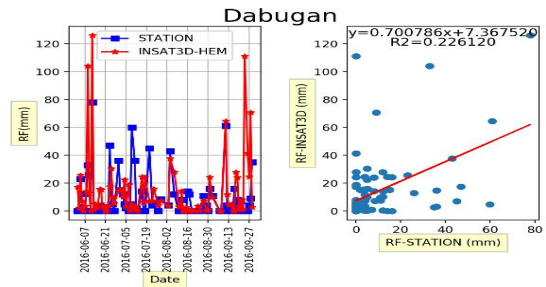

fig 3f

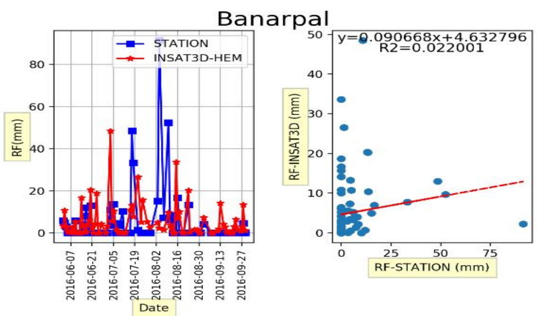

fig 3g

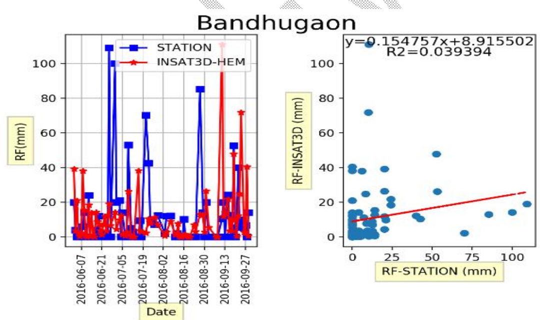

fig 3h

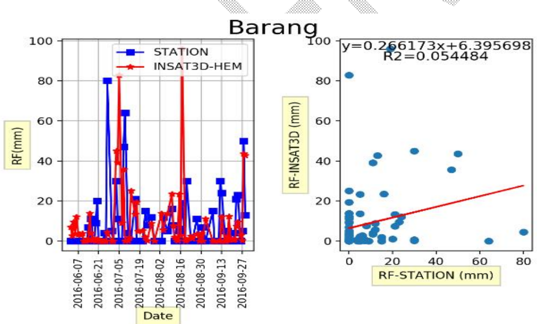

fig 3i

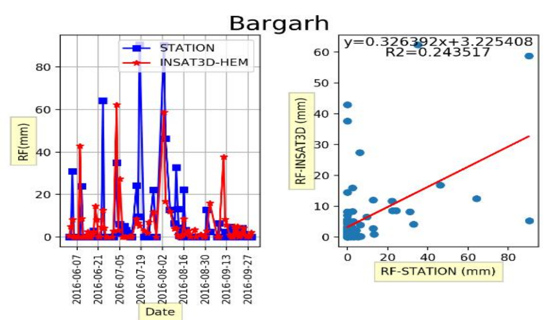

fig 3j

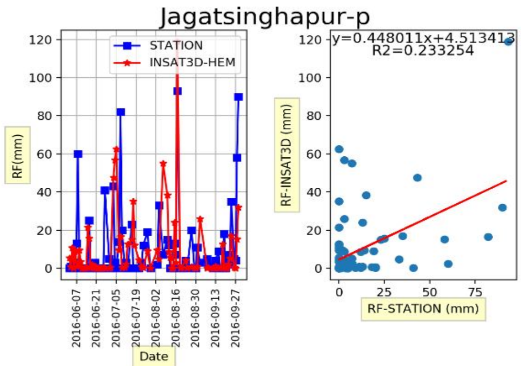

fig 3k

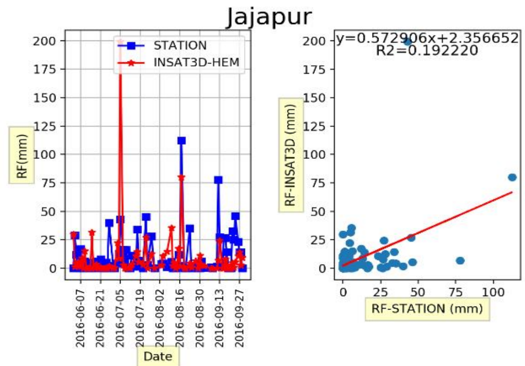

fig 3l

Fig 3 a-l: Block level scatter plot designs of some blocks

4. Conclusion

In this study, satellite derived rainfall estimates *viz.*, HEM, were evaluated with rain gauge based gridded data *viz.*, IMD-GRIDDED Dataset for the year 2016 over the Odisha region at the summer monsoon period. The satellite derived rainfall estimates HE have exhibited some good results with the IMD-GRIDDED Dataset its average R^2 on a daily basis for different blocks is 0.34 and on a monthly basis it is 0.44. RMSE has also been determined to different block for JJAS month. The average RMSE on daily basis is 17.7 and on monthly basis is 94.6 as shown in bias maps.HE performs better, especially in hilly terrains like the Western Ghats and NE hilly regions (bias maps). This study has increased the confidence level for HE. The findings of this study will be used for further improvements in respected rain estimate algorithms. The possibility may be explored of using HE rainfall estimated product to generate.

In the era of high resolution models down scaling the forecast up to any level (*viz.*, district, blocks and village level) is going to give the forecast of almost the same skill. Moreover, the forecasts have become skillful up to day five to seven, of course, with a slight decrease in skill. Hence, forecasts can easily be issued up to day-5.

In our research analysis. it is concluded that the HE rainfall product is good in comparison with station data, but also needs human intervention and value addition to improve skill score. Also, we derived that verification of rainfall forecasting (yes/no aspect) is also good, but it can be better by some quality improvements.

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